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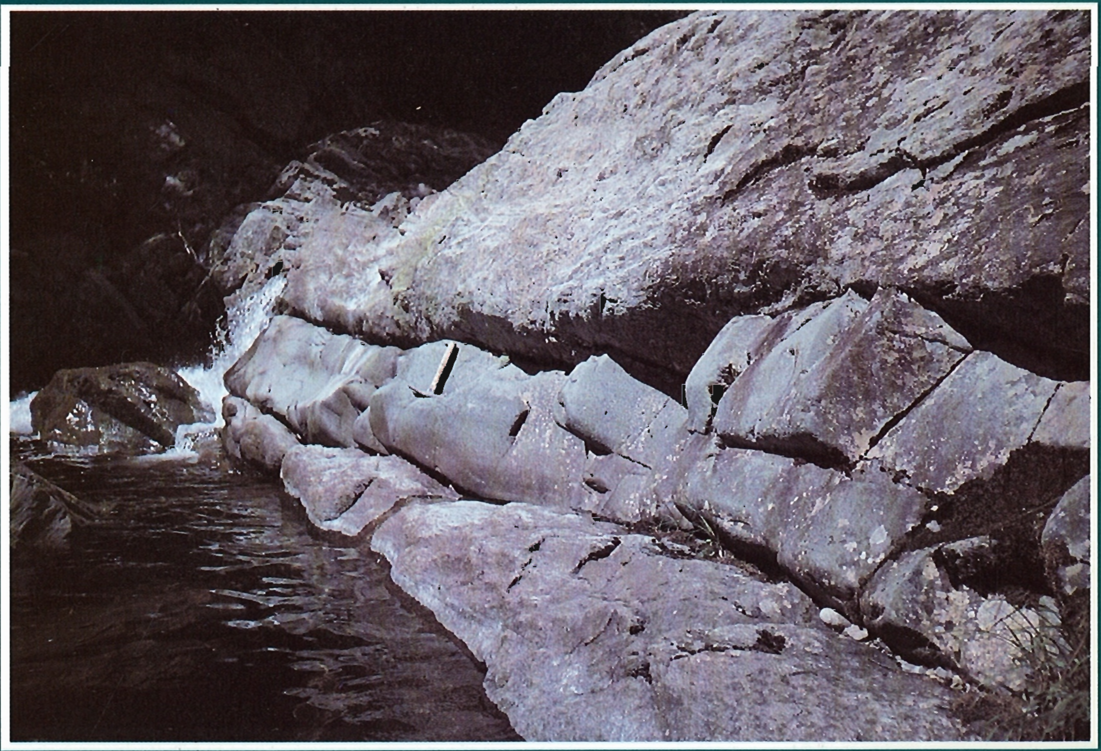
FIELD RELATIONS, PETROLOGY, AND STRUCTURE OF NEOPROTEROZOIC ROCKS IN THE CALEDONIAN HIGHLANDS, SOUTHERN NEW BRUNSWICK

S.M. Barr and C.E. White



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Mafic dyke in crystal tuff of unit Bdt (Broad River Group) in Broad River (also known as Salmon River) (NTS 21 H/10-U3). Photograph courtesy of A.S. Macdonald.

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FIELD RELATIONS, PETROLOGY, AND STRUCTURE OF NEOPROTEROZOIC ROCKS IN THE CALEDONIAN HIGHLANDS, SOUTHERN NEW BRUNSWICK

Abstract

The Caledonian Highlands of southern New Brunswick consist dominantly of Late Neoproterozoic rocks generally considered typical of the Avalon terrane of the northern Appalachian Orogen. Mainly tuffaceous metavolcanic and metasedimentary rocks of the Broad River Group and cogenetic dioritic to granitic plutons with ages ca. 620 Ma form most of the eastern Caledonian Highlands. The igneous rocks have petrological features indicative of origin in a continental-margin subduction zone. Tuffaceous metasedimentary rocks in the group host the Teahan and Lumsden Cu-Pb-Zn-Ag-Au deposits. Significantly younger (ca. 560-550 Ma) volcanic and clastic sedimentary rocks of the Coldbrook Group form most of the western highlands, and occur locally throughout the highlands. The mainly tuffaceous lower part of the group has been intruded by gabbroic and syenogranitic plutons that are interpreted to be cogenetic with basaltic and rhyolitic flows in the upper part of the group. This voluminous continental magmatism may have occurred during extension within the earlier subduction zone complex represented by the Broad River Group and associated plutons.

The Broad River Group was deformed, regionally metamorphosed to greenschist facies, and locally mylonitized prior to deposition of the unconformably overlying Coldbrook Group. Both units were folded and slightly metamorphosed, probably during the Silurian and Devonian. This event may have been related to juxtaposition with terranes to the northwest. Subsequent mid- to late Paleozoic mylonitization, thrusting, and brittle faulting may have been related to initiation of the Maritimes Basin, and to movement along the Avalon–Meguma terrane boundary to the south and east.

Résumé

Les hautes terres de Caledonia du sud du Nouveau-Brunswick se composent majoritairement de roches du Néoprotérozoïque tardif qui sont généralement considérées représentatives du terrane d'Avalon (partie nord de l'orogène des Appalaches). La partie orientale des hautes terres susmentionnées consiste essentiellement en des roches métavolcaniques et métasédimentaires généralement tufacées du Groupe de Broad River et en des plutons dioritiques à granitiques cogénétiques (environ 620 Ma). Les roches ignées présentent des caractéristiques pétrologiques indiquant qu'elles sont originaires d'une zone de subduction à la marge d'un continent. Les gisements de Teahan et de Lumsden (Cu-Zn-Pb±Ag±Au) sont encaissés dans les roches métasédimentaires tufacées du Groupe de Broad River. Dans la partie occidentale des hautes terres de Caledonia, on observe surtout des volcanites et des clastites sédimentaires sensiblement plus jeunes (environ 560-550 Ma) du Groupe de Coldbrook; ces roches ont aussi été identifiées par endroits dans la partie orientale des hautes terres. Des plutons gabbroïques et syénogranitiques ont fait intrusion dans la partie inférieure essentiellement tufacée du Groupe de Coldbrook. Ils sont considérés comme étant cogénétiques des coulées basaltiques et rhyolitiques de la partie supérieure du Groupe de Coldbrook. Ce volumineux magmatisme continental a peut-être eu lieu au cours d'une phase d'extension au sein du complexe de zone de subduction (plus récent) représenté par le Groupe de Broad River et ses plutons associés.

Le Groupe de Broad River a été déformé, régionalement métamorphisé au faciès des schistes verts et localement mylonitisé avant le dépôt du Groupe de Coldbrook (contact sus-jacent discordant). Cet ensemble a été plissé et légèrement métamorphisé, vraisemblablement au cours du Silurien et du Dévonien, peut-être en raison de la juxtaposition du terrane de Caledonia à des terranes au nord-ouest. L'amorce de la formation du Bassin des Maritimes et des mouvements le long de la limite entre les terranes d'Avalon et de Meguma, respectivement au sud et à l'est des hautes terres de Caledonia, sont peut-être à l'origine de la mylonitisation, des chevauchements et des mouvements de faille cassants ultérieurs (Paléozoïque moyen à tardif).

SUMMARY

Field mapping and petrological and structural studies, combined with the results of precise U-Pb (zircon) dating, have resulted in an increased understanding of the geology and geological evolution of the Caledonian Highlands in southern New Brunswick. Neoproterozoic volcanic and associated sedimentary rocks are divided into two groups, the ca. 620 Ma Broad River Group, which forms most of the southern and eastern part of the highlands, and the ca. 560-550 Ma Coldbrook Group, which forms most of the western part. The Coldbrook Group also extends into the eastern part, where it is inferred to originally have had an unconformable relationship with the underlying Broad River Group, although most contacts are now faulted. Previously, all these rocks were included in, or considered equivalent to, a single unit termed the Coldbrook Group.

The Broad River Group consists mainly of intermediate and felsic crystal and lithic crystal tuff, with less abundant mafic tuff, mafic and felsic flows, tuffaceous sedimentary rocks, and arkosic sandstone and conglomerate. Many of these rocks are now slate, phyllite, or schist as a result of regional metamorphism to greenschist facies, as well as widespread ductile deformation. Mineral assemblages are generally typical of the lower greenschist facies, with abundant albitic plagioclase, chlorite, sericite, epidote, actinolite, quartz, and carbonate. Mainly as a result of deformation, stratigraphic relations among the various lithological units are uncertain. The tuffaceous sedimentary and arkosic sedimentary rocks may be subaqueous, but the associated pyroclastic rocks do not show evidence of reworking, and rhyolitic flows are welded, and likely subaerial. Petrochemical characteristics are ambiguous, but overall, patterns of variation in relatively immobile elements, such as Ti, V, and Zr, are indicative of calc-alkalic affinity and a volcanic-arc setting. The Broad River Group hosts both the Teahan and Lumsden Cu-Zn-Pb ±Au±Ag deposits, and other less well known sulphide occurrences.

Plutonic units of known or inferred ca. 620 Ma age occur mainly in the eastern Caledonian Highlands, in spatial association with the Broad River Group. Most contacts now appear to be faulted, and the sill-like form of most plutons is probably the result of shearing and mylonitization after intrusion, and does not reflect the original intrusive shape of the bodies. Like the Broad River Group, the plutonic rocks show widespread effects of metamorphism and shearing, and in many places are protomylonitic to mylonitic. The plutons show a wide range in composition from gabbro and diorite to tonalite, granodiorite, and granite. Uranium-lead (zircon) ages from 4 units average about 620 Ma. The plutons appear to form a calc-alkalic, I-type suite interpreted to be cogenetic with the volcanic rocks of the Broad River Group. Both the plutonic and volcanic rocks formed in a continental-margin magmatic arc. Interlayering of coarse, quartz-rich sedimentary rocks in the volcanic sequence indicates that older crustal

SOMMAIRE

Des travaux de terrain ainsi que des études pétrologiques et structurales, combinés aux résultats de datations précises U-Pb (zircon), ont permis de mieux comprendre le contexte géologique et l'évolution des hautes terres de Caledonia du sud du Nouveau-Brunswick. Des volcanites et des roches sédimentaires associées du Néoprotérozoïque s'y divisent en deux groupes, celui de Broad River (environ 620 Ma) qui constitue l'essentiel des parties méridionale et orientale des hautes terres, et celui de Coldbrook (560-550 Ma) qui en domine la partie occidentale. Le Groupe de Coldbrook s'observe également dans la partie orientale des hautes terres, où l'on suppose qu'il recouvrait d'abord en discordance le Groupe de Broad River; cependant, la plupart des contacts sont maintenant faillés. Toutes ces roches étaient antérieurement regroupées dans une même unité nommée «Groupe de Coldbrook» ou considérées équivalentes à ce dernier.

Le Groupe de Broad River est constitué essentiellement de tufs à cristaux et de tufs à cristaux et fragments lithiques de composition intermédiaire et felsique, ainsi que, en moindre abondance, de tufs mafiques, de coulées mafiques et felsiques, de roches sédimentaires tufacées de même que de grès arkosiques et de conglomérats. Plusieurs de ces roches se présentent aujourd'hui sous la forme d'ardoises, de phyllades ou de schistes, conséquence d'un métamorphisme régional au faciès des schistes verts ainsi que d'une déformation ductile étendue. Les assemblages minéraux sont généralement représentatifs du faciès des schistes verts inférieur et contiennent en abondance de l'albite, de la chlorite, de la séricite, de l'épidote, de l'actinote, du quartz et des carbonates. Les relations stratigraphiques entre les diverses unités lithologiques sont incertaines en raison principalement de leur déformation. Les roches sédimentaires tant arkosiques que tufacées semblent avoir été déposées en milieu sous-marin, bien que les roches pyroclastiques associées ne présentent pas d'indices de remaniement et que les coulées rhyolitiques soient soudées et se soient vraisemblablement formées en milieu subaérien. Les caractéristiques pétrochimiques sont ambiguës, mais les tendances générales de variation des éléments relativement immobiles (tels que Ti, V et Zr) abondent dans le sens d'affinités calco-alcalines et d'une formation dans un milieu d'arc volcanique. Le Groupe de Broad River est l'hôte des gisements de Teahan et de Lumsden (Cu-Zn-Pb±Au±Ag) et d'autres occurrences de sulfures moins bien connues.

Des unités plutoniques d'âge connu ou déduit d'environ 620 Ma s'observent surtout dans la partie orientale des hautes terres de Caledonia, en association spatiale avec le Groupe de Broad River. La plupart des contacts sont aujourd'hui faillés. Quant à l'aspect en forme de filons-couches de la majorité des plutons, il est vraisemblablement la résultante de mouvements de cisaillement et d'une mylonitisation postérieurs à l'intrusion et ne reflète pas la forme originale de ces corps. Tout comme le Groupe de Broad River, les roches plutoniques ont été en grande partie métamorphisées et cisaillées et, en maints endroits, se caractérisent par des textures protomylonitiques à mylonitiques. Les plutons présentent un éventail de compositions allant des gabbros et des diorites aux tonalites, granodiorites et granites. La datation U-Pb sur zircon de quatre d'entre eux a permis d'obtenir un âge moyen d'environ 620 Ma. Les plutons semblent former une suite calco-alcaline du type I considérée comme étant cogénétique des volcanites du Groupe de Broad River. Les roches plutoniques et les volcanites ont été formées dans un arc magmatique à la marge d'un continent. Dans la

rocks were exposed to erosion during the evolution of the arc. Inherited volcanic zircon populations with ages back to ca. 650 Ma, as well as limited evidence for continued volcanism to ca. 600 Ma, indicate that the subduction zone was long-lived. Regional metamorphism and deformation may have been a result of collision with another volcanic arc or crustal block, possibly represented by the Hammondvale metamorphic suite and unexposed crust now underlying the western part of the Coldbrook Group.

séquence volcanique, l'interstratification de roches sédimentaires riches en quartz de granulométrie grossière indique que les roches crustales plus anciennes ont été exposées à l'érosion au cours de l'évolution de l'arc. Des populations de zircons hérités d'origine volcanique dont l'âge atteint environ 650 Ma ainsi que certains indices de la poursuite du volcanisme jusqu'à environ 600 Ma donnent à penser que la zone de subduction a été active pendant une période prolongée. Le métamorphisme et la déformation à l'échelle régionale pourraient résulter d'une collision avec un autre arc volcanique ou un autre bloc crustal, peut-être matérialisé par la suite métamorphique et les roches crustales de Hammondvale sous la partie ouest du Groupe de Coldbrook.

The ca. 560-550 Ma Coldbrook Group includes intermediate to felsic lithic lapilli tuff, crystal tuff, dacitic to rhyolitic flows and plugs, tuffaceous conglomerate, laminated tuffaceous siltstone, basaltic and rhyolitic flows, and coarse clastic sedimentary rocks. Although locally sheared, these rocks are generally less deformed than those of the Broad River Group, and show limited evidence of regional dynamothermal metamorphism. Although the age data are not sufficiently precise to resolve stratigraphic relations among these ca. 560-550 Ma volcanic units, field observations indicate that the tuffaceous units and dacitic to rhyolitic flows and plugs form the lower part of the group, whereas basaltic and rhyolitic flows and clastic sedimentary rocks form the upper part. The latter units extend into the eastern Caledonian Highlands where they unconformably overlie, or are in faulted contact with, the Broad River Group and associated ca. 620 Ma plutons. The lower part of the group is dominated by varied lapilli tuffs, interpreted to represent volcanogenic debris flows and ash-flow deposits. Several belts of laminated siliceous siltstone are present as well, and may represent lacustrine deposits. Subaerial eruption of the volcanic rocks is indicated by ignimbritic appearance and the presence of pumaceous fragments in the rhyolitic rocks, and the intensely amygdaloidal character and lack of pillows in the basaltic flows.

Le Groupe de Coldbrook (environ 560-550 Ma) comprend des tufs à lapilli lithiques de composition intermédiaire à felsique, des tufs à cristaux, des coulées et des culots dacitiques à rhyolitiques, des conglomérats tufacés, des siltstones tufacés laminés, des coulées basaltiques et rhyolitiques, ainsi que des clastites sédimentaires à granulométrie grossière. Bien que ces roches soient cisaillées localement, elles sont en général moins déformées que celles du Groupe de Broad River et présentent peu d'indices de métamorphisme dynamothermique à l'échelle régionale. Les âges obtenus ne sont pas suffisamment précis pour permettre d'établir les relations stratigraphiques entre ces unités volcaniques, mais les observations de terrain indiquent que les unités tufacées ainsi que les coulées et les culots dacitiques à rhyolitiques constituent la partie inférieure du Groupe de Coldbrook, tandis que les coulées basaltiques et rhyolitiques et les clastites sédimentaires en forment la partie supérieure. Ces dernières unités s'observent aussi dans la partie orientale des hautes terres de Caledonia, où elles sont en contact faillé avec le Groupe de Broad River et ses plutons associés (environ 620 Ma) ou le recouvrent en discordance. La partie inférieure du Groupe de Coldbrook est surtout composée d'une variété de tufs à lapilli, interprétés comme étant des coulées de débris volcanogènes et des dépôts pyroclastiques. On note en outre la présence de plusieurs bandes de siltstones siliceux laminés, qui représentent peut-être des dépôts lacustres. Les volcanites ont fait éruption dans un milieu subaérien, comme l'indiquent l'aspect ignimbritique des roches rhyolitiques et la présence dans celles-ci de fragments ponceux, mais aussi le caractère fortement amygdaloïde des coulées basaltiques et l'absence chez ces dernières de coussins.

Circa 560-550 Ma plutons are widespread throughout the central and western parts of the Caledonian Highlands, intruded into the lower units of the Coldbrook Group. Most consist mainly of syenogranite with less abundant diorite and gabbro. Both granitic and dioritic units yielded U-Pb zircon ages of ca. 550-560 Ma. Because of the similarity in age and petrological characteristics, the syenogranitic and gabbroic to dioritic intrusions are interpreted to be comagmatic with rhyolite and basalt of the upper part of the Coldbrook Group.

Les plutons d'environ 560-550 Ma sont nombreux dans les parties centrale et occidentale des hautes terres de Caledonia, sous la forme d'intrusions dans la partie inférieure du Groupe de Coldbrook. La plupart sont constitués essentiellement de syénogranite et, en moindre abondance, de diorite et de gabbro. Tant les unités granitiques que les unités dioritiques ont fourni des âges U-Pb (zircon) d'environ 550-560 Ma. En raison de leur similitude pour ce qui est de leur âge et de leurs caractéristiques pétrologiques, les deux types d'intrusions (syénogranitiques et gabbroïques à dioritiques) sont interprétées comme étant comagmatiques des rhyolites et des basaltes de la partie supérieure du Groupe de Coldbrook.

Chemical data do not provide unequivocal evidence for the paleotectonic setting of the Coldbrook Group and coeval plutons. The volcanic rocks show subtle chemical differences from those of the Broad River Group, with more indications for a within-plate (extensional) environment rather than a

Les données chimiques ne fournissent pas d'indices clairs sur le contexte paléotectonique du Groupe de Coldbrook et des plutons contemporains. Les volcanites du Groupe de Coldbrook présentent des différences chimiques subtiles par rapport à celles du Groupe de Broad River, les indices témoignant plus d'un environnement intra-plaque (régime extensif) que d'une zone de subduction. Il est

subduction zone. It is possible that the parent magmas inherited subduction-like signatures from their source rocks, in the infrastructure of an older ca. 620 Ma volcanic arc.

The Hammondvale metamorphic suite occurs along the faulted northern margin of the Caledonia terrane, and consists dominantly of albite-mica schist, with minor interlayered marble and amphibolite, and mineral assemblages indicative of relatively high-pressure metamorphism (8-10 kbars). Its contacts with the adjacent Coldbrook Group and associated plutons are faulted, and it is unconformably overlain by Carboniferous units to the northwest. Muscovite from the schist yielded ^{40}Ar/^{39}Ar ages of ca. 617 to 605 Ma. The Hammondvale metamorphic suite may represent deeper levels of the Caledonia terrane, brought to the surface by faulting.

A mainly red clastic sedimentary unit (unit ZꞒ$_{rb}$) with a distinctive quartzite-pebble conglomerate at or near its top overlies the Coldbrook Group in many areas, and is unconformably(?) overlain by fossiliferous Cambrian to Lower Ordovician sedimentary rocks of the Saint John Group. Small areas of dacitic tuff of Ordovician age and rhyolite and tuffaceous sedimentary rocks of Devonian age have also been recognized, mainly on the basis of geochronology, and basaltic and sedimentary units of possible Carboniferous age occur along the Bay of Fundy coast. Carboniferous and locally Triassic sedimentary rocks occur mainly in faulted contact with the older units around the periphery of the Caledonian Highlands.

The Broad River Group was deformed, regionally metamorphosed to greenschist facies, and locally mylonitized prior to deposition of the unconformably overlying Coldbrook Group. These events may have been related to amalgamation of the crustal blocks that constitute the Caledonia terrane. Both units were folded and slightly metamorphosed, possibly during the Silurian and Devonian. These events may have been related to juxtaposition of the Caledonia terrane with terranes to the northwest. Subsequent mid- and late Paleozoic mylonitization, thrusting, and brittle faulting may have been related to initiation of the Maritimes Basin and movement along the Avalon–Meguma terrane boundary to the south and east of the Caledonian Highlands.

possible que les magmas parentaux aient conservé la trace de matériaux entraînés par subduction par leurs roches mères, dans l'infrastructure d'un arc volcanique plus ancien d'environ 620 Ma.

La suite métamorphique de Hammondvale s'observe le long de la marge septentrionale faillée du terrane de Caledonia. Elle est constituée essentiellement de schistes à albite-mica, avec des quantités mineures de marbres et d'amphibolites interstratifiés; les assemblages métamorphiques sont caractéristiques d'un métamorphisme de pression relativement haute (8-10 kbars). Ses contacts avec le Groupe de Coldbrook adjacent (et ses plutons associés) sont faillés; au nord-ouest, des unités carbonifères la recouvrent en discordance. La muscovite du schiste a fourni des âges ^{40}Ar/^{39}Ar d'environ 617 à 605 Ma. La suite métamorphique de Hammondvale représente peut-être des niveaux profonds du terrane de Caledonia, ramenés à la surface par des mouvements de faille.

Une unité sédimentaire clastique essentiellement rouge (unité ZꞒ$_{rb}$) renfermant un conglomérat à galets de quartzite distinctif à son sommet ou à proximité de celui-ci est en de nombreux endroits sus-jacente au Groupe de Coldbrook; elle est recouverte en discordance (?) par des roches sédimentaires fossilifères du Cambrien à l'Ordovicien inférieur du Groupe de Saint John. Des tufs dacitiques de l'Ordovicien ainsi que des rhyolites et des roches sédimentaires tufacées du Dévonien ont également été identifiés à certains endroits, essentiellement sur la base de données géochronologiques; des unités basaltiques et sédimentaires peut-être d'âge carbonifère s'observent le long de la côte de la baie de Fundy. Des roches sédimentaires du Carbonifère et, localement, du Trias se présentent surtout en contact faillé avec les unités plus anciennes en périphérie des hautes terres de Caledonia.

Le Groupe de Broad River a été déformé, régionalement métamorphisé au faciès des schistes verts et localement mylonitisé avant le dépôt du Groupe de Coldbrook (contact sus-jacent discordant). Ces événements sont peut-être liés à l'amalgamation des blocs crustaux constituant le terrane de Caledonia. Il se peut qu'au cours du Silurien et du Dévonien, cet ensemble ait été plissé et légèrement métamorphisé, peut-être en raison de la juxtaposition du terrane de Caledonia à des terranes au nord-ouest. L'amorce de la formation du Bassin des Maritimes et des mouvements le long de la limite entre les terranes d'Avalon et de Meguma, respectivement au sud et à l'est des hautes terres de Caledonia, sont peut-être à l'origine de la mylonitisation, des chevauchements et des mouvements de faille cassants ultérieurs (Paléozoïque moyen à tardif).

INTRODUCTION

The Caledonian Highlands of southern New Brunswick (Fig. 1) are underlain mainly by volcanic, sedimentary, and plutonic rocks of Neoproterozoic age. These rocks have been considered generally to be typical of the Avalon zone or terrane of the northern Appalachian Orogen (e.g. Williams, 1978, 1979; Williams and Hatcher, 1982; Nance, 1987a; Murphy and Nance, 1989), and southern New Brunswick has been widely considered to exemplify the stratigraphic relations and tectonic evolution of the Avalon terrane (e.g. Rast et al., 1976; Nance, 1986; Murphy and Nance, 1989). However, the stratigraphy, age, and petrology of the rock units in the Caledonian Highlands were not well constrained prior to this study. The area had been mapped mainly on a reconnaissance basis (e.g. Kindle, 1962; Ruitenberg et al., 1979), and few geochronological or petrological studies had been done. As a result, previous stratigraphic and tectonic models (e.g. O'Brien et al., 1983; Nance, 1987b; Murphy and Nance, 1989; Dostal and McCutcheon, 1990; Keppie and

Dostal, 1991) were based on assumptions about field relations and age, many of which have not been confirmed by this study, and on geochemical data from samples of limited distribution (e.g. Currie and Eby, 1990; Dostal and McCutcheon, 1990).

This report presents the results of field mapping, combined with petrological and geochronological studies of Neoproterozoic volcanic, sedimentary, and plutonic rocks in the Caledonian Highlands. The project, initiated in 1985, had three main goals:

1. to interpret field and stratigraphic relations among the Neoproterozoic volcanic and sedimentary rocks in the study area;
2. to determine the distribution, field relations, petrochemistry, and age of plutonic units;
3. to interpret the tectonic setting and geological history of the area, based on characteristics of its constituent volcanic, sedimentary, and plutonic rocks.

This report, along with Open File 3615, summarizes the results of the project. Open File 3615, a set of 1:50 000 scale geological maps of this study area by the same authors, shows in detail the rock units discussed in this bulletin. Readers are referred to these detailed maps for the locations of geographic localities cited in this report. These maps supersede preliminary maps published earlier (Barr and White, 1988b, 1989a, 1991a, 1993). Although specific studies of mineral deposits in the Caledonian Highlands were not part of this project, the results of this study lead to a better understanding of the geological setting of known mineral deposits in the area and may help to focus exploration for additional deposits on lithological units of highest potential.

ACKNOWLEDGMENTS

This project was funded by the Canada–New Brunswick Mineral Development Agreement, 1984–1989, and by the Canada–New Brunswick Cooperation Agreement, 1990–1995. In both cases, the project was carried out by the Geological Survey of Canada, and we are grateful to W.H. Poole and K.L. Currie for initiating the project. Additional funding for analytical work was from a research grant to S.M. Barr from the Natural Sciences and Engineering Research Council of Canada. We thank Alan Macdonald for his contributions to mapping in the Fundy National Park area, and K.L. Currie for enjoyable and helpful discussions and field trips. We are also grateful to Malcolm McLeod for sharing his knowledge of the Caledonian Highlands with us, and for his helpful comments as reviewer which led to improvements in this report. Discussions with many other individuals have also been helpful, particularly L.R. Fyffe, S.C. Johnson, R.D. Nance, A.A. Ruitenberg, and S.E. Watters.

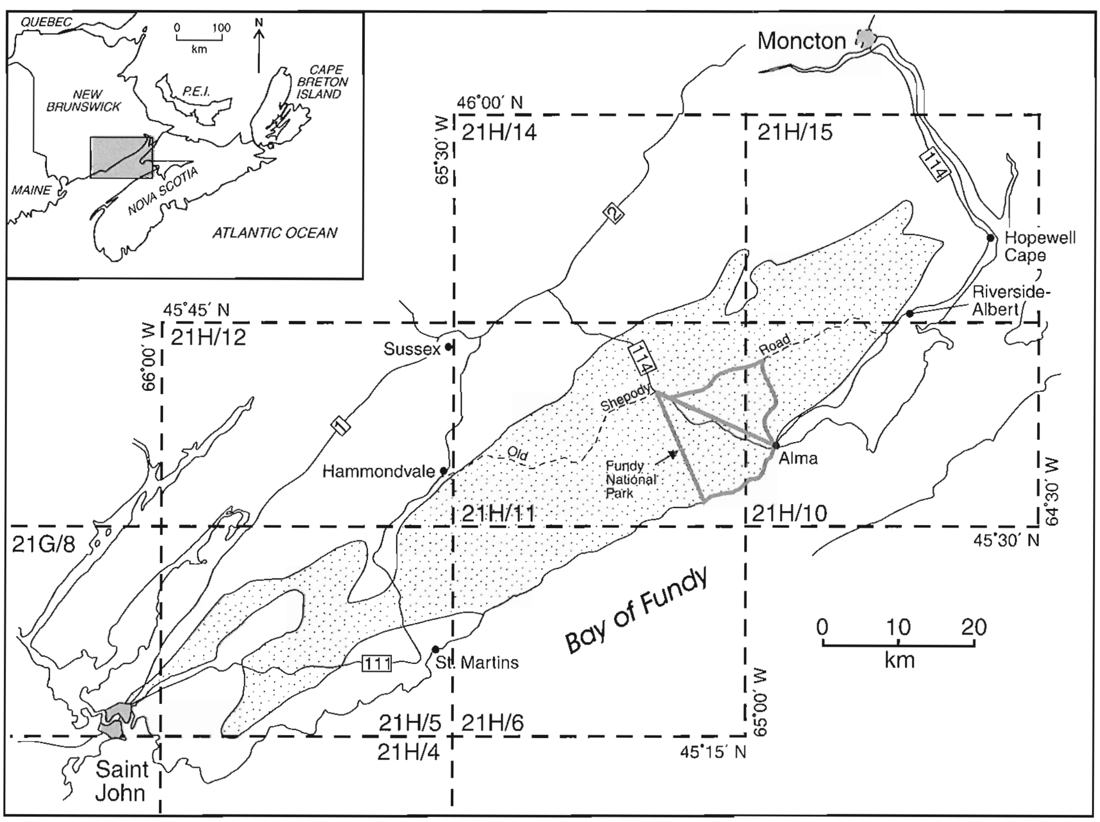

Figure 1. Location of the Caledonian Highlands (stippled) in southern New Brunswick, with NTS sheets indicated by dashed lines. Major access routes are shown, as described in the text.

U-Pb dating has been essential to the interpretations made in this report, and we are indebted to M. L. Bevier, formerly based at the Geological Survey of Canada in Ottawa, for providing most of these data.

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LOCATION AND ACCESS

The Caledonian Highlands (Weeks, 1957) are a prominent upland area that extends 130 km northeastward from the city of Saint John to close to Hopewell Cape, south of Moncton (Fig. 1). The highlands rise steeply from the Bay of Fundy to a maximum elevation of about 450 m. They are relatively flat on top, and descend more gradually to the Carboniferous basin on their northwestern margin. The highlands include all or parts of National Topographic System map sheets 21 G/8 (Saint John), 21 H/4 (Cape Spencer), 21 H/5 (Loch Lomond), 21 H/6 (Salmon River), 21 H/10 (Alma), 21 H/11 (Waterford), 21 H/12 (Sussex), 21 H/14 (Petitcodiac), and 21 H/15 (Hillsborough) (Fig. 1).

Access to the area is mainly by Highway 111 east from Saint John to St. Martins and from there north to Sussex. Highway 114 crosses the highlands from east of Sussex to Alma, through the Fundy National Park, and then follows the margin of the highlands to Riverside–Albert and Hopewell Cape. The Old Shepody Road follows the axis of the highlands from Highway 111 at Hammondvale to Highway 114 near Riverside–Albert, and provides the main access within the belt. A network of logging roads and trails extends both north and south of the Old Shepody Road, and from highways 111 and 114. However, deeply incised streams which mainly flow south or north provide the best outcrop exposure throughout the belt. The coastline has excellent outcrop exposure with long stretches of near-vertical cliffs. However, much of the coast is accessible only by boat, and the large tidal range and seaweed cover make boat work both difficult and dangerous.

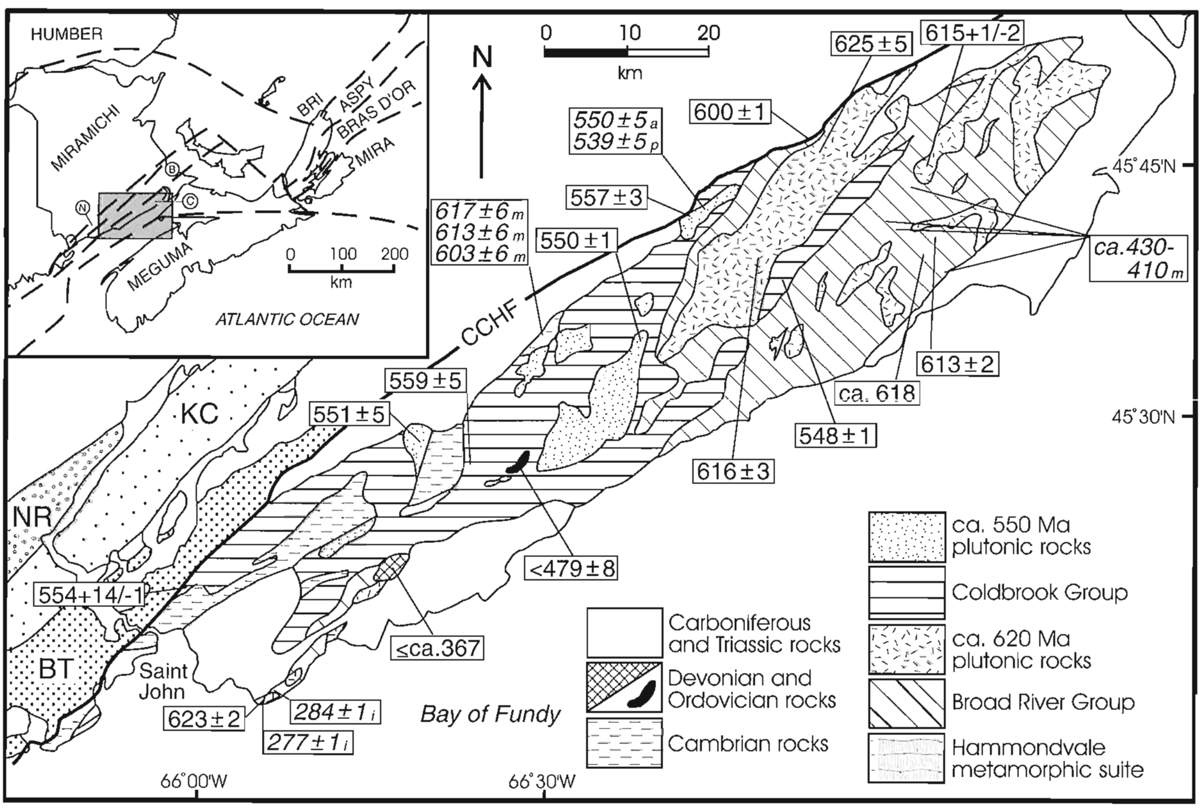

Figure 2. *Simplified geological map of the Caledonian Highlands showing the distribution of the major units included in this study. Non-italicized numbers in boxes are U-Pb (zircon) ages from Bevier and Barr (1990), Barr et al. (1994), and Grammatikopoulos et al. (1995). Italicized numbers in boxes are $^{40}Ar/^{39}Ar$ mineral ages from White (1995), Grammatikopoulos et al. (1995), Watters (1993b), and Dallmeyer and Nance (1992); mineral abbreviations: m, muscovite; a, amphibole; p, phlogopite; i, illite. Inset map shows the location of the study area in the context of proposed terranes in Maritime Canada (after Barr and White, 1996b); abbreviations: CCHF, Caledonia–Clover Hill Fault; KC, Kingston Complex; NR and N, New River belt; BT and B, Brookville terrane; C, Caledonia terrane; BRI, Blair River inlier.*

SCOPE OF THE STUDY AND METHODOLOGY

The study area covers the Caledonian Highlands southeast of the Caledonia–Clover Hill fault system (Fig. 2, Open File 3615). It includes the Central Volcanic, Central Intrusive, and Eastern Volcanic belts of Giles and Ruitenberg (1977) and Ruitenberg et al. (1979), and constitutes the area termed the 'Caledonia terrane' by Barr and White (1989b, 1996b). The entire area was mapped during the summers of 1985–1991 by the authors of this report. Mapping was mainly at a scale of 1:25 000, with less detailed mapping in some areas of limited outcrop and/or difficult access. Orthophotomaps (1:10 000 scale) published in 1971 by the New Brunswick Department of Natural Resources were used as base maps, with new logging roads surveyed in by compass. More than 2500 samples were collected, all of which were slabbed to obtain an unweathered surface for examination. More than 1000 samples were studied in thin section for more detailed petrographic information. Mineral analyses were done in selected representative samples to provide data on precise mineral compositions. However, because of the large size of the area and the wide range in age and character of the rocks, the petrographic work is considered to be of only a reconnaissance nature, even though a large number of samples were studied. Terminology used in describing and naming the rocks is discussed in Appendix A.

Radiometric dating by the U-Pb method was a major component of the project, and the results have been published (Bevier and Barr, 1990; Barr et al., 1994; Grammatikopoulos et al., 1995). Figure 2 shows the locations and ages of samples that were successfully dated, and the data are summarized in Table 1. Obtaining reliable ages proved difficult because of the small number, or, in some cases, absence, of zircon grains in units that, based on field relations, are important to date.

Petrochemical features of both volcanic and plutonic rocks are used to aid in characterization of the rocks, and to constrain their origin and tectonic setting. Brief petrographic descriptions of the analyzed samples are presented in Appendix B. Analytical methods are described and chemical data presented in Appendix C. Barr and White (1996a) presented a summary interpretation of the data in terms of tectonic setting. Hence, the emphasis in this report is on petrochemical variations within and among units.

REGIONAL GEOLOGICAL SETTING — AN OVERVIEW

This section provides an overview of the geological units in the study area and in adjacent areas, and summarizes the various interpretations that have been made for their ages and stratigraphic relations. Although the major rock units in southern New Brunswick are generally agreed upon, their inter-relationships remain controversial. Barr and White (1989b) introduced the term 'Caledonia terrane', encompassing the Neoproterozoic to Cambrian rocks of this study area,

Table 1. Summary of U-Pb age data from the Caledonian Highlands.

Age (Ma)	Sample #	Unit	Lithology	NTS (east, north)	Ref	Comment
625 ± 5	NB86-1119	Z_{PWgd}	Pollet River granodiorite	21 H/14(337094, 5071043)	1	
623 ± 2	KC82074	Z_{ML}	Millican Lake granodiorite	21 H/04 (271000, 5009000)	4	
ca. 618	NB85-126	Bdt	Fortyfive River Road rhyolite	21 H/10 (348448, 5058876)	2	
616 ± 3	NB87-4551	Z_{PWgg}	Old Shepody Road granite	21 H/11 (328500, 5056637)	1	
615 +1/-2	NB91-8130	Z_{KH}	Kent Hills granodiorite	21 H/10 (348791, 5065425)	2	
613 ± 2	NB85-609	Bdt	felsic tuff	21 H/10 (350496, 5059305)	1	
600 ± 1	NB86-1120	Bdr	intermediate tuff	21 H/14 (337173, 5071662)	1	
559 ± 5	NB90-7095	Cr	felsic tuff	21 H/05 (296745, 5036400)	2	
557 ± 3	MS130	Z_{MS}	quartz diorite	21 H/11 (323140, 5063525)	3	
554 +14/-1	NB89-627A	Cgd	Dacite, Somerset Street	21 G/08 (730070, 5017855)	2	
551 ± 5	NB89-6208	Z_{UM}	Upham Mtn. syenogranite	21 H/05 (291469, 5038421)	2	
550 ± 1	NB87-4626	Z_{BBG}	Bonnell Brook syenogranite	21 H/11 (316043, 5049091)	1	
548 ± 1	NB86-1159	Cr	Coldbrook Group rhyolite	21 H/11 (331564, 5053538)	1	
<479 ± 8	NB88-5542	O_G	Grassy Lake fm dacite	21 H/05 (302507, 5034491)	2	
<367	NB89-6218	D_{Fr}	Fairfield fm rhyolite	21 H/05 (288252, 5023452)	2	
no age	NB90-7034	Cr	rhyolite at Mystery Lake	21 H/05 (265849, 5022052)		no zircon
no age	NB89-6217	Cft	dacite on Highway 111	21 H/05 (272310, 5024375)		no zircon
no age	NB89-6027	Cr	Vernon Mtn. rhyolite	21 H/05 (281955, 5022932)		no zircon

References:
1 Bevier and Barr (1990)
2 Barr et al. (1994)
3 Grammatikopoulos et al. (1995)
4 Watters (1993b)

to emphasize their differences compared to rocks in adjacent areas, in particular in the Brookville terrane (Fig. 2). However, the significance of these differences is the subject of ongoing debate (e.g. Dallmeyer and Nance, 1992, 1994; Murphy et al., 1992a; Whalen et al., 1994; Barr et al. 1995; Barr and White, 1996b), as discussed below. Although Cambrian and younger rocks are not a focus of this study, they are included in this section as part of the regional framework.

Traditionally, gneissic rocks in the Saint John area, termed the 'Brookville Gneiss', were assumed to be the oldest rocks exposed in southern New Brunswick (e.g. Nance, 1987a). The gneissic rocks occur in association with marble, calcareous metapelite, metasiltstone, and quartzite of the Green Head Group. Based on the nature of locally preserved stromatolites, Hofmann (1974) suggested that the Green Head Group is Neohelikian (Mesoproterozoic) in age. The Brookville Gneiss was interpreted to be either 1) an older (Aphebian to Grenvillian), remobilized and partially melted continental basement upon which the Green Head Group was deposited (Olszewski and Gaudette, 1982; O'Brien et al., 1983; Currie, 1984, 1986, 1987, 1988; Nance, 1986, 1987a, 1990) or 2) a high-grade, migmatitic portion of the lower Green Head Group (O'Brien, 1976; Rast et al., 1976; Wardle, 1978). However, neither of these interpretations appears to be correct because 1) paragneiss, which constitutes about 75% of the Brookville Gneiss, contains detrital zircons with a maximum age of ca. 640 Ma (Bevier et al., 1990) and 2) orthogneiss in the Brookville Gneiss has an igneous crystallization age of 605 ± 3 Ma, and was metamorphosed to amphibolite facies at 564 ± 6 Ma (Bevier et al., 1990; Dallmeyer et al., 1990). Therefore the gneiss does not represent an ancient continental basement to the Green Head Group. On the contrary, if a Neohelikian age (Hofmann, 1974) for the Green Head Group is correct, then the gneiss appears to be younger than the Green Head Group.

The belt of rocks that includes the Green Head Group, Brookville Gneiss, and associated plutons was termed the 'Western Intrusive Belt' by Ruitenberg et al. (1979), and the 'Brookville terrane' by Barr and White (1989b). The terrane designation emphasizes the lack of correlation between units in this area and the units in the Caledonian Highlands (Barr and White, 1996b; White and Barr, 1996) which are the focus of this study.

Volcanic and associated sedimentary rocks in the Saint John area, and to the east in the Caledonian Highlands, were traditionally assigned to the Coldbrook Group (or 'Coldbrook Equivalent') of Late Precambrian age, and interpreted to overlie the Green Head Group (e.g. Nance, 1987a). Based on differences in lithology, deformation, metamorphism, and age (Bevier and Barr, 1990; Barr et al., 1994), these rocks have been divided into two separate groups. The name Coldbrook Group is retained for rocks in the traditional 'type area' east of Saint John, and for rocks interpreted to be of similar age, mainly in the northern and western part of the highlands. These rocks occur mainly in the area termed the 'Central Volcanic Belt' by Ruitenberg et al. (1979). The new name Broad River Group is assigned to what are now known to be older units mainly located in the northeastern and southern parts of the highlands, mainly in the Eastern Volcanic Belt of Ruitenberg et al. (1979).

The U-Pb dating also led to the recognition in the Caledonian Highlands of two younger volcanic units (Fairfield and Grassy Lake formations) of restricted distribution, which are also described in this report.

As a result of the age data, and in contrast to interpretations linking the Coldbrook Group with the Green Head Group and Brookville Gneiss, Barr and White (1989b, 1991b, 1996b) interpreted the Coldbrook and Broad River groups and associated rocks to be in faulted contact with the Green Head Group, Brookville Gneiss, and associated plutons of the Brookville terrane, with no Late Precambrian to Cambrian stratigraphic links between the two areas. They used the term 'Caledonia terrane' to designate the area of outcrop of the Coldbrook and Broad River groups and associated rocks, located southeast of the Caledonia–Clover Hill fault (Fig. 1, 2).

Volcanic, sedimentary, and plutonic rocks also occur northwest of the Brookville terrane, in the area called the Western Volcanic Belt by Giles and Ruitenberg (1977) and Ruitenberg et al. (1979). Rast et al. (1978a) suggested that this area includes Precambrian volcanic and granitic rocks intruded by a dyke swarm (Kingston Complex of Currie, 1984) and mylonitized during the latest Precambrian. However, recent work has indicated a Silurian to Early Devonian age for much, if not all, of the Kingston Complex (Doig et al., 1990; Nance and Dallmeyer, 1993), and the relationship of Precambrian rocks in this area and in the New River belt to the north (Fig. 2) to rocks of the Caledonia terrane remains uncertain (Fyffe and McLeod, 1990; Currie and Hunt, 1991; McLeod et al., 1992; Murphy et al., 1992a; Johnson and McLeod, 1996; Barr et al., 1995; Barr and White, 1996b, Barr et al., 1997).

The Coldbrook Group is disconformably overlain by Lower Paleozoic rocks of the Saint John Group, a platformal sequence containing Acado-Baltic fossils. Currie (1984) suggested that the sedimentary and volcanic rocks underlying the basal Cambrian unit are distinct from and younger than the Coldbrook Group, and placed them in a separate 'Eocambrian' succession. He referred to this succession as 'Eocambrian' to emphasize its presumed intermediate age between the Coldbrook Group and the Saint John Group, and subsequently as the 'Lorneville beds' (Currie, 1992). Some or all of these rocks had been previously included with 1) the Coldbrook Group, 2) the Saint John Group, or 3) the Carboniferous Mispec Group (West Beach Formation). The status of the 'Lorneville beds' and their stratigraphic correlatives in the Caledonian Highlands remains controversial. However, U-Pb dating suggests that the volcanic rocks in this succession are not significantly younger than the Coldbrook Group (Barr et al., 1994), and hence most of these volcanic rocks are included here in the Coldbrook Group.

Tanoli and Pickerill (1988) presented a revised lithostratigraphy for the Saint John Group in which they recognized seven formations. The lowermost formation (Ratcliffe Brook) was interpreted to disconformably overlie volcanic and clastic sedimentary rocks of the Coldbrook Group (Tanoli and Pickerill, 1988, 1990). The Ratcliffe Brook Formation includes a distinctive, basal, quartzite-pebble conglomerate unit (Tanoli and Pickerill, 1990), and clastic sedimentary rocks that locally contain trace fossils (Hofmann and Patel, 1989). The Ratcliffe Brook Formation is overlain by quartz arenite and quartzite-pebble conglomerate of the Glen Falls Formation, sandstone and siltstone of the Hanford Brook Formation, and then by a Middle Cambrian to Lower Ordovician marine sedimentary sequence. In contrast to the terminology of Tanoli and Pickerill (1988), Landing (1991b, 1996a) has extended stratigraphic nomenclature from Newfoundland to southern New Brunswick. However, the units of Tanoli and Pickerill (1988) are generally followed in this report, except that the quartzite-pebble conglomerate and associated clastic rocks of the lowermost Ratcliffe Brook Formation are placed in a separate unit ($Z\mathrm{Є}_{rb}$) because field relations suggest that they are more closely associated with the underlying Coldbrook Group than with the overlying Saint John Group. In addition, following Watters (1993a, b), another Cambrian sedimentary unit, the Cape Spencer Formation, is recognized in the Cape Spencer area southeast of the city of Saint John (Open File 3615).

In the area southeast of the city of Saint John, Carboniferous rocks include grey sandstone, conglomerate, and siltstone of the Lancaster Formation and red conglomerate, sandstone, siltstone, and shale of the Balls Lake and Tynemouth Creek formations (Nance, 1990). Traditionally, some interbedded volcanic and sedimentary rocks in the Saint John area were called the Mispec Group and also considered to be of Carboniferous age. However, the name has since been abandoned, and the rocks assigned to other units (Nance, 1987b). The volcanic part of the Mispec Group (West Beach Formation or 'Lorneville Volcanics' of Rast et al., 1978b) was termed the 'Lorneville Beds' by Currie (1992) and interpreted to be of Eocambrian age. However, in this report these rocks are placed either in the Coldbrook Group or in a separate 'Carboniferous or older' unit (Open File 3615).

Elsewhere along the northern, northeastern, and southeastern margins of the Caledonian Highlands, Carboniferous rocks occur mainly in faulted contact with the Precambrian units, and include the Upper Devonian–Lower Carboniferous Horton Group and the Carboniferous Windsor, Hopewell and Cumberland groups. The distribution of these units has recently been documented by St. Peter (e.g. 1989, 1993), and his work has been followed during this study.

Red sandstone, shale, and conglomerate of the Triassic Fundy Group occur in small, mainly fault-bounded areas along the Bay of Fundy coast (Ruitenberg et al., 1979; Nadon and Middleton, 1985; Plint and van de Poll, 1984). Like the Carboniferous rocks, they were not included in this study, and their distribution has been taken from these other sources.

PREVIOUS WORK IN THE CALEDONIAN HIGHLANDS

Volcanic rocks in the Saint John area have been previously termed the 'Saint John Volcanics' (Hayes and Howell, 1937) or the 'Coldbrook Group' (Alcock, 1938; Cormier, 1969). They were considered to be of Precambrian age based on their position underlying fossiliferous Lower Cambrian strata. Attempts to subdivide these rocks in the Saint John area into lithological units met with only limited success (Hayes and Howell, 1937).

Mapping in the extension of the volcanic belt to the northeast also resulted in little stratigraphic information because of the complexity of the rocks and their extensive alteration and deformation (Flaherty, 1933, 1934; Norman, 1941; Norman and Flaherty, 1941; Stewart, 1941). Kindle (1962) mapped a large area in the central highlands, including Fundy National Park, and assigned the volcanic and sedimentary rocks to the Coldbrook Group of probable Precambrian age, by comparison with the Saint John area. He divided the rocks into three complexly intermixed lithological units: a felsic unit dominated by rhyolite and dacite, a mainly sedimentary unit of quartzite, slate, and conglomerate, and a mafic unit of andesite with minor dacite, basalt, and chlorite schist. Kindle (1962) also identified various plutonic units ranging from gabbro to alaskite.

The first mapping of the entire Caledonian Highlands was done by Ruitenberg et al. (1973, 1975, 1979). They recognized that the volcanic rocks of the Coldbrook 'type area' east of the city of Saint John typify only some of the rocks in the rest of the belt, and hence used the term 'Coldbrook Equivalents' for rocks outside the immediate Coldbrook area. They demonstrated lateral continuity of large units which were chosen to include distinct lithological assemblages. They also assigned names to most of the major intrusive units.

Ruitenberg et al. (1973, 1975, 1979) divided the area included in the present study into Eastern and Central Volcanic belts, and a Central Intrusive Belt. They reported that the Eastern Volcanic Belt is underlain mostly by volcanogenic sedimentary rocks and tuff with smaller amounts of mafic and felsic flows. Also characteristic are coarse-grained clastic sedimentary rocks intercalated with the volcanic rocks. The Eastern Volcanic Belt is separated for much of its length from the Central Volcanic Belt by the Central Intrusive Belt, but was described as having a gradational relationship with the Central Volcanic Belt in the southwest where the plutons are absent. The Central Volcanic Belt of Ruitenberg et al. (1979) includes the type area of the Coldbrook Group immediately east of Saint John. Typical rocks include coarse-grained, lithic lapilli tuff and volcanic flows. The tuffs were described as coarser in the Central belt than in the Eastern belt. Ruitenberg et al. (1979) also recognized the Black River fault block within the Central Volcanic Belt. This sequence of mafic and felsic flows and tuffaceous rocks was interpreted to be correlative with the Eastern Volcanic Belt, and thrust into its present position.

The Central Intrusive Belt of Ruitenberg et al. (1979) includes two major intrusions, Point Wolfe River and Bonnell Brook. The dominant rocks were identified as granodiorite, quartz diorite, diorite, granite, and gabbro. Plutonic rocks of similar compositions are also a major component of the Eastern Volcanic Belt. Ruitenberg et al. (1979) presented modal analyses for selected plutonic samples and whole-rock, major-element, chemical data for volcanic samples. They considered the age(s) of the plutonic units to be highly uncertain because few radiometric dates were available.

McLeod (1987) remapped the southwestern part of the Eastern Volcanic Belt of Ruitenberg et al. (1979), in the Big Salmon River–Goose River area. He made a more detailed subdivision into lithological units, and recognized the presence of Central Volcanic Belt units on the southeastern side of the Central Intrusive Belt. He proposed that a major southward-directed thrust, which he termed the 'Cradle Brook–Walton Brook Fault', is a tectonic boundary between the Eastern and Central volcanic belts in this area. McLeod (1987) also presented mainly major-element chemical data for selected volcanic and plutonic samples in his map area.

Ruitenberg et al. (1973, 1979) noted that deformation is inhomogeneous in the Caledonian Highlands. They recognized a Fundy Cataclastic Zone that included their Eastern Volcanic Belt as well as the southeastern margin of the Central Intrusive Belt. In this zone, the rocks show intense penetrative deformation. In contrast, in the adjacent Loch Lomond Deformed Zone, they suggested that the rocks show mainly the effects of open folding and tilting related to faulting. The Fundy Cataclastic Zone was said to be characterized by S_1 surfaces with shallow to moderate dips, with local steep dips and major changes in trend produced by later folding and faulting.

The Precambrian age assigned to the Coldbrook Group was based on the overlying, fossiliferous, Lower Cambrian Saint John Group (e.g. Hayes and Howell, 1937; Alcock, 1938). Fairbairn et al. (1966) tried to date the Coldbrook Group using Rb-Sr whole-rock analyses; however, the resulting date of 468 Ma appeared to be too young. Cormier (1969) also attempted to verify a Precambrian age using Rb-Sr whole-rock analyses. His results indicated an age of ca. 750 Ma for the volcanic rocks and a Devonian age (ca. 370 Ma) for regional metamorphism in the area.

McLeod and McCutcheon (1981) described several areas in the south-central Caledonian Highlands of rocks similar in lithology to those of the Lower Cambrian Ratcliffe Brook, Glen Falls, and Hanford Brook formations of the Saint John Group, and suggested that they are also of Early Cambrian age. The presence of Cambrian rocks was subsequently confirmed by paleontological study (Landing, 1996b).

Other mapping in the study area included the work of Watters (1987, 1993a, b), who completed detailed mapping of deformed Precambrian volcanic and plutonic rocks and Carboniferous sedimentary rocks in the Cape Spencer–Black River area southeast of Saint John. Currie (1989) mapped mainly in and west of the city of Saint John but also included the westernmost part of the present map area.

Mineral occurrences in the Caledonian Highlands were described by Ruitenberg et al. (1979) and McLeod (1987), and also in numerous specialized reports and assessment reports (e.g. Bichan, 1947; Flaherty, 1963; Wright, 1940; Wells, 1992).

BROAD RIVER GROUP

Overview

The term 'Broad River Group' was introduced by Barr et al. (1994) to encompass the low-grade metavolcanic and metasedimentary rocks of the Caledonian Highlands that had been shown by U-Pb (zircon) dating to be mainly older than ca. 620 Ma. These rocks form most of the northeastern and southern parts of the highlands, and host a variety of plutonic rocks of mainly similar age (Fig. 2).

The Broad River Group consists dominantly of intermediate and felsic crystal and lithic crystal tuffs, with less abundant intermediate and felsic flows, mafic tuffs and flows, and epiclastic sedimentary rocks. The group is divided into 13 map units (Fig. 3, Open File 3615), each of which is lithologically composite, but has some distinctive components which distinguish it from other units in the group. In general, stratigraphic relations among these units are not known, except in rare, less-deformed areas where bedding and evidence of younging direction have been preserved. Some units are likely to represent lateral facies equivalents, but outcrop is not generally sufficient to trace such variations.

In most places, original compositional layering appears to have been transposed to parallel the regional foliation (*see* section titled 'Deformation and Metamorphism'). Evidence of widespread shearing in the rocks and the elongate form of most map units indicate that many contacts have been modified by faults, although we have shown faulted contacts only where we have direct field evidence for their presence. Because of these structural complexities, the potential for lateral facies changes in this dominantly volcaniclastic assemblage, and the consequent stratigraphic uncertainties, it is difficult to estimate the thickness of the Broad River Group, but a minimum thickness of about 7 km is suggested. The units are described below in a highly speculative stratigraphic sequence based on the cross-sections described in the section titled 'Deformation and Metamorphism'. Contacts with the younger Coldbrook Group were nowhere directly observed, and now appear to be mainly faults; originally, the contact is likely to have been unconformable because of the gap of 40-60 Ma between the ages of dated rocks in the two groups.

Rocks of the Broad River Group have undergone low-grade regional metamorphism, and contain mineral assemblages typical of greenschist facies. They have also been affected by local contact metamorphism. Metamorphic names such as slate, phyllite, or schist could be used for most rocks. However, in many cases the volcanic or sedimentary protolith can still be inferred, and the protolith names are, therefore, used in describing and naming the rocks where possible. In some areas of pervasive shearing and mylonitization, the protolith is uncertain.

Most rocks in the Broad River Group are strongly foliated, with well developed slaty cleavage or schistosity. In addition, evidence of shearing is widespread, and in many areas the rocks are mylonitic. Much of the area assigned here to the Broad River Group is part of the Fundy Cataclastic Zone of Ruitenberg et al. (1973), and the Eastern Volcanic Belt of Giles and Ruitenberg (1977) and Ruitenberg et al. (1979). The group also includes the area southeast of the Cradle Brook–Walton Brook fault of McLeod (1987), and most of the rocks in the central and eastern Caledonian Highlands informally termed 'sequence A' by Barr and White (1988c). The differences in lithology and deformational character of these rocks compared to other volcanic-sedimentary units in the Caledonian Highlands were recognized by all of these workers, but without geochronological control, the difference in age between rocks of the Broad River Group and other rock units was not generally recognized.

Age controls in the Broad River Group are based on tuff and rhyolite samples from 3 locations which yielded U-Pb ages of ca. 618 Ma, 613 ± 2 Ma, and 600 ± 1 Ma (Fig. 2; Table 1). The group has been intruded by dioritic to granitic plutons with ages of ca. 615 +1/-2 Ma, 625 ± 5 Ma, 616 ± 3 Ma, and 623 ± 2 Ma (Barr et al., 1994; Watters, 1993b). Given the complexity of the age data, as well as field evidence of crosscutting relations, it seems most likely that the Broad River Group and the dated plutons are essentially cogenetic at ca. 620 Ma (Barr et al., 1994).

Description of lithological units

(Note: for brevity, the age indicator 'Z' is omitted from the Neoproterozoic unit designations in this section.)

Unit Bls (Lumsden unit)

Unit Bls is located between the Kent Hills Pluton and the Caledonia Road Granitoid Suite (Fig. 3, Open File 3615), and has been intruded by both of these plutonic units, as well as by the Caledonia Brook Granodiorite, Rat Tail Brook Pluton, and numerous other smaller and varied plutonic units. Not surprisingly, evidence for contact metamorphism is widespread within the unit. Unit Bls hosts the Lumsden Cu-Zn-Pb deposit, and hence is informally termed the 'Lumsden unit'.

Typical rocks of unit Bls are exposed along Crooked Creek (NTS 21 H/15). The most characteristic rock type is dark-coloured hornfels (typically fine-grained laminated metasiltstone or tuffaceous siltstone). The hornfels contains scattered quartz and plagioclase crystals. Interlayered with the metasiltstone are dacitic and rare mafic crystal and lithic crystal tuffs, and fine-grained cherty siliceous rocks of uncertain protolith. Pyrite is abundant in many rocks of all lithologies. As in most other units of the Broad River Group, porphyry sheets are present, and contain distinctive embayed quartz phenocrysts, in most cases accompanied by plagioclase phenocrysts. The groundmass contains abundant sericite. Where sheared, the porphyries are difficult to distinguish from crystal tuffs.

Compared to other units in the Broad River Group, the rocks of the Lumsden unit generally appear to be of higher metamorphic grade, and commonly contain abundant biotite and amphibole, as well as sericite, chlorite, and epidote. Rocks of both sedimentary and tuffaceous origin show evidence for contact metamorphism, including chlorite, epidote, and, rarely, altered cordierite spots, and recrystallized-looking groundmass textures. Some samples display a strong cleavage, defined by sericite/muscovite, and/or biotite, and/or chlorite. These samples appear to have been sheared and, in some cases, mylonitized after the contact metamorphism.

Unit Btp (Teahan unit)

Unit Btp is informally termed the 'Teahan unit' because of its occurrence in the vicinity of Teahans Corner and the Teahan Cu-Pb-Zn deposit (Fig. 3,Open File 3615). It corresponds in part to unit A2 of Barr and White (1988a). The most characteristic and abundant rock types in the unit are strongly cleaved phyllite and chloritic schist (Fig. 4) but a variety of other rocks including slate, amygdaloidal basalt, and arkosic sandstone and conglomerate, as well as mafic and felsic porphyritic dykes and small plutons, are also present. Unit Btp hosts the Teahan pyrite-copper-zinc-lead sulphide deposit, as described by Ruitenberg et al. (1979).

Rocks typical of the Teahan unit are well exposed in the upper part of Broad River and its tributary Barrett Brook (NTS 21 H/11). To the southwest, the distinctive phyllites of the unit can be mapped with certainty to beyond East Branch Goose Creek, where the unit seems to merge with unit Bmf (which locally contains some lithologies similar to those in the Teahan unit). To the northeast, the distinctive phyllites of the unit can be traced for several kilometres both north and south of the Kent Hills Pluton. However, on the northern side of the pluton they are replaced along strike by a dominantly arkosic metasedimentary unit (Bas), and on the southern side they are replaced by a unit of more massive tuffaceous sedimentary rocks (unit Bls). Both of these units could represent lateral facies equivalents of unit Btp, as both lithologies are present locally in the Teahan unit. However, outcrop is very limited in the areas of transition, and hence the nature and position of these unit boundaries are highly speculative.

The characteristic phyllites of the Teahan unit are dark green-grey and consist of abundant muscovite, chlorite, and epidote, as well as quartz and feldspar. With increasing and decreasing grain size, respectively, they grade to laminated siltstone and grey and maroon slate. Most of these rocks appear to have a tuffaceous protolith of andesitic to dacitic composition; most samples contain scattered angular quartz clasts. The chloritic schists contain more abundant chlorite and epidote than the phyllites, and their protoliths were probably mafic ash tuffs.

Rocks with crystal- and lithic crystal-tuff protoliths are also common in the Teahan unit, and are similar to tuffs in unit Bmf. They are characterized by quartz and feldspar lapilli, typically in a cleaved and sheared fine-grained matrix of sericite, chlorite, and epidote, and are predominantly of dacitic composition.

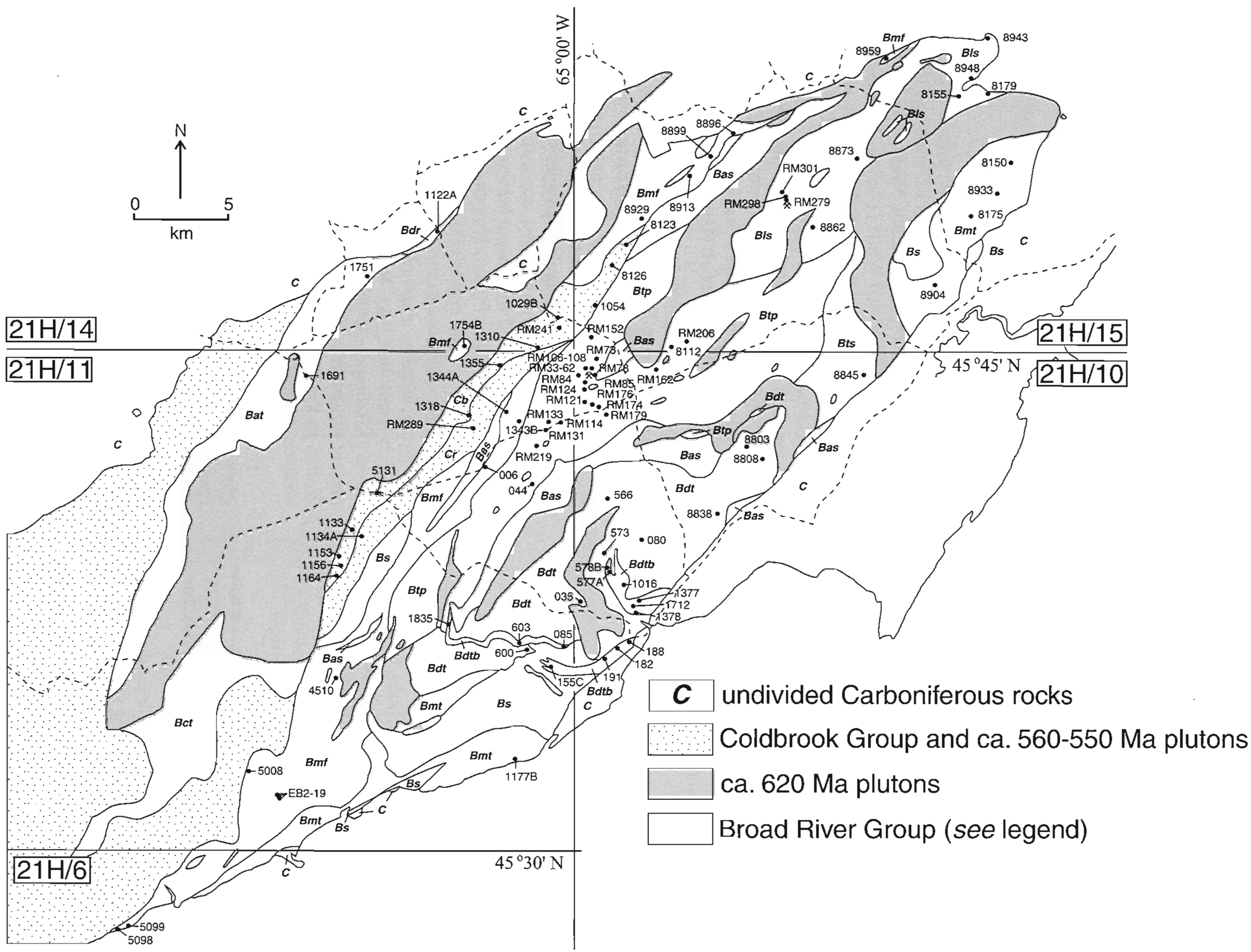

Figure 3. Simplified geological map of the northeastern part of the Caledonian Highlands (simplified from Open File 3615), showing units of the Broad River Group (except units Bit and Bft which are included on Figure 9). Numbered dots are locations of samples used for chemical analysis (Appendix B; Appendix C, Table C.1).

Figure 3 LEGEND

CARBONIFEROUS

C Undivided Carboniferous sedimentary rocks

NEOPROTEROZOIC*

Coldbrook Group (ca. 560-550 Ma)

Cb Amygdaloidal to massive basalt flows with less abundant mafic tuff

Cr Pink to red to grey, commonly flow-banded rhyolite and rhyolitic tuff; minor laminated siltstone/chert

Broad River Group (ca. 620 Ma)

Bdr Dacitic and rhyolitic tuff

Bat Andesitic to basaltic crystal tuff, minor basaltic flows, andesitic/dacitic crystal and lithic tuff; volcanogenic epiclastic rocks

Bct Crystal and lithic tuff, mainly of dacitic to rhyolitic composition; minor laminated siltstone, arkosic sandstone, and mafic tuff

Bs Red, maroon, and grey slate, phyllite, arkosic metasiltstone and metasandstone, metaconglomerate, minor micaceous quartzite

Bmt Mafic to intermediate crystal tuff, lithic tuff, basaltic flows, volcanogenic epiclastic rocks; locally chlorite schist and phyllite

Bmf Mafic and felsic tuff; amygdaloidal basalt; minor rhyolite; abundant pyrite-rich felsic layers; locally phyllitic metasedimentary and metatuffaceous rocks

Bts Dacitic to andesitic crystal-lithic tuff; laminated grey-green siliceous siltstone

Bdt Dacitic crystal tuff and crystal-lithic tuff; pyritiferous felsite and felsic tuff; minor flow-banded rhyolite. Includes mappable areas of amygdaloidal basalt (unit Bdtb).

Bas siltstone, sandstone, pebble conglomerate (mainly arkosic)

Btp Tuffaceous phyllite, chloritic schist, slate, felsite, arkosic sandstone and conglomerate (Teahan unit)

Bls Metasiltstone (hornfels); dacitic crystal and lithic-crystal tuff; mafic tuff; minor chert/felsite (Lumsden unit)

*Note that age symbol is omitted from unit designations for brevity.

Metasedimentary rocks in the Teahan unit occur as lenses or layers throughout the unit. The arkosic metasandstone and metaconglomerate are similar to those in unit Bas. The slates vary from grey to maroon to buff, and are similar to those in unit Bs.

Various porphyritic intrusive units are common in the Teahan unit. Most distinctive are mafic bodies with abundant large plagioclase phenocrysts, and more felsic porphyries with large embayed quartz phenocrysts. Other plutonic rocks are also abundant in the unit, and range from mappable bodies of diorite, leucotonalite, tonalite, and granodiorite to dioritic and gabbroic dykes. Most of these plutonic units are extensively altered, and, like the larger dated plutons, are likely to be similar in age to their tuffaceous host rocks. Exceptions are rare bodies of much fresher gabbroic rocks in the central part of the unit around the Teahan Corner area. They preserve both pyroxene and olivine, and hence are mineralogically similar to the ca. 557 Ma Mechanic Settlement Pluton, and may be of similar age.

Unit Bas

Unit Bas is composed mainly of interlayered quartz-rich sandstone, siltstone, and conglomerate with abundant quartzite clasts. Rocks of this unit occur both north and south of unit Btp, in lenses closely associated and apparently within unit Btp, and in several slivers faulted against Carboniferous rocks along the southern margin of the map area (Fig. 3, Open File 3615). It is not likely that these widely separated areas are directly time-correlative, but they have many lithological features in common, and were clearly derived from similar source areas and deposited under similar conditions. The area of unit Bas south of unit Btp was informally termed the 'Fortyfive River arkose' by Ruitenberg et al. (1979), and 'unit A3' by Barr and White (1988a). Typical outcrops occur along Fortyfive River Road.

Unit Bas is one of the few in the Broad River Group in which younging direction can be determined. Both graded bedding and crossbedding are preserved in many outcrops, except in strongly sheared areas. In the faulted lenses of unit Bas along the southern margin of the highlands, the rocks seem to coarsen to the northwest toward apparently faulted contacts with granitoid plutons. This observation suggests the presence of a nearby source area, and younging to the southeast, but none of the rock units presently exposed in the Caledonian Highlands is a suitable source because of the abundance of quartzite clasts in unit Bas. The 'Fortyfive River arkose' body also youngs mainly to the southeast, based on sedimentary structures in outcrops of these rocks, for example, along the Fortyfive River Road northeast of Fundy National Park. Although locally younging directions to the northwest were also observed, overall unit Btp appears to grade into unit Bas in this area.

Lenses of unit Bas associated with unit Btp in the Dustin Brook, Shepody Road, and Teahan areas appear to grade into more tuffaceous rocks both above (to the northwest) and below (to the southeast). In the area of unit Bas located on the northern margin of unit Btp, the rocks also young to the north, and appear to gradationally overlie unit Btp. Thus, the lithological distribution and structure of units Btp and Bas are consistent with the presence of a northeast-trending anticlinal structure in the northeastern highlands (*see* section titled 'Deformation and Metamorphism'). In the area north of unit Btp, unit Bas includes grey slate and mafic rocks, the latter perhaps originally dykes or sills. Compared to the other areas of unit Bas, a larger component of the constituent clasts in unit Bas in this area were derived from granitoid sources, as indicated by an abundance of large K-feldspar clasts. However, as rocks in this area are mainly strongly sheared to mylonitic, the protolith is not everywhere resolvable. Where sheared, the rocks of unit Bas in this area are difficult to distinguish from granitoid rocks.

In thin section, samples from unit Bas characteristically are seen to contain angular quartz and quartzite clasts in a dominantly sericitic matrix. In some samples, the matrix also contains abundant epidote and chlorite. The quartzite clasts contain sutured quartz grains, and range from fine to coarse grained. Most samples contain only minor feldspar, and it is mainly untwinned alkali feldspar. However, as noted above, samples from the area north of unit Btp and the Kent Hills Pluton contain more K-feldspar, and unit Bas in this area is more immature and, locally, contains abundant epidote. Also it appears more metamorphosed, with large aligned flakes of muscovite, in places crenulated. The muscovite may have been originally detrital. Clasts are mainly of quartz, rather than quartzite.

The relationship of unit Bas to associated granitoid units is uncertain. The present outcrop distribution suggests that the contacts were originally intrusive, locally modified by later faults. Although the rocks are arkosic and appear to have had a granitoid contribution, granitoid clasts are relatively rare in the conglomeratic facies of the unit, and none can be traced compositionally to plutons now exposed in the area. Although no evidence of contact metamorphism was noted in sedimentary outcrops close to granitoid outcrops, the rocks contain regional metamorphic mineral assemblages, and hence any contact metamorphic affects may have been minimal.

Unit Bdt (and subunit Bdtb)

Unit Bdt is a varied, but mainly tuffaceous unit that underlies much of the Fundy National Park area and also extends northeast of the park (Fig. 3, Open File 3615). Unit Bdt includes unit A6 of Barr and White (1988a), as well as areas of basalt (here designated Bdtb) and rhyolite included by Barr and White (1988a) in their sequence B. On the Fortyfive River Road, younging directions in the adjacent arkosic unit (Bas) indicate that unit Bdt overlies unit Bas in this area. Typical sections of unit Bdt are well exposed in Fortyfive River upstream from its junction with Broad River, and in Point Wolfe River in the vicinity of the Bennett Brook tributary (NTS 21 H/10, 11).

The most abundant lithology in the unit is medium-grained, grey-green crystal tuff containing 20-50% plagioclase (now albite) crystals in a fine-grained groundmass of sericite, epidote, and quartz. In some samples, plagioclase forms most of the clasts and also the groundmass. Rhyolitic crystal lapilli tuff is less common than the dacitic varieties, and contains sparse plagioclase crystals in a quartz and feldspar groundmass. In places, lithic fragments are abundant, and the rocks are more mafic, grading to andesitic lithic lapilli tuff. The lithic fragments in these rocks are commonly pink and light grey chert/felsite. Grey to buff pyrite-rich felsite and felsic tuff is also a characteristic component of unit Bdt. These highly siliceous rocks are massive and featureless, lacking either sedimentary layering or volcanic structures. Their protolith is uncertain, but may have been felsic ash tuff.

Areas of both basalt and rhyolite are also present in the unit. They were previously assigned to sequence B (the present Coldbrook Group) by Barr and White (1988a, c), based on their similarity to basalt and rhyolite in the Coldbrook Group. However, their spatial association with unit Bdt and, more importantly, a U-Pb date of ca. 618 Ma from one of the rhyolite areas (Barr et al., 1994) support their inclusion in the Broad River Group. The rhyolitic flows typically display well developed, swirly 'flow banding'. The basaltic flows are more extensive and form mappable units (Bdtb). They are locally amygdaloidal with chlorite-filled amygdules.

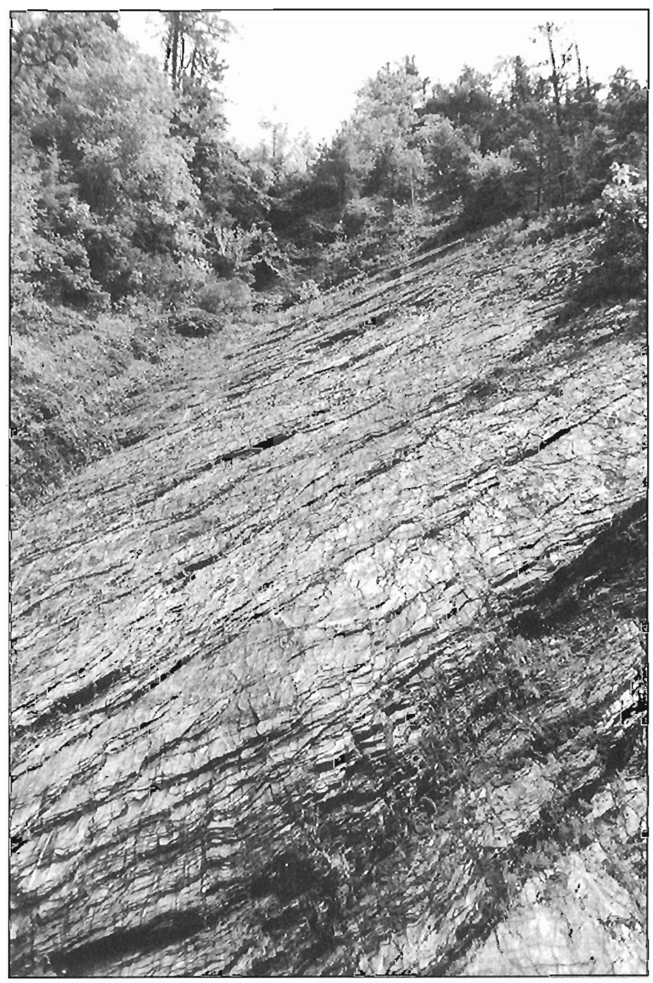

Figure 4. *Typical phyllite of the Broad River Group, unit Btp, in East Branch Point Wolfe River. Photograph by S.M. Barr. GSC 1998-049a*

Unit Bdt contains abundant small granitoid bodies throughout, but they are especially abundant in the vicinity of the Fortyfive River and Alma plutons. The most common variety is red, medium- to coarse-grained leucogranite, but dioritic and granodioritic intrusions are also present. The intimate association between volcanic and plutonic rocks suggests that they are approximately comagmatic. Also abundant in the unit are andesitic and andesitic porphyry dykes and sills, felsite porphyry intrusions, and gabbroic dykes and sills ranging from fine to coarse grained.

Unit Bts

Unit Bts forms a large area northeast of Fundy National Park (Fig. 3, Open File 3615). It consists of dacitic to andesitic crystal and crystal lithic tuff, with minor but distinctive, finely laminated, grey-green tuffaceous siltstone layers. The crystals in the tuff are mainly plagioclase and quartz. Lithic fragments commonly include light grey to buff-grey chert/siltstone and minor dark green amygdaloidal basalt. Epidote, chlorite, and carbonate are abundant in the groundmass. These minerals are also recognizable in the fine-grained to cryptocrystalline tuffaceous siltstone, as well as scattered larger grains of plagioclase and quartz. Mafic crystal tuffs and flows with chlorite patches occur rarely in unit Bts.

Compared to other units, these rocks are not strongly cleaved, and preserve quite well their original volcaniclastic textures. No contacts with adjacent units were observed. Mafic and tonalitic dykes are an abundant component.

Unit Bmf

Unit Bmf is a mainly tuffaceous unit that locally appears to gradationally overlie unit Btp, and underlie unit Bs (Fig. 3, Open File 3615). Hence, it may be a lateral facies equivalent of unit Bmt and/or unit Bdt. Both mafic and felsic rocks are abundant, but intermediate compositions and sedimentary rocks are less abundant than in unit Bdt or unit Btp, respectively. Well exposed sections of the unit are present in Quiddy River and along logging roads southwest of Quiddy River (NTS 21 H/11).

Basalt and basaltic tuff are a major component of the unit, and in some areas can be separated as mappable areas. In most places the basalts are amygdaloidal, with amygdules filled with chlorite, epidote, calcite, and quartz. Chlorite and epidote are also abundant in the groundmass, together with saussuritized plagioclase laths. Pillow basalts, indicating subaqueous eruptions, were observed in two areas, one in the vicinity of Cradle Brook and the other along a logging road southwest of Point Wolfe River. The basaltic tuffs are well exposed in the Quiddy River section; most are fine-grained crystal tuffs of uncertain origin but some are lithic tuffs that may have been a result of autobrecciation of flows.

Along the northern margin of the Caledonian Highlands, southeast of the Point Wolfe River Pluton, rocks assigned to unit Bmf are highly sheared. Amygdaloidal basalts in this area are difficult to distinguish from those of the Coldbrook Group in the field, but in thin section they are seen to contain amphibole, probably as a result of contact metamorphism. In addition, the associated tuffaceous rocks, as well as the abundant granitoid lenses, are typical of unit Bmf.

The felsic rocks in unit Bmf are mainly rhyolitic crystal tuff, porphyry sheets, and quartz-rich granitoid sheets, with minor areas of flow-banded rhyolite. The crystal tuffs contain abundant embayed quartz clasts in a felsic matrix containing abundant sericite. The rhyolitic porphyry sheets are distinctive, containing large rounded and embayed quartz crystals in a locally spherulitic matrix. Along roads southwest of Quiddy River, alternating basaltic flows and rhyolitic porphyry sheets give the appearance of a sheeted dyke complex. The felsic sheets typically contain abundant pyrite, and gossan is common. McLeod (1987) referred to these felsic porphyritic intrusions as keratophyre because of their high sodium and low potassium contents. The quartz-rich granitoid sheets contain varying amounts of K-feldspar (microcline), and grade to leucotonalite with up to 50% quartz.

The unit locally contains lenses of quartz-rich to arkosic sedimentary rocks assigned to unit Bas, and to the northwest, contains interlayered grey-green and maroon slaty horizons similar to those in the overlying mainly sedimentary unit Bs.

In addition to the felsic porphyry and quartz-rich granitoid rocks described above, sheets and small plutons of mafic porphyry, gabbro, diorite, tonalite, and granodiorite are characteristic features of unit Bmf. The mafic porphyries have abundant plagioclase phenocrysts, in some cases up to 2 cm in length, and are similar to those in unit Btp. The gabbroic intrusions include both metamorphosed and relatively fresh varieties, the latter mainly dykes that preserve clinopyroxene. The tonalitic rocks are similar to those of the Goose Creek Leucotonalite. Hornfelsing of the tuffaceous host rocks and the development of biotite in the groundmass is apparent adjacent to the larger plutons. Most of these minor intrusions are at the scale of a single outcrop and are not identified on Open File 3615.

Unit Bmt

Rocks of unit Bmt occur in two areas (Fig. 3,Open File 3615): 1) in the northeastern part of the highlands, north of Riverside–Albert, and 2) in the southwestern part of Fundy National Park and farther to the southwest along the coast of the Bay of Fundy. The latter area formed unit A1 of Barr and White (1989a). Excellent sections through the units are exposed in Memel Creek and in the lower part of Crooked Creek in the Riverside–Albert area (NTS 21 H/10, 15), and in the lower parts of Quiddy River and Jim Brook southwest of Alma (NTS 21 H/11). Cliff sections along the coast are difficult to access, and the rocks are very sheared. Hence, in spite of excellent exposure, they are not optimum sites for examination of these rocks.

In both the Riverside–Albert and Fundy National Park coastal areas, the unit consists mainly of mafic to intermediate volcaniclastic rocks, and grey and green laminated volcanogenic epiclastic rocks (wackes). Dark green amygdaloidal mafic flows with numerous epidote veins and pods are also a major component of the unit. Varied gabbroic

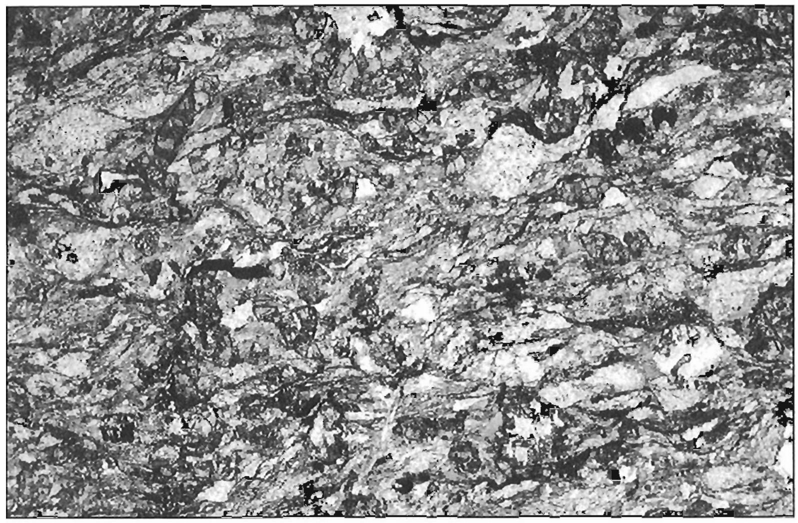

Figure 5.

Photomicrograph of mafic crystal tuff of the Broad River Group, unit Bmt (analyzed sample 8933). Plagioclase and epidote form porphyroclasts in a foliated groundmass of chlorite and plagioclase. (Plane polarized light; width of photo is 4 mm.)

sills or dykes are also present; in most cases they are relatively less deformed than the host rocks, preserve clinopyroxene, and are relatively unaltered, suggesting that they are significantly younger than their greenschist-facies host rocks. In the Riverside–Albert area, pink felsite dykes, up to 2 m wide, occur close to the contact with the Caledonia Road Granitoid Suite, and in Fundy National Park, granitoid dykes occur in the vicinity of a small granitoid pluton (unit Zgt).

Although variable in composition, the rocks of unit Bmt are characterized by greenschist-facies mineral assemblages. The most abundant minerals in most samples are albitic plagioclase and chlorite, with less abundant sericite, epidote, quartz, and carbonate (Fig. 5). Most tuffaceous samples have a well developed cleavage defined by chlorite and sericite. The matrix in tuffaceous samples, originally ash, is now dominated by chlorite and/or sericite. Such rocks are typically phyllitic or schistose, depending on the grain size. Most of the fine-grained rocks appear to have been originally ash tuffs or fine-grained crystal tuffs. Less common lapilli tuffs are dominated by plagioclase-rich basaltic and andesitic clasts.

Near the Bay of Fundy coast, as noted above, the rocks are strongly sheared, and most accurately described as chloritic schists. The protolith of such samples is difficult to determine, but in many cases was probably mafic crystal tuff.

Unit Bmt hosts the Roman Wolfe and Mile Brook copper vein deposits described by Ruitenberg et al. (1979), and also occurs in close proximity to the Vernon copper deposit (Fig. Open File 3615).

Unit Bs

Unit Bs consist mainly of metasedimentary rocks, and occurs in three separate areas (Fig. 3, Open File 3615): 1) in the northeast (Riverside–Albert area; NTS 21 H/15), 2) in the Fundy National Park area (NTS 21 H/11), and 3) in the East Branch Point Wolfe River area (NTS 21 H/11). Although the rocks are similar in all three of these areas, correlation among them cannot be made with certainty. The status of these rocks as part of the Broad River Group is also uncertain because they show lithological similarities to some sedimentary rocks in the Coldbrook Group, and also to sedimentary rocks in the Saint John Group, as previously noted by McLeod (1987), who included some of unit Bs in the Saint John Group. However, field relations, especially in the Fundy National Park and East Branch Point Wolfe River areas, indicate that these rocks are conformable with the mainly mafic to intermediate tuffs of unit Bmt, and with mafic tuffs and flows of unit Bmf. Furthermore, some components are similar to sandstone and conglomerate in unit Bas. Hence, inclusion in the Broad River Group seems most appropriate (*see* section titled 'Neoproterozoic and Cambrian Sedimentary Rocks' for further discussion).

Riverside–Albert area

Metasedimentary rocks assigned to unit Bs outcrop in an ellipsoidal area centred on Crooked Creek. The rocks are well exposed in Crooked Creek and its tributaries, including Canada Creek. They include interbedded grey slate/siltstone and maroon arkosic siltstone/sandstone with maroon quartz arenite beds and lenses. The sandstone units are characterized by abundant irregular quartz veins. In thin section, they are seen to consist of angular quartz clasts in a somewhat foliated matrix of sericite and chlorite. Crossbedding preserved at several locations indicates a consistent younging direction to the northwest. The interlayered slates grade to laminated siltstone, and typically are strongly crenulated (Fig. 6). Minor thin (<2 cm wide) rusty-brown carbonate layers and concretions are interbedded with the grey slates.

Mafic dykes are common in the unit; in places they are amygdaloidal and may be flows. Porphyritic textures (with plagioclase phenocrysts) are also common in the dykes.

Unit Bs in this area is interpreted to be in faulted contact with adjacent units. In the lower part of Crooked Creek, maroon arkosic sandstone and quartz arenite are in sheared contact with basaltic rocks of unit Bmt. On the western and northern margins, contacts are not exposed, but adjacent granitoid rocks of the Caledonia Road Granitoid Suite are altered and brecciated, suggesting that these contacts are also faulted.

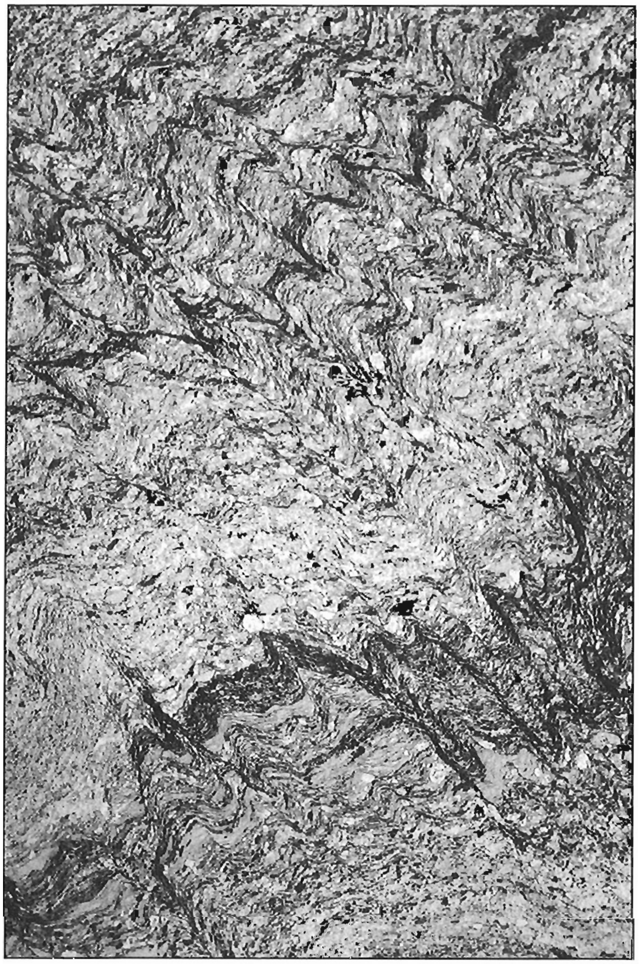

Figure 6. *Photomicrograph of siltstone of the Broad River Group, unit Bs, composed mainly of quartz grains, chlorite, epidote, sericite, and hematite. Foliation (S_1) is deformed by a strong crenulation cleavage (S_2). (Plane polarized light; height of photo is 4 mm.)*

Fundy National Park area

In unit Bs in the Fundy National Park area, the rocks are more varied than in the Riverside–Albert area. They include well cleaved maroon and grey-green laminated metasiltstone and interbedded grey slate, as in the Riverside–Albert area, but also grey slate; massive, quartz-rich, arkosic sandstone; quartzite; maroon to grey phyllitic conglomerate; and grey-green metatuffaceous rocks (now chlorite schist). Clasts in the conglomerate are mainly of quartz and maroon and green siltstone. The arkosic sandstone is a distinctive component of the unit. It is pink and green (due to the presence of hematite and epidote/chlorite) and similar to arkosic sandstone in other units of the Broad River Group. Mafic dykes and sills, commonly porphyritic, occur widely, and are similar to those in the Riverside–Albert area and in the adjacent unit Bmt. A typical section through unit Bs is exposed in Goose River.

The metasedimentary rocks are internally folded but conformable with the adjacent mafic tuff unit (Bmt). Younging directions indicated by crossbedding and graded bedding are mainly to the southeast in the northern part of the area, suggesting that the sedimentary unit overlies the mafic tuff unit. No younging directions were found in the southern part of the unit, but it may form a synclinal structure, with the underlying mafic tuff unit exposed both to the south and north.

East Branch Point Wolfe River area

A lens-shaped unit of mainly metasedimentary rocks is well exposed in the area of East Branch Point Wolfe River, with well exposed sections along a logging road west of the river, and in Point Wolfe River to the southwest. The unit consists mainly of strongly cleaved slate, varying from grey to green and maroon, with interlayered maroon to green arkosic sandstone and dark maroon/grey crystal tuff beds. Based on well preserved crossbedding and graded bedding, the rocks young consistently to the northwest. Toward the top of the succession, prominent blue-grey quartzite layers containing lensoid

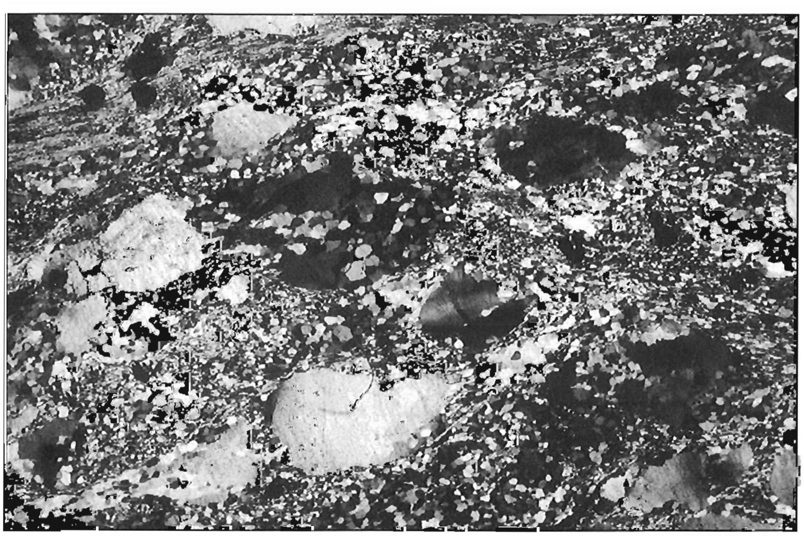

Figure 7.

Photomicrograph of arkosic sandstone of the Broad River Group, unit Bs. Recrystallized quartz grains form clasts and most of the matrix. Sericite and muscovite parallel the foliation (S_1). (Crossed polarizers; width of photo is 4 mm.)

muscovite flakes are present, as well as distinctive maroon quartzite-pebble conglomerate layers. The latter contain clasts up to 10 cm in diameter, mainly composed of quartzite, with less abundant clasts of metasiltstone, in a matrix of quartz, detrital muscovite, and opaque phases (Fig. 7). Large rounded zircon grains are a prominent accessory component. The conglomerate is very similar to conglomerate in unit Bas, as described previously. On the northwest, rocks of unit Bs are faulted against sheared rhyolite of the Coldbrook Group, dated in this area at ca. 550 Ma (Barr et al., 1994). On the southeast, the sedimentary units appear to grade conformably into underlying mafic lithic tuffs of unit Bmf.

Unit Bct

Unit Bct occurs along the southern margin of the Old Shepody Road granite (Fig. 3; Open File 3615; NTS 21 H/11). The irregular shape of the contact with the granite, and the presence of abundant granitoid material (possibly dykes) in unit Bct, indicate that the contact was originally intrusive, although rocks of unit Bct do not show evidence of contact metamorphism. Many outcrops in the area now show evidence of shearing. To the south and southwest, unit Bct appears to have complex relations with younger rocks of the Coldbrook Group. The latter units may have been originally deposited unconformably on top of the Broad River Group and associated plutons, and/or thrust over these older units.

Unit Bct consists mainly of intermediate (dacitic) crystal tuff and lithic crystal tuff, locally interlayered with laminated siltstone. Typical rocks are well exposed in Little Salmon River. Mafic tuff and arkosic metasandstone occur rarely. The overall dacitic composition and relative scarcity of mafic rocks distinguishes unit Bct from unit Bmf, although there is certainly some lithological overlap between the two units. Scattered quartz clasts are prominent in most of the dacitic tuffs, although plagioclase forms most of the clasts. Lithic fragments vary in abundance but are everywhere subordinate to crystals.

In the vicinity of the southern margin of the Point Wolfe River Pluton, the tuffaceous rocks are mixed with a variety of plutonic rock types, apparently forming sheets, dykes, and small plutons. They are dissimilar to the Old Shepody Road granite/granodiorite and other lithological units of the Point Wolfe River Pluton, and include fine-grained monzodiorite and diorite, tonalite, granodiorite, felsite, and felsite porphyry with quartz and feldspar phenocrysts. Where sheared, the dacitic tuffs and varied granitoid rocks are difficult to distinguish, and the identity of some outcrops as tuff or granitoid is difficult to determine (even in thin section).

Unit Bat

Unit Bat occurs along the northwestern margin of the Point Wolfe River Pluton (Fig. 3; Open File 3615; NTS 21 H/11, 14). The irregular shape of the contact, an abundance of granitoid sheets in unit Bat, and the presence of metamorphic biotite in the groundmass of some samples from adjacent to the pluton, indicate that the contact is intrusive. The pluton margins and adjacent rocks generally show less evidence of shearing than do the equivalent areas on the southeastern side of the pluton. The northwestern margin of unit Bat is interpreted to be faulted against rocks of the younger Coldbrook Group. The relationship of unit Bat to other units of the Broad River Group is uncertain because it is nowhere observed in contact with them.

Unit Bat consists mainly of fine- to medium-grained andesitic crystal tuff. Typical outcrops occur along Highway 114 northeast of Mechanic Lake, and along branch roads to the northeast. Typical andesitic tuff is dark grey in hand specimen, with a well developed cleavage. It consists dominantly of plagioclase and chlorite, with less abundant epidote, carbonate, sericite, and quartz. Sericite, chlorite, and in some samples biotite, parallel the cleavage. Lithic crystal tuffs of andesitic to dacitic composition are also present. Andesitic to basaltic flows occur rarely, and are typically amygdaloidal. They have an intergranular texture, with subhedral plagioclase laths and interstitial chlorite, in contrast to the less crystalline appearance of the tuffaceous rocks.

Unit Bdr

Unit Bdr occurs in a faulted sliver in the Pollet River area, between the Pollet River granodiorite and Carboniferous sedimentary rocks to the north (Fig. 3, Open File 3615; NTS 21 H/14). It consists mainly of dacitic to rhyolitic crystal tuff, with minor lithic crystal tuff (Fig. 8) and siliceous felsite. Pyrite is abundant. The relationship of these rocks to the andesitic rocks of unit Bat to the southwest, and to other units of the Broad River Group, is unknown. A U-Pb date of 600 ± 1 Ma was reported by Bevier and Barr (1990) for a dacitic tuff in this area. This age seems incompatible with the age of 625 ± 5 Ma obtained from the adjacent Pollet River granodiorite, and with the age of 616 ± 3 Ma from the Old Shepody Road granite which intruded unit Bat to the southwest. It may be that this sliver of tuff along the northern margin of the Pollet River granodiorite is slightly younger than both the granodiorite and the bulk of the Broad River Group.

Unit Bit

Unit Bit is located in the southwestern part of the Caledonian Highlands near Cape Spencer (Fig. 9, Open File 3615; 21 H/4). It consists dominantly of well cleaved, grey intermediate crystal tuff. Inclusion of these rocks in the Broad River Group is based on their lithological characteristics, but also on the fact that they occur in close association with the Millican Lake plutons, which have yielded an age of 623 ± 2 Ma at Cape Spencer (Watters, 1993b).

Unit Bft

Unit Bft also occurs in the southwestern part of the study area (Fig. 9, Open File 3615; 21 H/4), and is assigned to the Broad River Group for the same reasons as the associated unit Bit described above. Unit Bft consists of pink to red to buff felsic crystal tuff, locally flow banded, with minor red siltstone/tuff. It contains distinctive bodies of dacitic porphyry, similar to those in unit Bmf.

Depositional setting

The abundance of andesitic, dacitic, and rhyolitic tuffaceous and epiclastic sedimentary rocks in the Broad River Group is consistent with origin in a volcanic arc built on continental crust. Interlayering of quartz-rich sedimentary rocks in the volcanic sequence suggests that older crustal rocks were exposed in the vicinity during volcanism. Primary sedimentary and igneous features are not well preserved because of metamorphism and deformation, and hence a detailed assessment of the environment of deposition is difficult. Chert, laminated tuff, and well bedded epiclastic sedimentary units may have been subaqueous, but there is little evidence as to whether a marine or nonmarine setting was involved. The presence of red and maroon arkosic conglomerate and sandstone may indicate fluvial deposition. Many of the pyroclastic rocks do not show evidence of extensive reworking, such as sorting and rounding of clasts, which would be expected in a marine setting. Where well preserved, rhyolitic flows and tuffs appear welded and contain pumice fragments, they likely formed in subaerial eruptions. Associated mafic flows are highly amygdaloidal, and pillows were observed at only one location in unit Bmf. They may represent flow into a lake, rather than a submarine environment.

Further assessment of the tectonic environment is presented in the Discussion.

COLDBROOK GROUP

Overview

The name 'Coldbrook Group' is retained for volcanic and sedimentary units inferred to be similar in age to those in the 'Cold Brook' area east of Saint John, after which the group was originally named by Alcock (1938). These rocks underlie most of the central and southwestern parts of the Caledonian Highlands (Fig. 2, 9, Open File 3615). They are assigned an age range of 560-550 Ma, based on U-Pb (zircon) ages of 554 +14/-1 Ma, 559 ± 5 Ma, and 548 ± 1 Ma from widely separated volcanic components of the group, and ages of 551 ± 5 Ma, 550 ± 1 Ma, and 557 ± 3 Ma from crosscutting plutons (Fig. 2; Table 1). Contacts with the older Broad River Group are not exposed, but appear to be faulted. However, an originally unconformable relationship is inferred. The total thickness of the Coldbrook Group is uncertain but a minimum thickness of 10 km is likely, based on the apparent stratigraphic sequence preserved in the central part of the highlands.

The Coldbrook Group consists of two main groups of rock types. Mainly dacitic flows and tuffs form the area that extends from the city of Saint John through Loch Lomond to the Mechanic Settlement area, whereas basaltic and rhyolitic units dominate on the southern margin of the group, and locally on the northern margin in the Hanford Brook area. Although U-Pb ages are not precise enough to consistently resolve a difference in age between these two assemblages of units, the basaltic and rhyolitic units, together with associated sedimentary rocks, are interpreted to be the youngest units in the group because they occur in close association with Cambrian rocks in the Hanford Brook area, the Mackin Settlement–Vernon Mountain area, and the city of Saint John. A sedimentary unit ($Z\mathrm{Ꞓ}_{rb}$) that locally overlies the rhyolite includes a distinctive quartzite-pebble conglomerate that has been previously included as the basal member of the Cambrian Ratcliffe Brook Formation (e.g. McCutcheon, 1987; Tanoli and Pickerill, 1988, 1990; Hofmann and Patel, 1989); however, our mapping suggests that it may be more closely associated with the underlying interlayered volcanic-sedimentary unit than with the overlying Cambrian rocks (*see* section titled 'Neoproterozoic and Cambrian Sedimentary Rocks'). On the basis of similarity in petrological characteristics (*see* section titled 'Geochemistry'), it seems likely that the basaltic and rhyolitic units of the Coldbrook Group are the extrusive expression of the same magmatism that formed the Bonnell Brook, Mechanic Settlement, and related plutons. As these plutons mainly intruded the dacitic units of the Loch

Figure 8.

Photomicrograph of dacitic crystal lithic tuff of the Broad River Group, unit Bdr. Plagioclase and dacitic lithic clasts form porphyroclasts in a foliated groundmass of chlorite, epidote, quartz, and feldspar. (Plane polarized light; width of photo is 4 mm.)

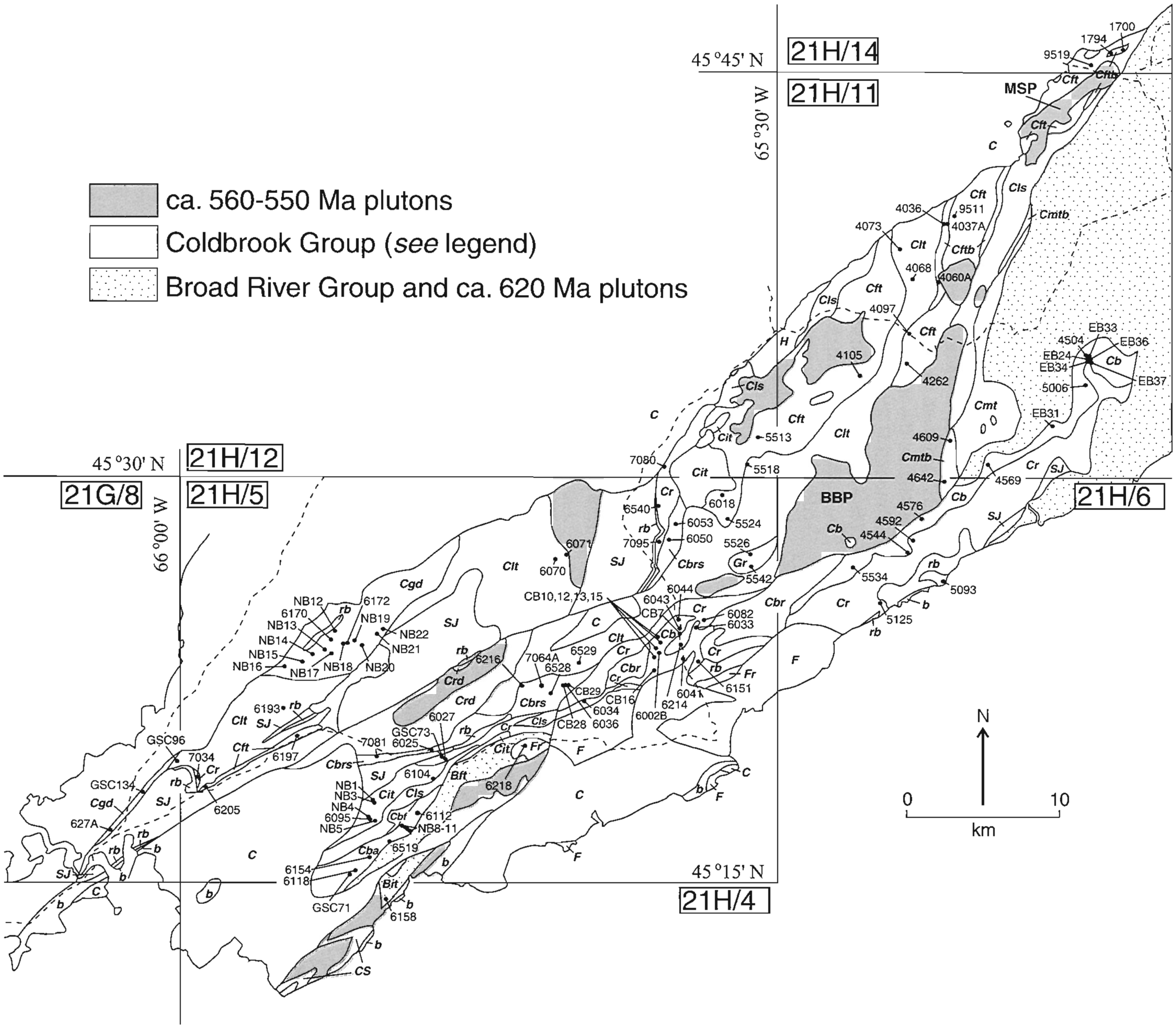

Figure 9. Simplified geological map of the southwestern part of the Caledonian Highlands (simplified from Open File 3615), showing distribution of units in the Coldbrook Group (except parts of units Cb and Cr northeast of the Point Wolfe River, which are included on Figure 3). Numbered dots are locations of samples used for chemical analysis (Appendix B; Appendix C, Table C.3).

Lomond–Mechanic Settlement belt, it seems likely that the dacitic units are somewhat older than the basaltic and rhyolitic units. However, the age difference cannot be more than a few million years because of constraints provided by U-Pb dates, which overlap within error limits (Fig. 2).

Figure 9 LEGEND*

TRIASSIC
F Fundy Group (undivided): sandstone, siltstone, conglomerate

CARBONIFEROUS
C Undivided Carboniferous sedimentary rocks

CARBONIFEROUS OR OLDER
b Epidotized basalt; minor siltstone and limestone

DEVONIAN
Fr **Fairfield formation**: rhyolitic flows and lithic tuff

ORDOVICIAN
G **Grassy Lake formation:** grey flow-banded rhyolite/dacite

CAMBRIAN
SJ **Saint John Group**: sedimentary rocks
CS **Cape Spencer Formation**: sandstone, conglomerate

NEOPROTEROZOIC TO CAMBRIAN
rb Micaceous siltstone, sandstone, and conglomerate

NEOPROTEROZOIC
Coldbrook Group (ca. 550-560 Ma)

Cbrs	Amygdaloidal basalt flows with interlayered rhyolite, red conglomerate and sandstone
Cbr	Interlayered amygdaloidal basalt, basaltic tuff, rhyolite, rhyolitic to dacitic tuff
Cb	Amygdaloidal to massive basalt flows, mafic tuff
Cr	Pink to red to grey, commonly flow-banded rhyolite, rhyolitic tuff; minor laminated siltstone/chert
Cbf	Bloomington Mountain brown felsite
Cba	Green epidotized basaltic and andesitic rocks
Crd	Grey to reddish-grey banded rhyolite to dacite, rhyolitic lapilli tuff, minor crystal tuff
Cit	Mainly dacitic lapilli tuff; minor dark grey to black dacite
Cmt	Mixed tuffaceous conglomerate, laminated siltstone, basaltic lenses and layers (Cmtb)
Cls	Laminated black to grey to green siliceous siltstone; minor tuffaceous conglomerate
Cft	Dark grey to black dacitic to rhyolitic lapilli and crystal tuff; basaltic lenses and layers (Cftb)
Clt	Volcanogenic lapilli tuff with dacitic to rhyolitic, subrounded to subangular clasts
Cgd	Grey-green dacitic tuff, flows and crystal tuff; minor tuffaceous sandstone

Broad River Group (ca. 620 Ma)

Bft	Felsic crystal tuff, dacitic porphyry
Bit	Grey intermediate crystal tuff; well cleaved

H **Hammondvale metamorphic suite**: mica schist, albite porphyroblastic minor marble

*Note that age symbols are omitted from most unit designations for brevity.

The Coldbrook Group is generally less deformed and metamorphosed than the Broad River Group. However, at least in part, this difference is related to geographic distribution, as the northwestern part of the Caledonian Highlands is generally less deformed than the coastal and eastern parts, and the deformation may be as young as Silurian to Carboniferous (*see* section titled 'Deformation and Metamorphism'). Nevertheless, it is likely that the Broad River Group experienced a low-grade metamorphic and deformational event prior to deposition of the Coldbrook Group. Deformation in the Coldbrook Group is most intense in the band along the southern margin of the Point Wolfe River Pluton and extending southwest toward Big Salmon River.

The structure in the Loch Lomond–Mechanic Settlement belt is inferred to be antiformal, based on the distribution of the basaltic and rhyolitic units, which are inferred to be younger, mainly on the flanks. The units are described below in sequence from the core to the margins of this structure, but it is emphasized that stratigraphic relations are uncertain, and a stratigraphic sequence consistent throughout the whole area of the Coldbrook Group cannot be constructed.

Description of lithological units

(Note: for brevity, the age indicator 'Z' is omitted from the Neoproterozoic unit designations in this section.)

Unit Cgd

The most common rock type in unit Cgd is grey-green dacite, most of which appears, based on homogeneity and texture, to represent lava flows. Tuff and tuffaceous sandstone are minor components. The unit is best exposed on the road between Upper Golden Grove and Second Lake–Loch Lomond (Fig. 9, Open File 3615; NTS 21 H/5). However, it is interpreted to extend to the southwest into the city of Saint John where a flow-banded, welded, dacitic tuff sample yielded a U-Pb (zircon) age of 554 +14/-1 Ma (Barr et al., 1994).

The flows vary in texture but are characterized mainly by flow-aligned plagioclase laths, in some cases in a spherulitic or 'blotchy' groundmass of plagioclase, quartz, and K-feldspar. Some samples contain abundant plagioclase phenocrysts, as much as 2 mm in length, forming up to 25% of the rock . Like the groundmass, they show flow alignment. In addition to the dacitic flows, some more felsic (rhyolitic) flows are also present. Mafic rocks with fine- to medium-grained intergranular texture also occur locally, and may be dykes or sills. Sericitic alteration is present in some sheared samples, but secondary minerals in most samples from unit Cgd are mainly carbonate and chlorite, replacing phenocrysts and mafic minerals, and less commonly in the groundmass.

Unit Cgd is separated from Clt (*see* below) because it is dominated by dacitic flows rather than tuffs. However, tuffaceous rocks similar to those in unit Clt are present locally, and many of the clasts in Clt resemble the flows of unit Cgd. Hence, a close relationship between the two units is suggested.

Unit Clt

Unit Clt is the most areally extensive and distinctive unit in the western part of the Caledonian Highlands. It is exposed in a belt that extends from the city of Saint John northeast to the Chambers Settlement area where it disappears under Carboniferous cover (Fig. 2, 9, Open File 3615). Typical rocks of the unit are well exposed along Highway 111 east of the Golden Grove Road. The unit is dominated by volcanogenic lithic lapilli tuff or tuffaceous conglomerate, typically with subrounded to subangular lapilli of dacitic and rhyolitic composition (Fig. 10). Colour varies from grey to black to pink to orange and, more rarely, red. Black dacitic lapilli tuff, grey crystal tuff, and grey to light brown laminated siltstone/chert occur locally in unit Clt.

The most abundant types of lapilli in the tuffs are microcrystalline to cryptocrystalline and of andesitic to dacitic composition. Lapilli with visible crystals are commonly composed of felted plagioclase laths, in many cases with flow alignment or flow banding. More mafic lapilli are present in some samples, and are commonly amygdaloidal basalt, with chlorite-filled amygdules. Crystal fragments are less abundant than lithic fragments in tuffs of this unit, and are mainly composed of plagioclase. Quartz clasts occur rarely, and in some cases are embayed. Sparse clinopyroxene clasts occur in some samples.

The groundmass in most samples is cryptocrystalline ash, in which few crystals can be recognizable. Presumably this was originally glassy material, but glass shards were recognized in only one sample. In rare samples the groundmass is welded, with well developed swirly flow banding. In some samples, the groundmass has been altered to sericite, and a weak cleavage developed, apparently in response to local shearing.

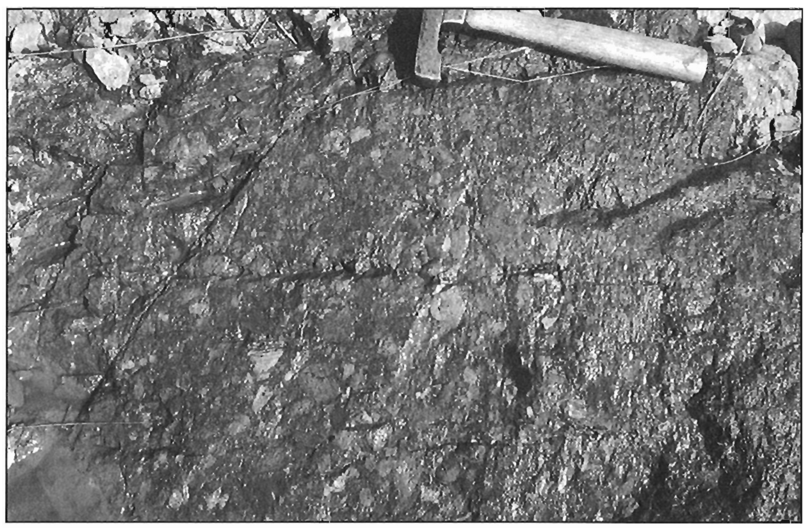

Figure 10.

Rhyolitic lithic lapilli tuff of the Coldbrook Group, unit Clt, west of the Bonnell Brook Pluton on the northeastern part of NTS 21 H/5. Photograph by S.M. Barr. GSC 1998-049b

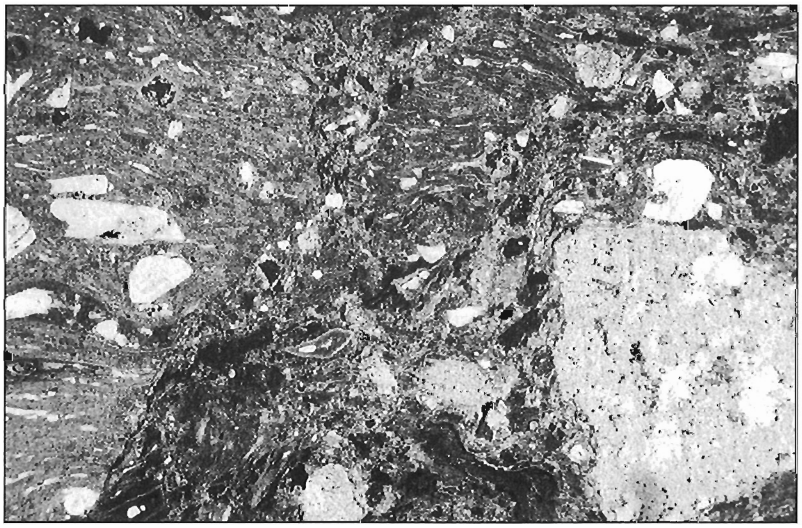

Figure 11.

Photomicrograph of dacitic crystal lithic tuff of the Coldbrook Group, unit Cft. Mainly plagioclase crystals and varied dacitic lithic clasts occur in a groundmass of chlorite, magnetite, and cryptocrystalline material (originally ash). (Plane polarized light; width of photo is 4 mm.)

The rocks in unit Clt are interpreted to represent mainly volcanogenic debris flows. They preserve some primary textures and mineralogy, and do not appear to have been metamorphosed. However, secondary minerals such as chlorite and carbonate and rarely prehnite are present in most samples.

Unit Cft (and subunit Cftb)

Unit Cft is characterized by dark grey to black, crystal lithic lapilli tuff, although a variety of other tuffs and flows are also present. The unit forms a band along the southeastern margin of unit Clt in east Saint John, and flanks unit Clt on both the northwest and southeast of the Bonnell Brook Pluton (Fig. 9, Open File 3615; 21 H/5, 11, 12). Typical outcrops occur in the Mount Theobald area northwest of the Bonnell Brook Pluton (northeastern part of NTS 21 H/5). In many outcrops the tuffs are mainly dark grey to black, but brown and green varieties are also present. The latter are similar to lapilli tuffs in unit Clt, and hence a close relationship is inferred between these two units. Composition of the lithic lapilli is generally dacitic to rhyolitic, although some samples contain more mafic lapilli. As in unit Clt, textures in the lapilli are variable; common types include those with flow-aligned plagioclase laths, granular microcrystalline, spherulitic, flow-banded cryptocrystalline, and massive cryptocrystalline (Fig. 11). Much more than in Unit Clt, the fragments are elongate, likely due to flow while still hot, and the groundmass is typically welded. Bands of alternating spherulitic and granular texture are common, on a scale of 1 mm or less. Some samples are glassy in places, with spectacular welded textures. Crystal lapilli are composed almost entirely of plagioclase. Rare clinopyroxene and quartz lapilli are also present.

Other rock types in the unit include black to grey dacite, amygdaloidal in some places and with aligned plagioclase laths similar to those in dacite flows in unit Cgd, and intergranular to spherulitic rhyolite flows or domes. Amygdaloidal basaltic flows and lithic tuffs are also present locally, and form mappable layers flanking the unit in the area north of the Bonnell Brook Pluton.

Attempts to date dacitic crystal tuff of this unit were unsuccessful because 25 kg samples from two separate localities yielded no zircon grains. However, the unit is intruded by the Bonnell Brook Pluton which indicates a minimum age of 550 Ma, and dacitic parts of the unit are lithologically similar to dated unit Cgd.

Unit Cls

Unit Cls is characterized by well laminated, black to grey to green siliceous siltstone and chert (Fig. 12). It occurs in two belts (eastern and western) flanking unit Cft in the area north of the Bonnell Brook Pluton, and in a third belt in the Vernon Mountain–Black River area (Fig. 9, Open File 3615). Similar looking laminated siltstone occurs locally in the rhyolitic unit Cr. However, the laminated rocks in unit Cr are ash tuffs, and lack the detrital muscovite present in unit Cls.

The eastern belt of laminated siltstone and chert extends from east of the Bonnell Brook Pluton to the northeast, beyond the Mechanic Settlement Pluton (Fig. 9, Open File 3615). The western belt contains very similar rocks, but is less extensive and less well exposed. It occurs adjacent to the Hammondvale metamorphic suite on the western margin of the Caledonian Highlands. In addition to the characteristic laminated siltstone, both of these belts also include outcrops of tuffaceous conglomerate, black lapilli tuff, and black dacite, similar to rocks that are minor components of units Clt and Cmt. The siltstone tends to weather to a distinctive light grey to light brown colour. Adjacent to the Mechanic Settlement Pluton, the siltstone is contact metamorphosed, and contains abundant biotite. It also is spotted locally in the Black River area, with what appear to be altered cordierite porphyroblasts. No cause of the metamorphism is apparent in the latter area.

Younging direction appears to be to the west in the eastern belt, but could be determined at only two locations. No younging-direction indicators were found in the western belt. The younging directions combined with the symmetry of the eastern and western siltstone belts and adjacent belts of unit

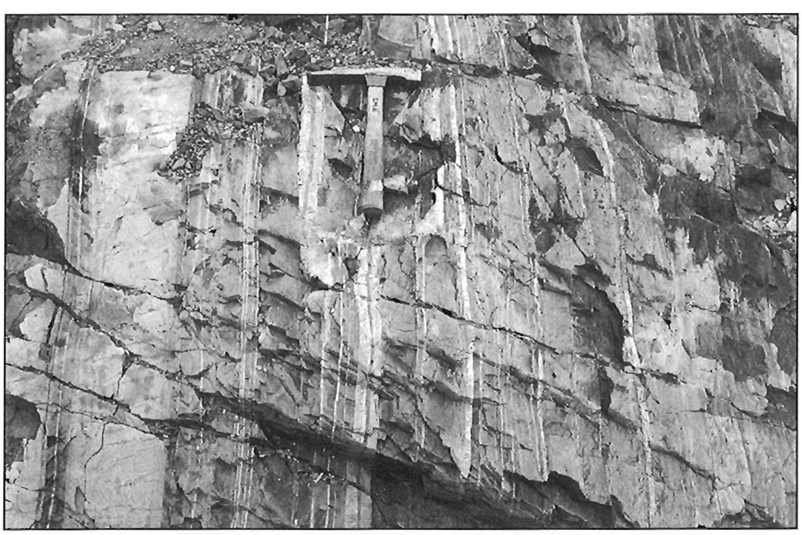

Figure 12.

Laminated ash tuff/siltstone of the Coldbrook Group, unit Cls, west of the Point Wolfe River Pluton on NTS 21 H/11. Photograph by S.M. Barr. GSC-1998-049c

Cft are consistent with a synclinal structure; however, these sparse younging-direction indicators are not overly convincing, and, as explained previously, an antiform is more compatible with the overall distribution of units.

The eastern band appears gradational with unit Cmt to the east, which also contains laminated siltstone, although dominated by lapilli tuff. On the west, unit Cls is associated with a similar (and possibly correlative) tuffaceous unit, Cit, as well as with flow-banded rhyolite of unit Cr. Contact relations among these units are uncertain due to lack of exposure.

The belt of laminated siltstone in the Vernon Mountain–Black River area (southern part of NTS 21H) appears to be interlayered with dacitic tuff unit Cit, and overlain by the Vernon Mountain rhyolite. These relations are constrained by well preserved crosslaminations and graded bedding in the siltstone. In thin section, most samples are so fine grained that little can be identified other than quartz and, rarely, feldspar grains. However, some coarser layers contain abundant feldspar laths and fragments. Rare coarse layers are clearly volcanogenic, with abundant mainly dacitic and rhyolitic rounded volcanic fragments. A characteristic feature in all three areas of unit Cls is the presence of small flakes of detrital muscovite.

Unit Cmt (and subunit Cmtb)

Unit Cmt contains a mixture of the rock types that occur in other units of the Coldbrook Group. It occurs in the area west of the Point Wolfe River Pluton and around the southwestern tip of the pluton. Field relations are uncertain due to limited exposure, but it is likely that unit Cmt is in faulted contact with unit Bat west of the Point Wolfe River Pluton, but may unconformably overlie both the pluton and unit Bct around the southwestern tip of the pluton. This interpretation is based on outcrop distribution only; no direct field evidence was observed that could shed light on the relationships in this area.

Characteristic outcrops of the tuffaceous conglomerate occur in Big Salmon River below Walton Dam, in the area where an old road crosses the river, and similar outcrops occur locally throughout the unit. The conglomerate is typically dark red or grey in overall colour. Clasts are generally rounded, and are mainly dark grey, grey, or red. In thin section, they are seen to be entirely volcanic in origin, but extremely varied in texture and composition, including aphanitic and porphyritic, and dacitic to trachytic. Clasts are mainly small (less than 1 cm in diameter). They range from rounded to subangular, and are generally close-packed, with very little matrix material. In a few places in unit Cmt, outcrops of black lapilli tuff like that of underlying unit Cft were observed; the characteristic black colour in these tuffs appears to be due to a high abundance of very fine opaque material (magnetite?). Unit Cmt also includes minor massive, flow-banded, black dacite, similar to that in unit Cft.

Grey and dark grey siltstone, similar to that in underlying(?) unit Cls, is also a component of the unit. Adjacent to a small pluton of biotite-hornblende granodiorite composition, the siltstone is contact metamorphosed, has a hornfelsic texture, and contains abundant biotite, showing that the unit is older than the pluton. Based on its freshness and abundance of interstitial granophyre, the pluton is likely to be part of the ca. 550 Ma Bonnell Brook suite. Where not contact metamorphosed, the siltstone is very fine grained with mainly sericite, chlorite, and minor quartz. It appears to be tuffaceous.

Other rock types found in the area included in unit Cmt are spherulitic rhyolite, basalt, and various porphyry-type rocks, including a plagioclase porphyry that appears to form a small body southwest of the Point Wolfe River Pluton (Open File 3615). Mappable areas of amygdaloidal basaltic flows (unit Cmtb) occur along the western margin of unit Cmt.

It is possible that unit Cmt is correlative with unit Cit described below. However, unit Cit is much less varied than unit Cmt, and due to their geographic separation, a direct correlation is not made.

Unit Cit

Unit Cit consists mainly of dacitic, lithic lapilli tuff and dark brownish grey to grey dacitic flows. Basaltic lithic lapilli tuff and amygdaloidal basaltic flows are minor components of the unit. Both the dacitic and basaltic rocks tend to be massive and dark grey on fresh surfaces, and hence the texture is best displayed on weathered surfaces. Although lithic fragments are mainly of lapilli size, in places they are much larger, and reach 1 m or more in maximum dimension. Some lithic fragments consist themselves of lapilli tuff which locally contains flattened pumice pyroclasts. Rare fragments of laminated siltstone are also present, and are similar to siltstone in the underlying unit Cls. Ash layers are present locally, and flow banding is evident in some dacitic outcrops. Plagioclase crystals occur locally in both tuffs and flows.

Rocks in two separate areas are assigned to unit Cit. In the Vernon Mountain area (NTS 21 H/5), these rocks appear to both overlie and underlie the siltstone unit Cls and, locally where the siltstone is missing, they directly underlie flow-banded rhyolite of unit Cr. In the Silver Hill area (NTS 21 H/5,11,12), no siltstone is present, although it occurs to the north, and unit Cit underlies the rhyolite of unit Cr. Stratigraphic relations in this area may have been disturbed by numerous intrusions of the Bonnell Brook suite. These intrusions place a minimum age of 550 ± 1 Ma on unit Cit in this area.

Unit Crd

Unit Crd occurs adjacent to the Baxters Mountain Pluton (Fig. 9, Open File 3615; 21 H/5), and is not well exposed. In some outcrops it is similar to unit Clt but, overall, it seems to contain more rhyolitic flows relative to lapilli tuff than unit Clt. The rhyolitic flows are typically grey to reddish grey and banded, and the lapilli tuffs are dominated by light-coloured rhyolitic fragments. Unit Crd also contains minor amounts of felsic crystal tuff. A characteristic feature of the unit is the presence of abundant pink rhyolite/felsite dykes(?) and mafic dykes. The latter are typically ophitic, range from fine to coarse grained, and contain relict pyroxene. These mafic and felsic dykes may be related to basaltic and rhyolitic flows in adjacent unit Cbrs on the southeast, or to gabbroic and granitic rocks of the Baxters Mountain Pluton.

Unit Cba

Unit Cba was identified only in the Black River area south of Highway 111 (Fig. 9, Open File 3615 ; NTS 21 H/5). It consists mainly of green basaltic and andesitic flows, with extensive alteration to chlorite and epidote. In contrast to the basaltic unit Cb to the north, no relict pyroxene was observed in samples from unit Cba. In places, the rocks contain abundant (15-20%) plagioclase phenocrysts up to 1 cm or more in length. Typically, amygdules containing coarse epidote and chlorite are abundant.

Mainly because of its degree of alteration, unit Cba is unlike other mafic units in the Coldbrook Group in this area, and more similar to mafic units in the Broad River Group. However, the unit is included in the Coldbrook Group because of its geographical association with rhyolite unit Cr. In places, unit Cba contains dacitic to rhyolitic sheets. One of these, examined in thin section, contains quartz and sparse plagioclase phenocrysts in a spherulitic groundmass, and could be related to unit Cr to the north, or to unit Cbf described below.

Unit Cbf

Unit Cbf consists of very fine-grained felsic rocks which occur in the area of Bloomington Mountain (Fig. 9, Open File 3615; 21 H/5) They have a distinctive texture, consisting of felty to feathery intergrowths of quartz, albite, and K-feldspar, and are cut by veinlets of quartz and albite. In outcrop and hand specimen the rocks are massive and featureless, and lack evidence of flow. They are interpreted to represent a high-level felsic dome, possibly related to the rhyolitic flows of unit Cr.

Unit Cr

Unit Cr is dominantly composed of rhyolitic flows, locally with spectacular flow banding, and felsic tuffs. Many of the rocks appear to have been originally welded tuffs, and contain sparse quartz and feldspar crystals as well as lithic fragments. However, in many cases, the groundmass has been recrystallized, and sericitic alteration is intense.

Unit Cr occurs in an almost continuous belt through the southwestern and central Caledonian Highlands, and also in the Silver Hill area of the north-central highlands. These areas are interpreted to be approximately correlative, based on petrological similarity and U-Pb dates (Barr et al., 1994). Because of the large geographic extent of unit Cr and the presence of internal variations in deformation and alteration, the unit is described below in five separate parts.

1. *Northeast of Point Wolfe River*. Rhyolitic rocks in this area are flanked to the northwest by basaltic rocks (unit Cb) and to the southeast by various units of the Broad River Group. The rhyolitic rocks are mainly strongly cleaved to mylonitic, interpreted to be the result of a major fault zone which separates them from the adjacent Broad River Group. A cleaved rhyolitic tuff from the southwestern part of this area yielded an age of 548 ± 1 Ma (Bevier and Barr, 1990).

The rhyolitic rocks vary from pink to red to buff or light grey, and are commonly banded. In thin section, the banding is seen to consist of quartz-feldspar layers of varying grain size and texture, from polycrystalline to spherulitic. Sparse microphenocrysts of plagioclase and embayed quartz are present in some samples. Most samples contain abundant secondary muscovite and sericite, typically in thin layers, and protomylonitic textures are also common. Where less deformed, the rhyolite appears welded. More tuffaceous layers contain feldspar and quartz crystals, and in places fiamme and pumice fragments can be recognized. Mafic flows and tuffs occur rarely, especially near the adjacent basaltic unit; however, no evidence of 'younging direction' was found, and hence the stratigraphic relationship between the rhyolite and basalt in this area is uncertain.

2. *Southwest of Point Wolfe River*. Unit Cr forms a continuous belt through the southwestern Caledonian Highlands, from Quiddy River to west of Big Salmon River, and in this belt is informally termed the 'Big Salmon River rhyolite'. Excellent exposures occur throughout the area, but are especially spectacular in Big and Little Salmon rivers and Walton Brook. The unit cannot be traced continuously into the belt northeast of Point Wolfe River because of structural complexity northeast of Quiddy River, but the rhyolites in the two areas are petrologically similar, and both are flanked by similar basaltic units; hence, correlation is very likely. The Big Salmon River rhyolite consists mainly of welded tuffs, with well displayed flow banding. As described above, the banding is due to variation in grain size and texture. Many samples contain sparse crystals (quartz and feldspar) and lithic fragments, some of which are pumiceous. Minor laminated ash tuffs are interlayered with the rhyolite.

As in the area northeast of the Point Wolfe River, the rocks contain abundant sericite, and tend to be cleaved and protomylonitic. Overall the degree of deformation increases toward the southeast, reflecting proximity to major faults along the coast (*see* section titled 'Deformation and Metamorphism). The relationship of unit Cr in this area to units of the Broad River Group to the north and south is uncertain as a result of limited exposure in the critical areas.

3. *Vernon Mountain rhyolite*. Rhyolite forms an irregular but essentially continuous belt from the Big Salmon River area (described above) southwest to the Vernon Mountain area. The area is separated from the Big Salmon River area for purposes of description because the rocks in this area show much less evidence of deformation and alteration than those in the previously described rhyolite belts, probably because of the absence of major fault zones. The rhyolitic rocks are mainly welded tuffs, with abundant spherulitic textures, eutaxitic textures, and evidence of autobrecciation, but little evidence of recrystallization and only minor amounts of sericite. Textures in these rocks are varied, but crystal and lithic fragments are a minor component in most samples. An

attempt to obtain an U-Pb date was unsuccessful because the sample collected from Vernon Mountain (Table 1) did not yield any zircons.

4. *Silver Hill rhyolite*. The area around Silver Hill is underlain mainly by flow-banded rhyolite and rhyolitic tuff (Fig. 13) very similar to that in the Vernon Mountain area. Minor vesicular and amygdaloidal basalt occurs locally in the unit. The Silver Hills rhyolite underlies red sedimentary rocks in Hanford Brook; a sample from this classic location (e.g. McCutcheon, 1987) yielded an age of 559 ± 5 Ma (Barr et al. 1994). Unit Cr in this area is underlain by basaltic and interlayered sedimentary rocks of unit Cbrs, and overlain by conglomeratic unit $Z Є_{rb}$.

Spectacular exposures of rhyolite occur along logging roads over the Silver Hills area. Colour typically varies from pink to maroon and red, but, in places the rocks are dark grey and perhaps more dacitic, with abundant feldspar crystals. Flow banding, varying from laminar to chaotically folded, is well developed in many outcrops, and some samples consist entirely of spherulites. More obviously tuffaceous areas contain abundant pumice fragments.

5. *Blackall Lake rhyolite*. A small area of rhyolitic rocks similar to those in the Silver Hill and Vernon Mountain areas occurs in the city of Saint John near Blackall Lake. The Blackall Lake rhyolite underlies sedimentary rocks of unit $Z Є_{rb}$, similar to those in Hanford Brook. The rhyolite is pink and flow banded, and contains sparse feldspar phenocrysts in a very fine-grained spherulitic groundmass. An attempt to obtain an U-Pb date was unsuccessful because the sample collected from this area did not yield any zircon (Table 1).

Unit Cb

Basaltic unit Cb is a major component of the Coldbrook Group. Like the adjacent rhyolite, it forms an almost continuous belt from southwest to northeast through the highlands. A typical exposure of basalt occurs on the steep hill on Highway 111 north of St. Martins. Similar basalt also occurs in lithologically more composite units interlayered with rhyolite and/or sedimentary rocks (units Cbr and Cbrs); basalt in these units is described separately.

Unit Cb is composed almost entirely of basaltic flows, with less abundant basaltic tuff and rare rhyolite. The basalt is typically amygdaloidal, with amygdules filled by epidote, chlorite, calcite, albite, and quartz (Fig. 14). Amygdules are locally up to 2 cm or more in maximum dimension. The groundmass consists mainly of plagioclase (now mainly of albite composition), chlorite, epidote, and opaque phases (magnetite and hematite). No relict pyroxene was observed in the basalt in the area northeast of St. Martins, but north and west of St. Martins (the Shanklin area), the basalt contains relict clinopyroxene, together with abundant chlorite and epidote. No amphibole is present, and hence the mineral assemblage is indicative of lowermost greenschist or subgreenschist facies. Texture is most commonly intergranular; plagioclase and chlorite are aligned in some samples, but probably due to deformation rather than flow. The unit also contains minor lapilli tuff with basaltic clasts; ash tuff was observed only rarely, and no crystal tuff was found. Rare interlayered rhyolite is similar to that in unit Cr.

In places the rocks of unit Cb are deformed (cleaved) as a result of proximity to faults, but mainly they show much less evidence of deformation than the adjacent rhyolite unit.

Unit Cbr

Unit Cbr is located at the southwestern margin of the Bonnell Brook Pluton, and in a smaller area to the west (NTS 21 H/6). It is a mixed unit that includes interlayered basalt and rhyolite together with a variety of mafic to felsic lithic lapilli tuffs. Some of the dacitic tuffs are similar to those in other parts of the Coldbrook Group, such as in unit Clt. Only the basaltic components were examined in thin section, and they are typically amygdaloidal and intergranular to very fine-grained, with abundant chlorite and epidote. They resemble basalts in unit Cb farther east.

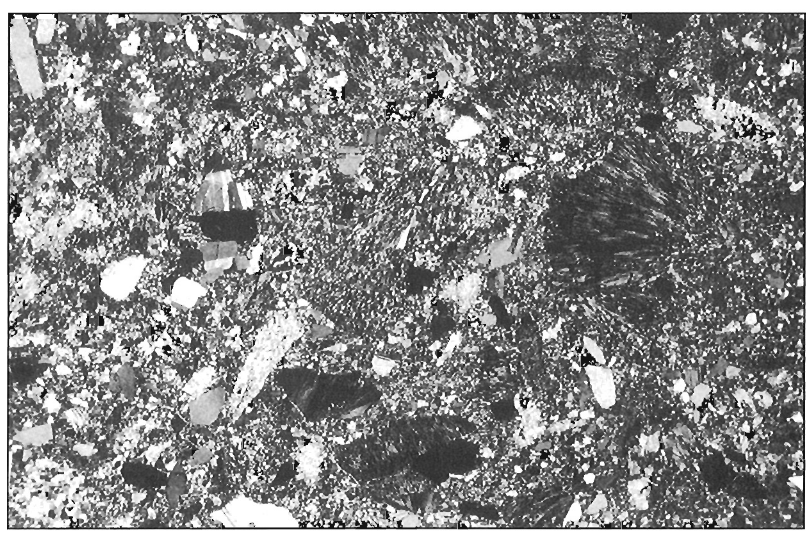

Figure 13.

Photomicrograph of rhyolitic crystal tuff of the Coldbrook Group, unit Cr (dated sample NB90-7095). Quartz, plagioclase, K-feldspar, and rhyolitic clasts occur in a fine-grained siliceous groundmass (ash). (Crossed polarizers; width of photo is 4 mm.)

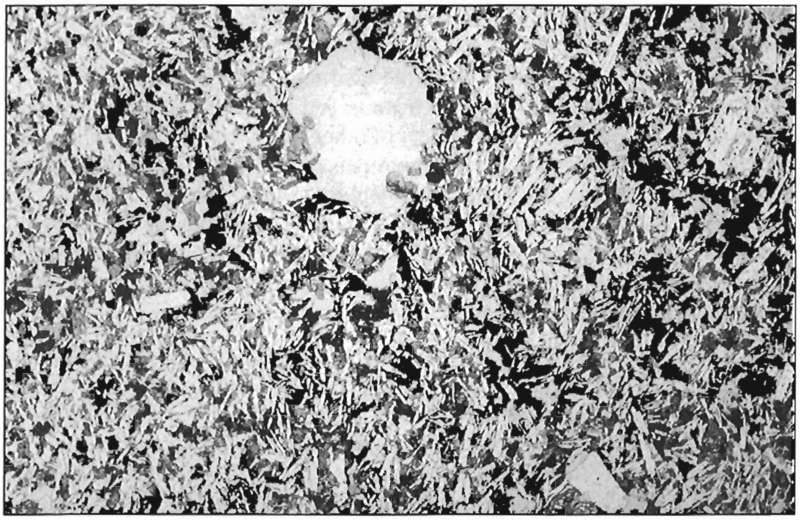

Figure 14.

Photomicrograph of basalt of the Coldbrook Group, unit Cb (analyzed sample 6043), composed mainly of plagioclase laths and interstitial chlorite, epidote, hematite, and relict clinopyroxene. Amygdule in upper centre of photo is filled by chlorite. (Plane polarized light; width of photo is 4 mm.)

Unit Cbrs

Unit Cbrs extends through the Vernon Mountain area, north of rhyolite unit Cr and south of lapilli tuff unit Clt, and also occurs in the Silver Hill area. In both areas it is associated with rhyolite unit Cr, but in the Vernon Mountain area it appears to overlie the rhyolite, whereas in the Silver Hill area it underlies the rhyolite. Hence, in the Vernon Mountain area, unit Cbrs directly underlies sedimentary unit $Z\mathrm{Є}_{rb}$, which underlies fossiliferous Cambrian rocks, whereas in the Silver Hill area, the rhyolitic unit separates unit Cbrs from unit $Z\mathrm{Є}_{rb}$. Because unit Cbrs also includes rhyolite, as well as sedimentary rocks similar to some of those in unit $Z\mathrm{Є}_{rb}$, it is likely that all of these units are very similar in age, and perhaps lateral facies equivalents, at least in part. In both areas, unit Cbrs appears to overlie tuffaceous units, in what is interpreted to be an unconformable relationship, based on the irregular shape of the contact and lack of evidence for faults.

Unit Cbrs consists mainly of amygdaloidal basalt flows, locally interlayered with rhyolite and red conglomerate and breccia, sandstone, and siltstone. Variation in texture and degree of alteration in the basalt shows no obvious pattern. Some samples from the Vernon Mountain area are relatively fresh and consist of well preserved clinopyroxene and labradorite laths intergrown in ophitic texture. More commonly, little or no clinopyroxene is preserved, and the groundmass consists of epidote and chlorite filling interstices among tiny plagioclase laths. In some samples, the plagioclase laths show well developed, swirly flow alignment. Hematite is locally very abundant, giving the rocks a reddish colour. Amygdaloidal samples contain undeformed amygdules filled with chlorite and carbonate. A few samples contain saussuritized plagioclase phenocrysts. Basaltic lapilli tuff is also present, and minor rhyolite with well developed eutaxitic or spherulitic textures. The associated red conglomerate and breccia contain mainly rhyolite and red siltstone clasts. No quartz or quartzite clasts or detrital muscovite was observed, in contrast to the rocks of unit $Z\mathrm{Є}_{rb}$ in which those components are characteristically abundant.

Depositional setting

Most of the rocks in the Coldbrook Group appear to have formed in a subaerial environment, and a continental rift is postulated. The lower part of the group is dominated by volcanogenic lapilli tuff and tuffaceous conglomerate, typically massive and poorly sorted with subrounded to subangular dacitic and rhyolitic clasts; these rocks may represent volcanogenic debris flows and ash-flow tuffs. They contain rare lapilli of laminated siltstone, similar to associated siltstone units, but no granitic or exotic clasts, such as metamorphic rocks. Ash layers are present locally. Associated dacitic flows have aligned plagioclase laths and spherulitic textures. Dark grey to black crystal-lithic lapilli tuff displays a welded groundmass in which glass shards are recognizable in places. Laminated siltstone units may represent lake deposits because of their light and dark layers which resemble varves and thus may represent seasonal changes.

The upper part of the Coldbrook Group is dominated by basaltic flows and rhyolite, with interlayered and overlying mainly red, clastic sedimentary units. Subaerial eruption of the volcanic rocks in indicated by ignimbritic appearance and presence of pumice fragments in felsic rocks, and coarsely vesicular and amygdaloidal flow tops and lack of pillow structures in mafic flows. Interlayered and overlying redbeds contain abundant volcanic clasts, especially rhyolite. These units are likely to be fluvial deposits.

Further assessment of the tectonic setting is included in the Discussion.

NEOPROTEROZOIC AND CAMBRIAN SEDIMENTARY ROCKS

Unit $Z\mathrm{Є}_{rb}$

As this unit may span the Neoproterozoic–Cambrian boundary, the age indicator 'Z' is retained in the unit designation. Unit $Z\mathrm{Є}_{rb}$ is a mainly red, clastic sedimentary sequence which locally overlies the volcanic rocks of the upper part of the Coldbrook Group, in most places the rhyolite unit Cr or the rhyolite, basalt, and sedimentary unit Crbs. However, it also is typically associated with Cambrian units of the Saint John Group. Unit $Z\mathrm{C}_{rb}$ is characterized in most places by the presence of a distinctive quartzite-pebble conglomerate, which consists of rounded quartzite clasts up to 10 cm in diameter in a maroon sandstone matrix. Rhyolite clasts occur rarely. The quartzite clasts are mainly mylonitic, and contain abundant muscovite and zircon crystals. Muscovite also occurs in the matrix of the conglomerate. Typically, the conglomerate is overlain by red to maroon crossbedded sandstone.

The conglomerate of unit $Z\mathrm{C}_{rb}$ has been previously interpreted to be the basal member of the Cambrian Ratcliffe Brook Formation of the Saint John Group (e.g. Tanoli and Pickerill, 1988, 1990; McCutcheon, 1987; Hofmann and Patel, 1989). In the classic Precambrian–Cambrian section in Hanford Brook (northeastern part of NTS 21 H/5) (e.g. McCutcheon, 1987), Tanoli and Pickerill (1990) assigned the conglomerate to the basal unit RB1 of the Ratcliffe Brook Formation of the Saint John Group. However, we have identified it here as a separate unit, rather than including it with the undivided Saint John Group, to emphasize its wide distribution and to make the point that it is likely to be of Neoproterozoic, not Cambrian, age. This interpretation is based on the revised position of the Precambrian–Cambrian boundary at ca. 544 Ma (e.g. Brasier et al., 1994) and the radiometric dates of ca. 550 to 560 Ma from rhyolitic rocks of the upper Coldbrook Group that underlie the unit.

In the Porter Road–Hanford Brook area, and near Blackall Lake in the city of Saint John (west-central part of NTS 21 H/5), the mainly red clastic sedimentary rocks of unit $Z\mathrm{C}_{rb}$ are underlain by rhyolite (unit Cr of the Coldbrook Group) and overlain by the Saint John Group. Northeast of Blackall Lake, near Loch Lomond, unit $Z\mathrm{C}_{rb}$ and the younger units of the Saint John Group occur in an apparently fault-bounded sliver within unit Cgd, and no rhyolite is present. Farther northeast in the Ratcliffe Brook area, unit $Z\mathrm{C}_{rb}$ and overlying units of the Saint John Group are in faulted contact with unit Crd. In the Vernon Mountain area, unit $Z\mathrm{C}_{rb}$ is in faulted contact with the Vernon Mountain rhyolite (unit Cr) on the south, but appears to grade into unit Cbrs on the north. However, this contact may be faulted, because locally the Saint John Group also appears to be in direct contact with rocks of unit Cbrs. The linearity of these contacts suggests that they may be faults.

North of St. Martins (21 H/5), an area of red conglomerate, sandstone, and siltstone assigned to unit $Z\mathrm{C}_{rb}$ occurs between rhyolite of the Devonian Fairfield formation, and rhyolite of the Coldbrook Group (unit Cr). In places, the conglomerate is very similar to the quartzite-pebble conglomerate typical of unit $Z\mathrm{C}_{rb}$. However, in other outcrops, clasts in the conglomerate are more angular and are mainly of siltstone and rhyolite composition; these conglomerates are more similar to those that occur in unit Cbrs. No Cambrian rocks were found in this area.

Farther east in the area around the mouth of Big Salmon River and along the coast to the northeast (NTS 21 H/6), rocks of unit $Z\mathrm{C}_{rb}$ are widespread, and occur mainly in faulted contact with rhyolite of the Coldbrook Group (unit Cr) and locally with basalt of uncertain age (unit C_b). In the Big Salmon River area, the characteristic quartzite-pebble conglomerate and micaceous red quartz arenite are present, together with a variety of other rock types, including grey and red slate. These components of unit $Z\mathrm{C}_{rb}$ are similar to those in unit Bs of the Broad River Group, especially in the area of unit Bs northeast of the Point Wolfe River (NTS 21 H/11). However, the conglomerate component in unit Bs is different in that it lacks mylonitic quartzite and rhyolitic clasts, and is closely associated with mafic tuffaceous rocks.

It should be noted that a distinctive red sedimentary unit similar to $Z\mathrm{C}_{rb}$ also present in the Mira terrane of southeastern Cape Breton Island (Barr et al., 1992, 1996), where it overlies the Late Proterozoic Main-à-Dieu Group. Landing (1991a, b, 1996a) and Landing and Westrop (1996) include the conglomerate in both areas in the Upper Precambrian Rencontre Formation, following stratigraphic terminology in Newfoundland. The distinctive rounded and mylonitic quartzite clasts with abundant accessory muscovite and zircon crystals have no known source in Avalon terrane *sensu stricto*, and their origin is enigmatic.

Saint John Group and Cape Spencer Formation

The Saint John Group was not mapped as part of this study, and the reader is referred for information to publications by other workers that deal with this topic (e.g. Tanoli and Pickerill, 1988, 1990, and references therein; Landing and Westrop, 1996, and references therein).

However, the area of rocks assigned to the Saint John Group in the Vernon Mountain area (NTS 21 H/5) has not been included in earlier descriptions of the group (e.g. Tanoli and Pickerill, 1988; Landing and Westrop, 1996), and hence is described in more detail here. These rocks are in faulted contact with volcanic rocks of the Coldbrook Group on both the north and south, and appear to overlie unit $Z\mathrm{C}_{rb}$. On the southern margin, they dip at a moderate angle to the south, but young to the north (based on well preserved crosslaminations). Mainly red, laminated muscovite-rich siltstones are overlain by quartzite-pebble conglomerate, black sandstone (with white quartz-rich granules and pebbles), light grey quartz sandstone, and darker grey mica-rich siltstone and sandstone. The latter unit forms scattered outcrops through the western part of the area, and locally contains fossils (brachiopods).

An area of Cambrian rocks also has been confirmed to be present in the Cradle Brook area (NTS 21 H/6) (Landing, 1996b). This area previously had been postulated to be of Early Cambrian age based on lithology by McLeod and McCutcheon (1981), and this age was confirmed by the fossils reported by Landing (1996b). His detailed description of the complexity of the stratigraphy in this small area, and in a nearby coastal section, suggests that detailed studies may reveal similar complexity in the lithologically varied areas assigned to unit $Z\mathrm{C}_{rb}$ in the Big Salmon River area described above.

Another area of inferred Cambrian rocks has been recognized in the Cape Spencer area, and named the Cape Spencer Formation (Watters, 1993a, b; McLeod et al., 1994). These highly deformed clastic sedimentary rocks were described in detail by Watters (1993b). No direct evidence of their age was obtained, but they are closely associated with the ca. 623 Ma Millican Lake Pluton, and with tuffaceous rocks assigned to the Broad River Group. Watters (1993b) suggested that they unconformably overlie the Precambrian rocks, based on the presence of granitoid pebble conglomerate and arkose. However, some components of the Cape Spencer Formation are similar to clastic units in the Broad River Group, especially unit Bas.

GRASSY LAKE FORMATION (unit O_G)

Grassy Lake formation is a new name assigned to an area of flows and tuffs near Grassy Lake in the west-central Caledonian Highlands, north of the village of St. Martins (NTS 21 H/5). They are mainly dark grey, light grey, or pinkish grey, and of dacitic to rhyolitic composition. Well developed flow banding is present in flows and fine-grained crystal (welded) tuffs. The crystals include feldspar and embayed quartz, in a cryptocrystalline to spherulitic felsic groundmass. Locally, lithic lapilli tuff is abundant. All of these rocks are similar to those in surrounding dacitic unit Clt of the Coldbrook Group, and the Grassy Lake unit was recognized as separate from the Coldbrook Group only after U-Pb (zircon) dating indicated a maximum age of 479 ± 8 Ma (Barr et al., 1994). Contact relationships with surrounding rocks of the Coldbrook Group are unknown, in spite of detailed mapping, because of limited exposure. However, they are inferred to be unconformable because of the age contrast and lack of evidence for faulting.

FAIRFIELD FORMATION (unit D_F)

An area of rhyolite centred on Highway 111 west of St. Martins (21 H/5) appears to be of Devonian age, based on a U-Pb (zircon) dating which indicated a maximum age of 367 Ma (Barr et al., 1994). The rhyolite occurs with red tuff and tuffaceous siltstone and sandstone, and is well exposed in roadcuts along Highway 111. The relationship of these rocks to other units in the area is not known, in spite of detailed mapping, because of limited outcrop. No contacts were observed with surrounding cleaved tuffaceous rocks of the Broad River Group. Similar rhyolite occurs farther east in a small inlier surrounded by Carboniferous sedimentary rocks, and in a narrow belt north of the village of St. Martins, and hence these areas are also included in the formation. Red clastic sedimentary rocks ($Z\mathrm{C}_{rb}$) separate the Devonian rhyolite from similar-looking rhyolitic rocks of the Coldbrook Group.

CARBONIFEROUS(?) BASALTIC AND SEDIMENTARY UNIT (unit C_b)

Epidotized basaltic rocks that occur in scattered small areas near the Bay of Fundy (NTS 21 H/4, 5) are placed in a separate map unit, of uncertain age. These rocks also occur with minor intermixed sedimentary rocks on Quaco Head, as well as farther east along the coast. Some previous workers termed these rocks the 'Mispec Formation' or the 'West Beach Formation', and assigned them to the Carboniferous (Alcock, 1938; Rast et al., 1978b; Strong et al., 1979). McLeod (1987) identified them as Carboniferous or older. Unit Cb is tentatively correlated with similar rocks in the drydock area in the city of Saint John (Currie, 1987), and to the southwest of the city in the Taylors Island–Lorneville area, which were assigned by Currie (1992) to the 'Lorneville beds'.

The basaltic rocks in unit Cb are similar to those in the western part of the Coldbrook Group, and commonly contain relict clinopyroxene in ophitic and intergranular textures with plagioclase. Plagioclase phenocrysts are present in some samples. Epidote, chlorite, and hematite are abundant secondary minerals. In most outcrops, the basalts appear to be flows, but basaltic lithic tuffs also occur.

HAMMONDVALE METAMORPHIC SUITE (unit Z_H)

The Hammondvale metamorphic suite occurs in a narrow faulted block along the northwestern margin of the Caledonian Highlands near Hammondvale (NTS 21 H/11, 12). It consists mainly of mica-albite schist, locally garnet bearing, interlayered with minor marble and amphibolite. On its northwestern margin, the schist is unconformably overlain by limestone of the Carboniferous Windsor Group, but information from drill core shows that the schist extends under the Carboniferous cover to the northwest toward the Caledonia—Clover Hill fault (McCutcheon, 1978). Contacts with the Coldbrook Group and Bonnell Brook Pluton are not exposed, but are inferred to be faulted, based on evidence of shearing in rocks in the contact areas.

Schist of the Hammondvale metamorphic suite is typically dark grey and fine to medium grained, with a prominent foliation defined by alternating albite- and muscovite-rich layers. In places, muscovite is absent, and the rocks are massive, with subidioblastic albite porphyroblasts up to 5 mm in size. Locally, the schist shows a strong mineral lineation defined by elongate quartz ribbons and asymmetric albite and garnet porphyroclasts. Marble layers, 1-2 m wide, appear gradational with adjacent schist, and consist of grey, fine- to medium-grained, thinly banded marble. Amphibolite layers are generally less than 1 m wide, fine grained, and laminated with alternating plagioclase- and amphibole-rich laminae. They are in sharp contact with the adjacent schist and conformable with the foliation in the schist, and are interpreted to represent mafic dykes or sills.

Mineral assemblages (muscovite-garnet-albitic plagioclase) and compositions in the Hammondvale metamorphic suite are consistent with relatively high-pressure/low-temperature metamorphism (ca. 586°C and 9 kbar) (White, 1995). $^{40}Ar/^{39}Ar$ dates of ca. 617, 613, and 603 Ma from muscovite in three schist samples indicate the time of post-metamorphic cooling through the closure temperature of muscovite (White, 1995). Hence, they provide minimum ages for regional high-pressure metamorphism in this unit.

The Hammondvale metamorphic suite was previously interpreted to be a metamorphic equivalent of part of the Green Head Group (McCutcheon, 1978; Ruitenberg et al., 1979; McLeod et al., 1994). However, the composition of the suite and the type of metamorphism are significantly different from those of the Green Head Group, and the muscovite cooling ages are distinct from those in the Brookville terrane (White, 1995). The compositions of the rocks in the Hammondvale metamorphic suite suggest in part volcanic protoliths, and the cooling ages suggest a possible relationship to the Broad River Group. The unit may be part of the infrastructure of the Caledonia terrane, tectonically emplaced into its present position.

CIRCA 620 Ma PLUTONIC UNITS

Introduction

Circa 620 Ma plutonic units are most abundant in the eastern Caledonian Highlands (Fig. 2, 15). They show a wide range in composition from gabbro and diorite to tonalite, granodiorite, and granite. In the eastern highlands, they include the Point Wolfe River Pluton, Fortyfive River Granodiorite, Kent Hills Pluton, Rat Tail Brook Pluton, Alma Pluton, Goose Creek Leucotonalite, Caledonia Brook Granodiorite, and Caledonia Road Granitoid Suite (Fig. 3, 15), as well as several smaller unnamed bodies. In addition to these mappable intrusions, numerous small plutons, dykes, and sills, not large enough to be shown as separate map units, also are present in the Broad River Group, and most are probably of similar age. *Circa* 620 Ma plutons in the southwestern part of the highlands are grouped as the Millican Lake Pluton (following Watters, 1993a, b) and the Emerson Creek Pluton (NTS 21 H/4, 5) (Fig. 16).

Not all of these plutons have been dated, and assignment to the ca. 620 Ma group is based mainly on lithological similarities to dated units. The precisely dated (by U-Pb zircon) plutons are the Old Shepody Road and Pollet River units of the Point Wolfe River Pluton, granodiorite of the Kent Hills Pluton, and the Cape Spencer body of the Millican Lake Pluton (Fig. 2; Table 1).

Following recommendations of the North American Stratigraphic Code for lithodemic units (Salvador, 1994), a rock name is used in naming plutons in those cases where a particular rock type constitutes most of the body. However, in the case of composite intrusions, the generic term 'pluton' is used instead.

Ruitenberg et al. (1979) described many of the plutons in the eastern Caledonian Highlands as sills. However, most contacts appear to be faulted, and the sill-like forms are probably the result of shearing and mylonitization during(?) and after intrusion, and hence may not reflect the original intrusive shapes of the bodies.

Point Wolfe River Pluton

The Point Wolfe River Pluton is the largest in the Caledonian Highlands, and extends for a distance of nearly 50 km through the central and eastern highlands (Fig. 15). The pluton was named by Ruitenberg et al. (1979), and forms a major part of their Central Intrusive Belt. Based on our mapping, the Newman Brook Stock of Ruitenberg et al. (1979) forms the northeasternmost part of the Point Wolfe River Pluton, rather than a separate body.

The northwestern margin of the Point Wolfe River Pluton, where it is in contact with mainly tuffaceous rocks of the Broad River Group, is irregular and intrusive, whereas the southern margin is faulted, mainly against younger rhyolite and basalt of the Coldbrook Group. The plutonic rocks are typically protomylonitic in the vicinity of this contact.

Uranium-lead dating from the two largest units of the Point Wolfe River Pluton (Pollet River granodiorite and Old Shepody Road granite) gave ages of 625 ± 5 Ma and 616 ± 3 Ma, respectively (Bevier and Barr, 1990). Although these ages do not overlap, even considering error limits, the close spatial association and petrological similarities of the units suggests that they are comagmatic. A tuff in unit Bdr adjacent to the northern margin of the Pollet River granodiorite has yielded an age of 600 ± 1 Ma (Bevier and Barr, 1990), and thus is apparently younger than the pluton. Although the contact at this locality is faulted, elsewhere along the northern margin of the Point Wolfe River Pluton, tuffaceous rocks of the Broad River Group are clearly intruded by the Pollet River granodiorite and, farther southwest, by the Old Shepody Road granite. Tuff and a rhyolitic flow from the Broad River Group south of the pluton have given ages of 613 ± 2 and ca. 618 Ma (Barr et al., 1994). Hence, although the age data are somewhat equivocal, we consider the best overall interpretation to be that the Point Wolfe River Pluton and most of the volcanic rocks of the Broad River Group are essentially cogenetic at ca. 620 Ma.

The Point Wolfe River Pluton is divided here into six mappable lithological units, as described below. Although compositions overlap, none of these lithological units is identical to units in any of the other plutons in the region. An intrusive sequence from more mafic to more felsic rocks is inferred, although contact relations to confirm this assumption were rarely observed.

1. *Quartz diorite/tonalite* (unit Z_{PWqd}). Small bodies of quartz diorite/tonalite are minor components of the Point Wolfe River Pluton. They are characterized by 15 to 30% mafic minerals (amphibole or amphibole plus biotite) and only minor amounts of alkali feldspar. Modal compositions range from quartz diorite to tonalite and granodiorite (Barr and White, 1988a). Texture ranges from subporphyritic (with prominent subhedral plagioclase) to equigranular, and grain size from fine to medium.

2. *Quartz monzodiorite/tonalite* (unit Z_{PWqm}). Quartz monzodiorite/tonalite forms a small area in the northeastern part of the pluton. It is coarse grained, and contains about

20% amphibole, with less abundant, finer grained biotite. The most abundant mineral is plagioclase, and quartz and microcline are interstitial.

3. *Pollet River granodiorite* (unit Z_{PWgd}). The Pollet River granodiorite, the largest unit of the Point Wolfe River Pluton, consists of medium-grained granodiorite containing amphibole, biotite, and subporphyritic subhedral plagioclase, with interstitial quartz and microcline and accessory magnetite, apatite, allanite, and titanite. In its northeastern part, the granodiorite is mixed with abundant mafic material, apparently mafic metavolcanic rocks, and both are highly altered and sheared. Elsewhere, xenolithic material is less abundant.

4. *Old Shepody Road granite* (unit Z_{PWgg}). The Old Shepody Road granite forms most of the southwestern portion of the Point Wolfe River Pluton. Small intrusions of similar composition also occur within the Pollet River granodiorite, consistent with the U-Pb (zircon) dates which show that the Old Shepody unit is younger (Fig. 2). The rocks are mainly granite, but locally range to granodiorite. They are characterized by large (up to 2 cm) ovoid phenocrysts of quartz, which survive as augen in the more highly sheared to protomylonitic rocks near the faulted southern margin of the pluton. Plagioclase is subhedral and subporphyritic, and microperthitic microcline is interstitial. Biotite is the main mafic mineral, with minor amphibole in some samples. Allanite is an abundant accessory mineral. In its northwestern part, the granite is mixed with abundant mafic material, apparently mafic volcanic rocks. Small areas of fine-grained diorite, granodiorite, and granite occur near the western and southwestern margins of the Old Shepody Road granite. Poor exposure in these areas precluded mapping as separate lithological units, and they are mainly included in the Old Shepody Road unit. Dykes and irregular bodies of fine-grained pink syenogranite also occur locally in the Old Shepody Road unit. The syenogranite contains interstitial granophyre, not a typical feature of any of the units in the Point Wolfe River Pluton, and hence appears to be petrologically similar and possibly related to granite of the Bonnell Brook Pluton, described in a subsequent section.

5. *Blueberry Hill granite* (unit Z_{PWgt}). The Blueberry Hill granite extends along the southeastern margin of the Point Wolfe River Pluton. In many areas it is intensively sheared and reduced to a fine-grained, foliated protomylonite, but locally the original texture is partially preserved. In those places the rock is coarse grained and consists of approximately equal amounts of quartz, plagioclase, and alkali feldspar, as well as less than 10% mafic minerals. The felsic minerals form augen in a more granulated matrix, but the original texture appears to have been equigranular. The Blueberry Hill granite is somewhat similar to the Old Shepody Road granite, but lacks quartz phenocrysts.

6. *Granite porphyry* (unit Z_{PWgp}). A body of granite porphyry occurs within the Pollet River granodiorite in the northeastern part of the map area (Fig. 15). Most exposures of this unit are intensely deformed and altered, and mafic (metavolcanic?) xenoliths are abundant. The porphyry consists of euhedral plagioclase phenocrysts (up to 0.5 cm in length), less abundant ovoid quartz phenocrysts, and very rare, altered mafic phenocrysts in a fine-grained equigranular groundmass of anhedral quartz and alkali feldspar. The granite porphyry appears to have intruded the granodiorite and is probably the youngest (and highest level) unit of the pluton.

Fortyfive River Granodiorite

The Fortyfive River Granodiorite includes three separate bodies of similar granodioritic composition. The central body corresponds to the Fortyfive River Sill of Ruitenberg et al. (1979), and is well exposed along the Fortyfive River. The body to the east includes the pluton called the West River Sill by Ruitenberg et al. (1979), but is more extensive. The third body, located to the southwest of the central body, was not shown by Ruitenberg et al. (1979); McLeod (1987) showed it as a large area of unnamed granite.

All three bodies are composed of medium-grained, pink to green granodiorite, locally gradational to granite. Texture is subporphyritic, with subhedral plagioclase in a groundmass of quartz, K-feldspar, and amphibole (now mainly replaced by chlorite, epidote, and actinolite which, in places, give the rocks a distinctive green colour). Samples from the central and eastern bodies yielded a poorly defined Rb-Sr isochron 'age' of 597 ± 18 Ma (Barr, 1987). However, based on petrological similarity to dated granodiorite of the Kent Hills Pluton, it is likely that the age is close to the upper limit of the error range (*see* below).

Kent Hills Pluton

The Kent Hills Pluton is an extensive, but previously unidentified unit, located north of the Fortyfive River Granodiorite in the northeastern part of the Caledonian Highlands. It is poorly exposed, but inferred to extend from northeast of the Teahan sulphide deposit (NTS 21 H/11) across Caledonia Mountain to the eastern margin of the highlands (21 H/15). Isolated outcrops of granodiorite in the area of the Teahan deposit are similar to the main Kent Hills granodiorite, and assumed to be related.

The pluton consists mainly of hornblende-biotite granodiorite similar to the Fortyfive River Granodiorite, and grades to tonalitic compositions similar to rocks included in the Rat Tail Brook Pluton, and all of these bodies are considered to be correlative. However, near its northern margin, the Kent Hills body includes strongly sheared to mylonitic granite or felsite of uncertain but probable granitic protolith. This strongly sheared northern margin appears to be faulted against the arkosic sedimentary unit of the Broad River Group (unit Bas). In contrast, the southern contact of the Kent Hills Pluton with the Broad River Group appears to be intrusive, based on widespread contact metamorphism in the adjacent metasedimentary/metavolcanic rocks. Granodiorite of the Kent Hills Pluton has yielded a U-Pb (zircon) age of 615 +1/-2 Ma (Barr et al., 1994).

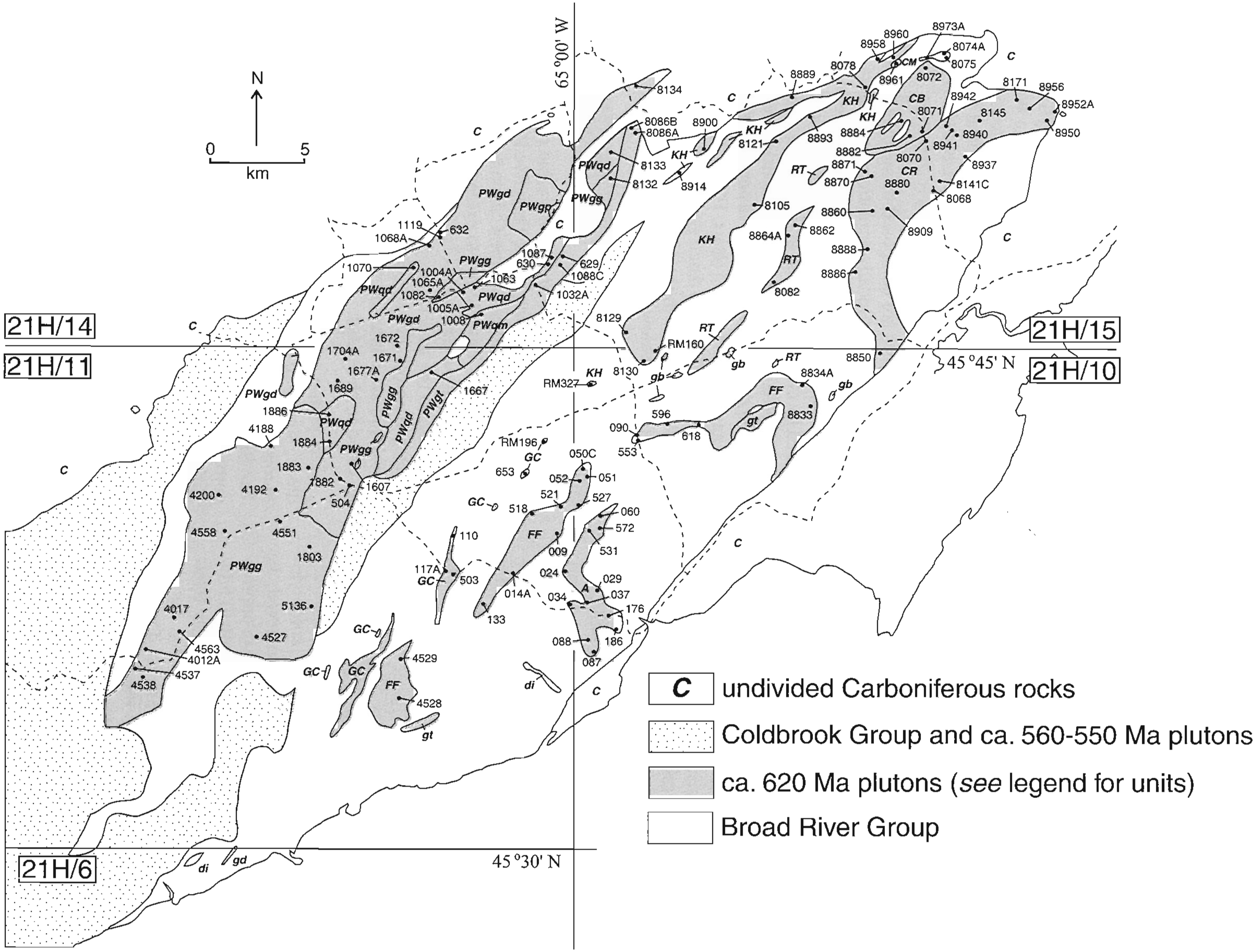

Figure 15. *Simplified geological map of the northeastern part of the Caledonian Highlands (simplified from Open File 3615), showing distribution of ca. 620 Ma plutons (except units Z_{EC} and Z_{ML}, which are included on Figure 16). Numbered dots are locations of samples used for chemical analysis (Appendix B; Appendix C, Table C.2).*

Figure 15 LEGEND*

NEOPROTEROZOIC (OR YOUNGER)
Minor (unnamed) Intrusive Units
- ***gd*** granodiorite
- ***gt*** granite, syenite
- ***di*** diorite
- ***gb*** gabbro, diorite

NEOPROTEROZOIC (ca. 560-550 Ma?)
- ***CM*** **Caledonia Mountain Pluton: diorite, gabbro**

NEOPROTEROZOIC (ca. 620 Ma)
- ***KH*** **Kent Hills Pluton**: granodiorite, granite
- ***CB*** **Caledonia Brook Granodiorite:** biotite-hornblende granodiorite
- ***CR*** **Caledonia Road Granitoid Suite**: granodiorite, granite, diorite

Point Wolfe River Pluton
- ***PWgp*** granite porphyry
- ***PWgt*** Blueberry Hill granite
- ***PWgg*** Old Shepody Road granite/granodiorite
- ***PWgd*** Pollett River granodiorite
- ***PWqm*** quartz monzodiorite/tonalite
- ***PWqd*** quartz diorite/tonalite
- ***FF*** **Fortyfive River Granodiorite**: granodiorite, granite
- ***A*** **Alma Pluton**: varied dioritic rocks
- ***RT*** **Rat Tail Brook and Similar Plutons** : tonalite, diorite, granodiorite
- ***GC*** **Goose Creek Leucotonalite:** leucotonalite, diorite, tonalite

*Note that age symbol is omitted from unit designations for brevity.

Rat Tail Brook and similar plutons

Several small plutons occur in rocks of the Broad River Group in the area north and northeast of Fundy National Park (NTS 21 H/10, 11, 15). The largest body outcrops in Rat Tail Brook and Crooked Creek, in the vicinity of the Lumsden base-metal sulphide showing, and smaller bodies occur to the southwest (Fig. 15). In all three areas, the rocks are strongly deformed (protomylonitic) and altered, with mafic minerals mainly replaced by epidote and chlorite. Few of their primary igneous features are preserved, but the rocks appear to have been coarse grained, with abundant quartz and plagioclase, and in some cases minor K-feldspar. The modal compositions range from quartz diorite to tonalite and granodiorite.

Alma Pluton

The Alma Pluton (Alma Stock of Ruitenberg et al., 1979) consists mainly of medium-grained quartz diorite, but grades to diorite, tonalite, and granodiorite. The major mineral phases include plagioclase and amphibole, with minor quartz, biotite, and interstitial K-feldspar. Locally, the rocks display well developed layering and banding of probable cumulate origin, but this feature has not yet been examined in detail. Generally, the rocks are not deformed, and igneous minerals and textures are well preserved compared to those in plutons to the north.

A K-Ar date on hornblende yielded an age of 598 ± 27 Ma (Barr, 1987), which is probably a minimum crystallization age for the pluton.

Goose Creek Leucotonalite

A series of small plutons of mainly leucotonalitic composition occur within map unit Btp of the Broad River Group, west and north of Fundy National Park. Ruitenberg et al. (1979) interpreted this unit to be more continuous and named it the Goose Creek Sill; however, our mapping did not provide evidence for the existence of a larger body. The leucotonalite is typically grey, medium grained, and composed almost entirely of quartz and plagioclase (albite), typically in granophyric-type intergrowth, and abundant secondary epidote. No primary mafic minerals are preserved.

Caledonia Road Granitoid Suite

Complex elongate intrusions of quartz diorite, granodiorite, and granite in the northeastern Caledonian Highlands were named the Caledonia Road, Crooked Creek, and Memel Creek sills, respectively, by Ruitenberg et al. (1979). However, we found that these lithological units have complex field relations and distributions and do not form mappable units of specific composition. Hence they are collectively named the Caledonia Road Granitoid Suite. Small bodies that are probably related to this suite occur commonly in adjacent metasedimentary and metavolcanic units. Deformation and alteration is intense throughout the unit; many samples are protomylonites, and original textures and, in some cases, minerals are not preserved.

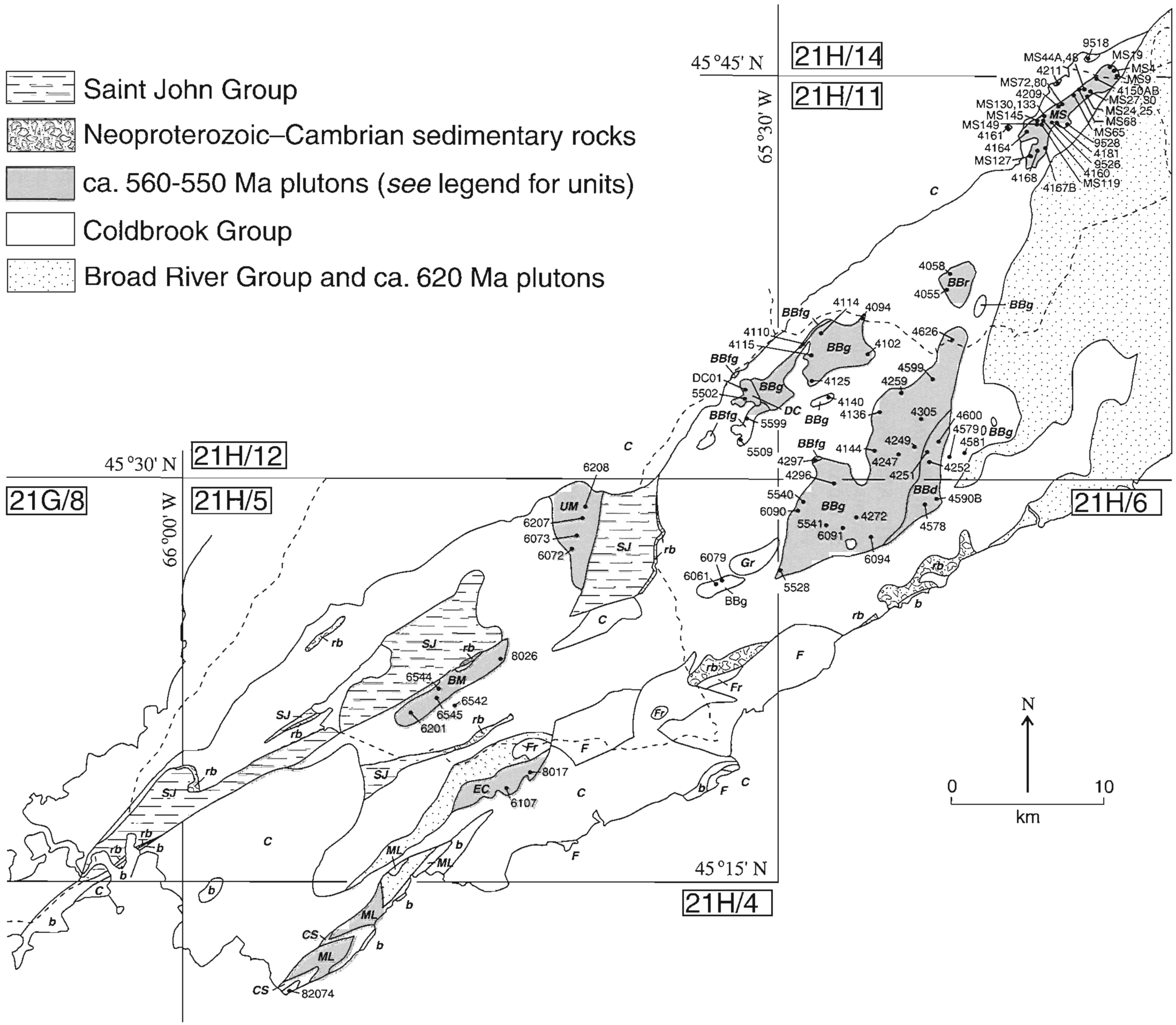

Figure 16. *Simplified geological map of the southwestern part of the Caledonian Highlands (simplified from Open File 3615), showing distribution of ca. 560-550 Ma plutons. Numbered dots are locations of samples used for chemical analysis (Appendix B; Appendix C, Table C.4).*

Figure 16 LEGEND*

TRIASSIC
- ***F*** Fundy Group (individed): sandstone, siltstone, conglomerate

CARBONIFEROUS
- ***C*** Undivided Carboniferous sedimentary rocks

CARBONIFEROUS OR OLDER
- ***b*** Epidotized basalt; minor siltstone and limestone

DEVONIAN
- ***Fr*** **Fairfield formation**: rhyolitic flows and lithic tuff

ORDOVICIAN
- ***G*** **Grassy Lake formation**: grey flow-banded rhyolite/dacite

CAMBRIAN
- ***SJ*** **Saint John Group**: sedimentary rocks
- ***CS*** **Cape Spencer Formation**: sandstone, conglomerate

NEOPROTEROZOIC TO CAMBRIAN
- ***rb*** Micaceous siltstone, sandstone, and conglomerate

NEOPROTEROZOIC (ca. 560-550 Ma)
- ***UM*** **Upham Mountain Pluton**: syenogranite, minor diorite and gabbro

Bonnell Brook Pluton
- ***BBr*** spherulitic rhyolite
- ***BBfg*** fine-grained granite
- ***BBg*** granite
- ***BBd*** diorite
- ***BM*** **Baxters Mountain Pluton**: diorite, gabbro, syenogranite
- ***DC*** **Devine Corner gabbro**
- ***MS*** **Mechanic Settlement Pluton**: gabbro, gabbronorite, olivine gabbronorite, peridotite, troctolite, olivine pyroxenite, feldspathic peridotite, anorthosite, diorite

NEOPROTEROZOIC (ca. 620 Ma)
- ***EC*** **Emerson Creek Pluton**: sheared granite and granodiorite
- ***ML*** **Millican Lake Pluton**: sheared granite and granodiorite

* Note that age symbols are omitted from most unit designations for brevity.

The quartz diorite in the Caledonia Road Granitoid Suite is similar to, and could be correlative with, the Alma Pluton. It consists of plagioclase and hornblende with interstitial quartz. With increasing abundance of quartz, the rocks grade to tonalite. Some samples contain abundant apatite. The plagioclase is extensively altered to saussurite, and chlorite and epidote are abundant. Granodioritic parts of the suite contain less hornblende and more K-feldspar (perthitic microcline where identifiable) and biotite. Granitic parts of the suite are mainly medium- to coarse-grained leucogranites, with no evidence for primary mafic minerals and only minor epidote and chlorite. Where recognizable, the K-feldspar is perthitic microcline. Perthitic K-feldspar seems to be characteristic of the Caledonia Road Granitoid Suite.

Caledonia Brook Granodiorite

The Caledonia Brook pluton (as named by Ruitenberg et al., 1979) is located south of, and in contact with, the Caledonia Mountain gabbroic stock. A gabbroic dyke in the Caledonia Brook pluton near the contact indicates that the gabbro stock is younger. The Caledonia Brook pluton consists of relatively undeformed and homogeneous biotite-hornblende granodiorite, and hence is here termed the 'Caledonia Brook Granodiorite'. Texture tends to be inequigranular, with plagioclase forming somewhat larger subhedral grains surrounded by interstitial quartz and K-feldspar. Biotite and amphibole form about 20-25% in most samples. Large grains of titanite and abundant apatite, magnetite, and zircon are also characteristic. Overall, the pluton contains a higher abundance of mafic minerals than the Kent Hills or Fortyfive River granodiorites.

Millican Lake and Emerson Creek plutons

Several highly sheared plutons occur southeast of the city of Saint John along the Bay of Fundy coast (Fig. 2, 16, Open File 3615). They were named the Millican Lake and Black River intrusions by Ruitenberg et al. (1979). Watters (1993a, b) retained the name Millican Lake intrusions and showed a revised interpretation of their distribution, based on her detailed mapping in the Cape Spencer area. Here we use the name Millican Lake Pluton to include all of these bodies, which may have formed one pluton prior to dismemberment by shearing. The new name Emerson Creek Pluton has been given to the former Black River intrusion because it does not occur in Black River, and also the name Black River is used for a well known Ordovician unit (T. Bolton, pers. comm., 1993). The age assignment for these plutons is based on petrological similarities to units of the Point Wolfe River Pluton (in particular the Pollet River granodiorite) and a U-Pb (zircon) date of 623 ± 2 Ma that has been reported for granite of the Millican Lake Pluton at Cape Spencer (Watters, 1993b).

Moderate to intense alteration and/or metamorphism is pervasive throughout the Millican Lake and Emerson Creek plutons, and strongly sheared to protomylonitic textures are typical, especially close to contacts. As a result, original igneous texture and mineralogy is difficult to recognize, but most of the rocks appear to be of granodioritic composition. Our observations are consistent with the more detailed work by Watters (1993b), who described the Millican Lake intrusions as consisting mainly of granite, granodiorite, and leucogranite and their mylonitized equivalents.

CIRCA 560-550 Ma PLUTONS

Introduction

Plutons in the ca. 560-550 Ma group consist of syenogranite and granite, with less abundant dioritic to gabbroic rocks, and are widespread throughout the central and western parts of the Caledonian Highlands (Fig. 2). The largest pluton is Bonnell Brook; others are Upham Mountain Pluton (Germaine Brook granite of Alcock, 1938) and Baxters Mountain Pluton (Otter Lake pluton of Ruitenberg et al., 1979) (Fig. 16, Open File 3615). Also included in the ca. 560-550 Ma group are several dominantly gabbroic plutons: the Mechanic Settlement Pluton, Devine Corner Gabbro, and Caledonia Mountain Gabbro.

The age of these plutons is well constrained by U-Pb zircon ages of ca. 560-550 Ma (Fig. 2; Table 1).

Bonnell Brook Pluton

The Bonnell Brook Pluton consists of several separate bodies in the central and western part of the Caledonian Highlands, and is a major component of the Central Intrusive Belt of Ruitenberg et al. (1979). It consists mainly of relatively homogeneous syenogranite (unit Z_{BBg}), composed of perthitic orthoclase, quartz, and plagioclase, with less than 3% biotite, amphibole, titanite, and allanite. Texture varies from medium grained, equigranular to fine grained, microporphyritic, the latter consisting of mainly plagioclase microphenocrysts in a granophyric groundmass. This granophyric granite occurs mainly along the northern margins of the pluton, and in places can be mapped as a separate unit (unit Z_{BBfg}). Especially where granophyric or fine-grained equigranular, the syenogranite contains miarolitic cavities. Based on these textural features, the Bonnell Brook Pluton is interpreted to be a high-level intrusion, with shallower parts exposed toward the northern part of the map area.

A dome-like body of spherulitic rhyolite (unit Z_{BBr}), located north of the largest body of the Bonnell Brook Pluton, is interpreted to be the highest level (subvolcanic) part of the pluton. It is texturally very similar to the granophyric unit of the pluton, except it contains subhedral plagioclase microphenocrysts, rimmed by spherulites, instead of granophyre.

Areas of diorite to quartz diorite (unit Z_{BBd}) are present mainly on the southeastern margin of the Bonnell Brook Pluton, and are intruded by dykes of the syenogranite, clearly showing the relative ages of the two rock types. The dioritic rocks consist mainly of plagioclase and hornblende, with minor interstitial quartz, K-feldspar and relict clinopyroxene in the cores of some hornblende grains.

A U-Pb (zircon) age of 550 ± 1 Ma has been obtained from the Bonnell Brook syenogranite (Bevier and Barr, 1990). Hornblende from the dioritic part of the pluton yielded a consistent but imprecise K-Ar date of about 548 ± 37 Ma (Barr and White, 1988c).

Upham Mountain Pluton

The Upham Mountain Pluton (unit Z_{UM})is located in the west-central Caledonian Highlands. It is in faulted contact with Cambrian rocks on the east, and has intrusive contacts with lapilli tuff of the Coldbrook Group on the west. The northern contact with Carboniferous sedimentary rocks is probably also faulted.

The pluton consists mainly of syenogranite, with minor areas of diorite and gabbro along the northeastern and northwestern margins; outcrop is insufficient to map these as separate units. The syenogranite is dominantly granophyric (Fig. 17), and similar to the granophyric parts of the Bonnell Brook Pluton. It exhibits a fine-grained (chilled) margin against dacitic tuff of the Coldbrook Group. Based on limited sampling, the gabbro and diorite vary from coarse grained

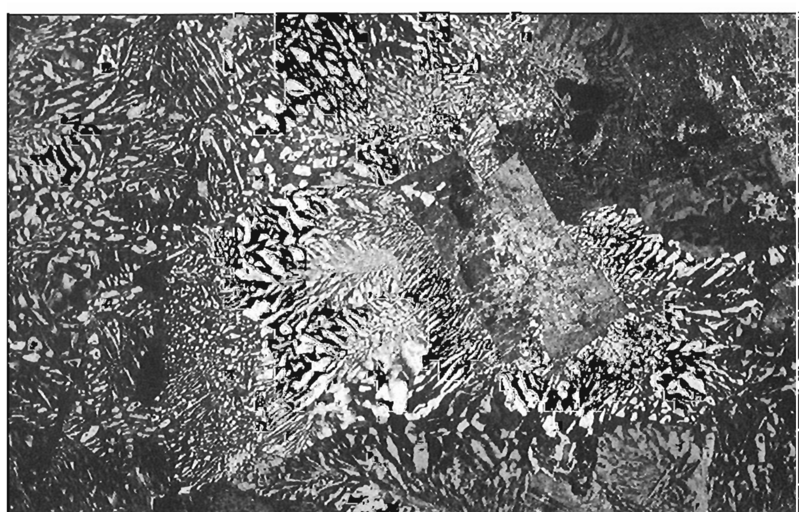

Figure 17.

Photomicrograph of Upham Mountain syenogranite, unit Z_{UM} (dated sample NB89-6208), showing characteristic granophyric texture filling interstices around plagioclase grains. (Crossed polarizers; width of photo is 4 mm.)

with intergranular texture of plagioclase, clinopyroxene, orthopyroxene, and magnetite, to medium grained intergranular with plagioclase laths, amphibole, chlorite, and minor relict pyroxene.

The age of the Upham Mountain syenogranite is 551 ± 5 Ma (Barr et al., 1994), the same age as the Bonnell Brook syenogranite.

Baxters Mountain Pluton

The Baxters Mountain Pluton (unit Z_{BM}) underlies Baxters Mountain and adjacent areas on the southeastern margin of the Cambrian basin occupied by the Loch Lomond Lakes, northeast of the city of Saint John. The pluton is not well exposed, but seems to consist mainly of quartz diorite and gabbro, with granite in the central and northeastern parts.

The quartz diorite is medium grained and consists of hypidiomorphic granular plagioclase and hornblende with minor biotite. Quartz and minor K-feldspar are interstitial. The gabbroic parts of the pluton are in the south (south of Otter Lake) and are very altered. The rocks are fine to medium grained, and may have originally contained pyroxene, but all the mafic phases have been altered to chlorite, epidote, actinolite, and iron oxides. Plagioclase is extensively saussuritized. The granite consists of medium-grained quartz, plagioclase, and orthoclase, with abundant interstitial granophyre. Amphibole and biotite are minor components (1-3%). Also present, especially in the dioritic parts of the pluton, are porphyritic granite dykes, with quartz, K-feldspar, and sparse plagioclase phenocrysts.

Mechanic Settlement Pluton

The Mechanic Settlement Pluton (unit Z_{MS}) occurs near the northern margin of the Caledonian Highlands in the vicinity of the community of Mechanic Settlement. It is mainly of gabbroic composition, but grades to ultramafic compositions (plagioclase-bearing lherzolite and pyroxenite) and to diorite and granodiorite. The latter two rock types were assigned to a separate 'Hamilton Lake pluton' by Grammatikopoulos (1992), but Grammatikopoulos et al. (1995) showed that they are probably comagmatic with the gabbroic and ultramafic rocks. Although layering is present locally, outcrop is insufficient to document the layering in detail. The host rock units of the Coldbrook Group display hornfelsing and development of biotite adjacent to the pluton.

In detail, the Mechanic Settlement Pluton contains a wide range of rock types including gabbro, gabbronorite, olivine gabbronorite, peridotite, troctolite, olivine pyroxenite, feldspathic peridotite, anorthosite, diorite, and granodiorite (Paktunc, 1989a; Grammatikopoulos, 1992; Grammatikopoulos et al., 1995). The rocks vary from fine to coarse grained, with a variety of cumulate and non-cumulate textures. The petrography is described in detail by Grammatikopoulos (1992). The Mechanic Settlement Pluton contains significant platinum-group-element mineralization (Paktunc, 1989b), and continues to be a focus for exploration (e.g. Wells, 1992).

Dioritic and gabbroic rocks in the Mechanic Settlement Pluton resemble dioritic and gabbroic rocks in the Bonnell Brook, Upham Mountain, and Baxters Mountain plutons, and all of these plutons are likely to be of similar age and origin. The age of the Mechanic Settlement Pluton is known from a U-Pb zircon date of 557 ± 3 Ma, and from $^{40}Ar/^{39}Ar$ dates for phlogopite of ca. 540-550 Ma (Grammatikopoulos et al., 1995).

Devine Corner Gabbro

A small body of gabbro occurs in the Devine Corner area, adjacent to the Bonnell Brook Pluton, near the northwestern margin of the map area (NTS 21 H/12). Although it appears to be entirely gabbroic, lacking the ultramafic components of the Mechanic Settlement Pluton, it is varied in texture and composition. Plagioclase is mainly saussuritized, in contrast to fresher clinopyroxene and orthopyroxene. Abundant apatite is present in most samples, and coarse phlogopite is present in one sample. Opaque phases (both ilmenite and magnetite) are abundant.

Caledonia Mountain Pluton

A small gabbroic pluton in the northeastern Caledonian Highlands (NTS 21 H/15) was named the Caledonia Mountain stock by Ruitenberg et al. (1979). The exposed area of this pluton appears to be less than indicated by Ruitenberg et al. (1979). The pluton is mainly composed of gabbro and gabbronorite, in places with cumulate layering, as described by Blackwood (1991), who referred to the pluton as the Weldon Creek stock. A contact metamorphic aureole has been developed in metasedimentary and metavolcanic rocks in the vicinity of the intrusion. The age of the gabbro is uncertain, but based on petrological similarities to the Mechanic Settlement Pluton to the southwest, an age of ca. 550-560 Ma seems likely.

OTHER PLUTONIC UNITS

Small plutonic units, in many cases represented by only a single outcrop, occur widely throughout the Broad River Group. They are particularly common in the area west of Fundy National Park, where they were also mapped by McLeod (1987). Many are of granodioritic (Z_{gd}) and granitic (Z_{gt}) composition, and may be related to the Fortyfive River Granodiorite. Other rock types in this area include plagioclase porphyry (Z_{pp}), diorite (Z_{di}), and gabbro (Z_{gb}). Also present in the Broad River Group, most notably in unit Bmt in the Quiddy River area, are the units identified as keratophyre or keratophyre porphyry by McLeod (1987). They appear to be sills within mafic volcaniclastic rocks, and many contain prominent quartz phenocrysts. Although abundant, they are too small to show as a separate map unit.

Other small bodies of gabbro (unit ZC_{gb}), as well as mafic dykes, occur more widely throughout the map area. Some of these bodies contain fresh pyroxene and rarely olivine, and hence are similar to gabbroic rocks of the Mechanic Settlement Pluton. These mafic intrusions may be the intrusive equivalents of the basaltic rocks of the Coldbrook Group.

GEOCHEMISTRY

Introduction

The chemical data on which the subsequent discussions are based were acquired mainly as part of this study. However, some data published by Currie and Eby (1990) and Dostal and McCutcheon (1990) are also used in these interpretations. A subset of the data from the central part of the study area was used by Barr (1987) and Barr and White (1988c) in preliminary interpretations of magmatic evolution, analyses from the Teahan area formed part of the M.Sc. thesis project of Moroz (1994), and an overview of the data was presented by Barr and White (1996a).

Brief petrographic descriptions of the analyzed samples are presented in Appendix B, and the chemical data are compiled in Appendix C. The samples display variable loss-on-ignition (LOI) values, mainly due to variations in water and CO_2 contents related to secondary processes such as weathering, hydrothermal alteration, and metamorphism. Felsic samples generally have lower values (less than 1%) than mafic samples, in which LOI values range from about 2 to 8%, although most mafic samples have values between 2 and 4%. In order to facilitate comparison among samples, the major-element oxides were recalculated to total 100%, volatile-free (with total iron expressed as Fe_2O_3), before plotting on the chemical variation diagrams presented here.

Broad River Group

Overview

A total of 85 samples have been analyzed from the Broad River Group. Locations for most of the analyzed samples are shown on Figure 3, petrographic descriptions are presented in

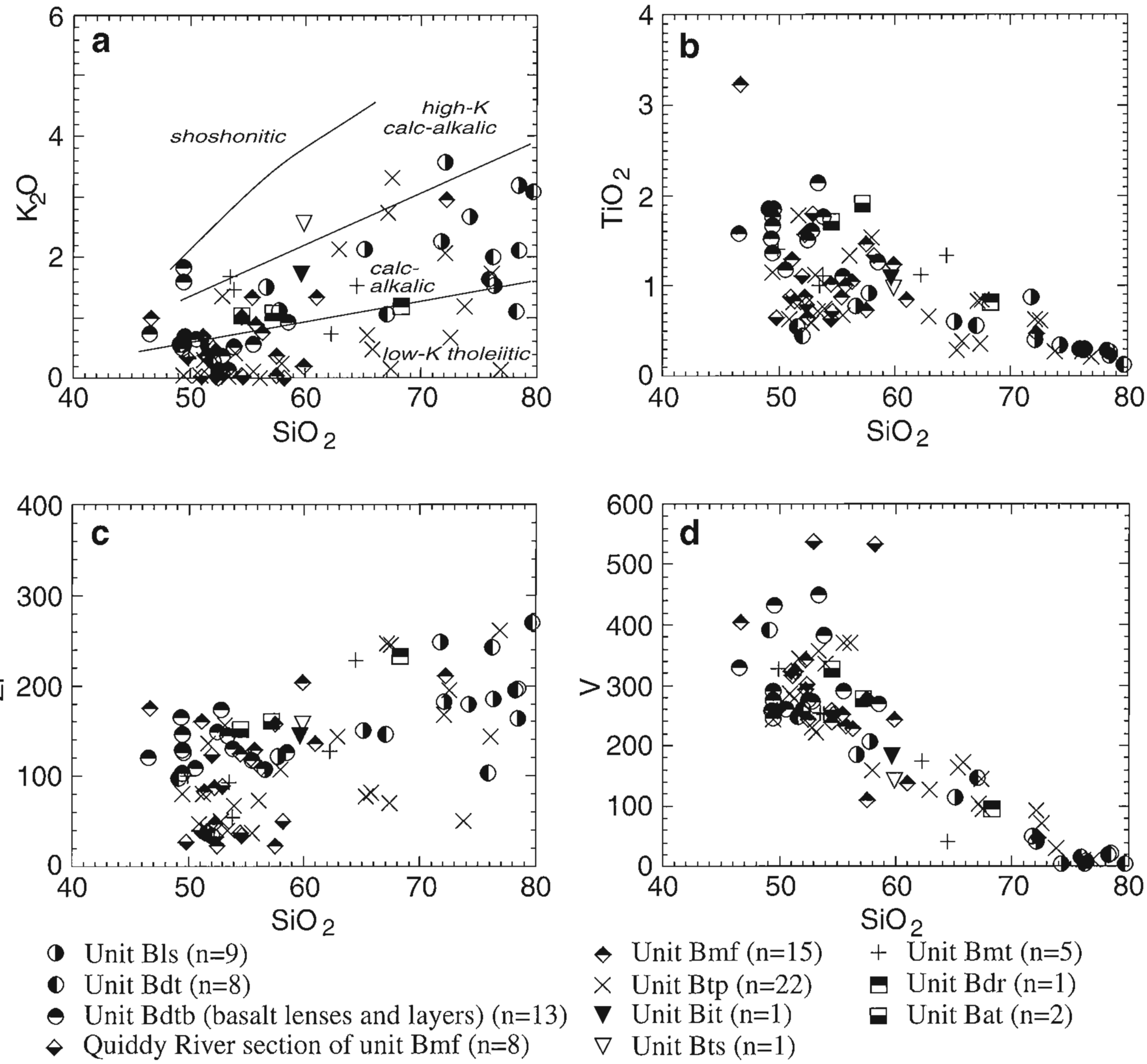

Figure 18. *Plots of **a)** K_2O, **b)** TiO_2, **c)** Zr, and **d)** V against SiO_2 (recalculated volatile-free as described in text) for samples from the Broad River Group. Fields in a) from Wilson (1989) after Middlemost (1975).*

Appendix B, and the chemical data are compiled in Appendix C (Table C.1). Many lithological units in the Broad River Group, such as lapilli tuff and tuffaceous sedimentary rocks, were not sampled for analysis because of the uncertainty in interpretation of such data in a reconnaissance geochemical study of this type, where the primary goal is general characterization of igneous rocks. The analyzed samples include a larger proportion of mafic rocks than the Broad River Group as a whole, in part because of the potential usefulness of such rocks in chemical and tectonic setting discrimination (e.g. Pearce and Cann, 1973), and also because the mafic rocks tend to be finer grained and less heterogeneous than the intermediate and felsic rocks, and thus more amenable to chemical characterization.

Chemical alteration in the analyzed samples is indicated by variable LOI values, especially in the mafic samples, and is also suggested by scatter in more mobile elements such as potassium. For example, a plot of K_2O against SiO_2 shows overall positive correlation but wide scatter (Fig. 18a), and any classification based on K_2O content is clearly unreliable.

Even trace elements that are generally considered less mobile under conditions of hydrothermal alteration and low-grade metamorphism, such as Ti and Zr (e.g. Winchester and Floyd, 1977; Floyd and Winchester, 1978), show considerable scatter (Fig. 18b, c). Hence, ratios of these elements may be more reliable as indicators of chemical affinity than their absolute abundances (Winchester and Floyd, 1977; Floyd and Winchester, 1978). On a plot of Zr/TiO_2 against Nb/Y, the Broad River Group is clearly subalkalic, although with a considerable range in Nb/Y ratio (Fig. 19). Distinction between tholeiitic and calc-alkalic within the subalkalic series is less clear; for example, the AFM diagram (Fig. 20) and plot of TiO_2 against FeO^t/MgO (Fig. 21) do not show either a tholeiitic or calc-alkalic pattern in the sample suite overall, and a mixed affinity may be suggested. However, negative correlation between TiO_2 and V and SiO_2 in mafic through felsic samples (Fig. 18b, d) is consistent with magnetite fractionation throughout their evolution and indicates that the sample suite may be calc-alkalic (e.g. Miyashiro and Shido, 1975; Shervais, 1982). Although scatter makes this correlation somewhat ambiguous for TiO_2 (Fig. 18b), it is more clear for V (Fig. 18d), although some units (e.g. Bdtb, Bat) are more consistently tholeiitic, as discussed in subsequent sections.

Whether calc-alkalic or tholeiitic, a plot of TiO_2 against Zr (Fig. 22) suggests that the rocks formed in a volcanic-arc setting. This setting is further supported by the ternary Ti-Zr-Y discrimination diagram for mafic rocks (Fig. 23), on which the mafic samples (those with less than 54% SiO_2) plot mainly in field B (overlapping low-potassium tholeiites, calc-alkalic basalts, and ocean-floor basalts). An ocean-floor basalt affinity probably can be excluded because of the dominantly intermediate to felsic tuffaceous character of the Broad River Group, and hence a calc-alkalic or island-arc tholeiitic (low-potassium) affinity is suggested by this diagram.

Overall, the chemical characteristics of felsic samples (those with more than 65% SiO_2) are also consistent with an arc setting (Fig. 24a, b). Spread of more evolved (higher SiO_2) samples into the within-plate fields on these diagrams is not uncommon in arc suites (e.g. Pearce et al., 1984).

Unit Bls

The Lumsden unit is represented by six intermediate to felsic, crystal-tuff samples, and three samples from mafic tuffs or flows. Two of the mafic samples (altered amygdaloidal basalts RM298 and RM301) are from the vicinity of the Lumsden deposit and contain anomalously low TiO_2 and Zr contents (Fig. 18b, c), elevated Ni and Cr values (Fig. 25a, b), and low Zn (Fig. 25d), but a felsic tuff sample from the same area does not show any unusual chemical features. Overall, the samples from unit Bls are chemically similar to those from other units in the Broad River Group, with subalkalic Nb/Y ratios (Fig. 19), and elemental concentrations and ratios consistent with a volcanic-arc origin (e.g. Fig. 20-24).

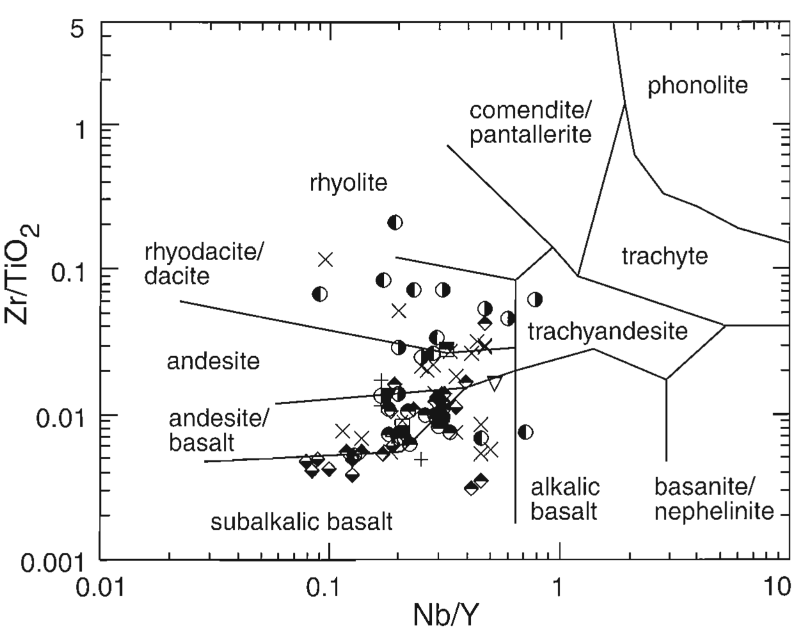

Figure 19.

Plot of Zr/TiO_2 against Nb/Y for samples from the Broad River Group, with fields from Winchester and Floyd (1977). Legend as in Figure 18.

Unit Btp

Unit Btp is represented by twenty-two samples mainly from tuffaceous rocks, but also including a few samples which represent flows. The samples range from mafic to felsic; most of the mafic samples have low K_2O contents, whereas the felsic samples show a wide range in K_2O that suggests extensive alteration (Fig. 18a). TiO_2 shows wide variation in the mafic samples (Fig. 18b), whereas Zr shows a wide range in the intermediate and felsic samples (Fig. 18c). The Nb/Y ratios are all less than 0.6, consistent with subalkalic affinity (Fig. 19). The TiO_2 content does not show a correlation with FeO^t/MgO ratio, and distinction between tholeiitic and calc-alkalic is not possible on the basis of this criterion (Fig. 21), although the V-SiO_2 correlation is indicative of calc-alkalic affinity (Fig. 18d). TiO_2 and Zr contents are consistent with a

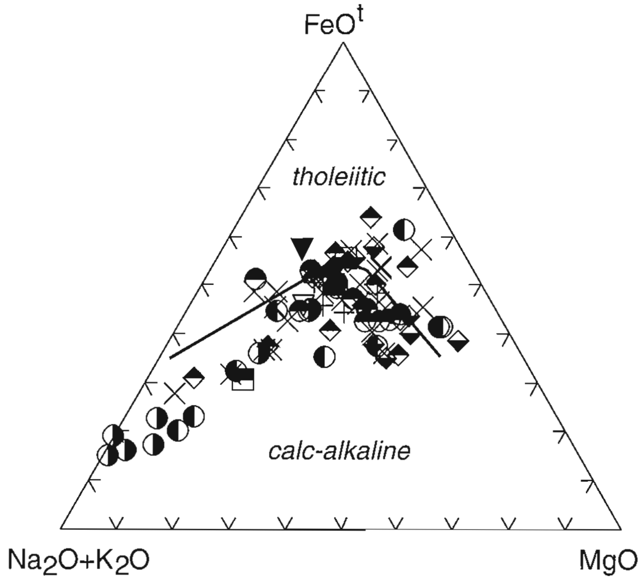

Figure 20. *AFM diagram for samples from the Broad River Group with tholeiitic/calc-alkalic dividing line from Irvine and Baragar (1971). Legend as in Figure 18.*

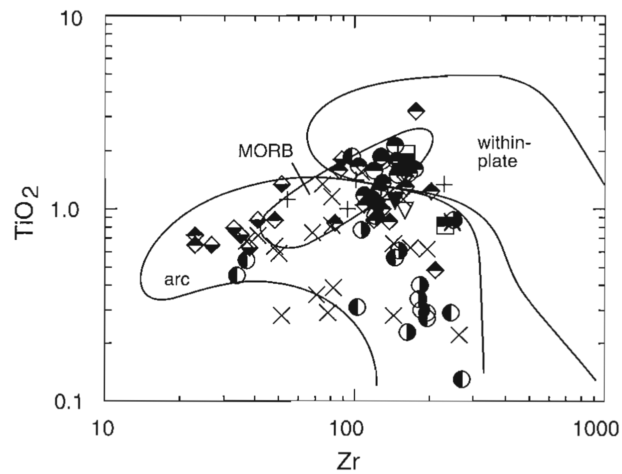

Figure 22. *Plot of TiO_2 against Zr for samples from the Broad River Group. Fields for mid-ocean-ridge basalt (MORB), within-plate lavas, and arc lavas are from Pearce (1982). Legend as in Figure 18.*

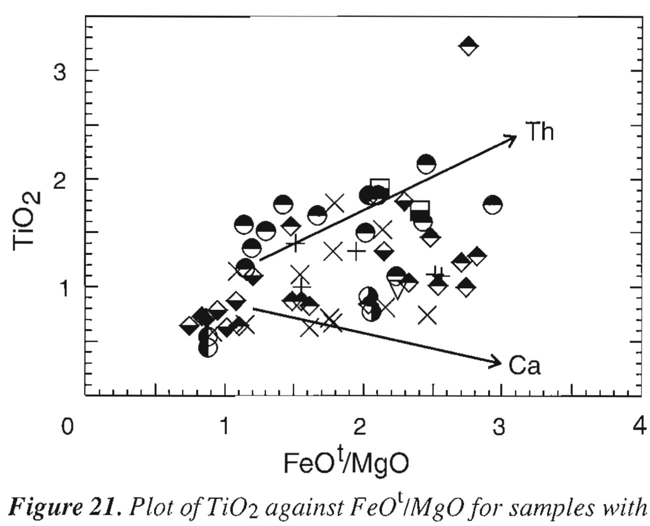

Figure 21. *Plot of TiO_2 against FeO^t/MgO for samples with 65% or less SiO_2 from the Broad River Group. Trends for typical tholeiitic (Th) and calc-alkalic (Ca) suites are from Miyashiro (1974). Legend as in Figure 18.*

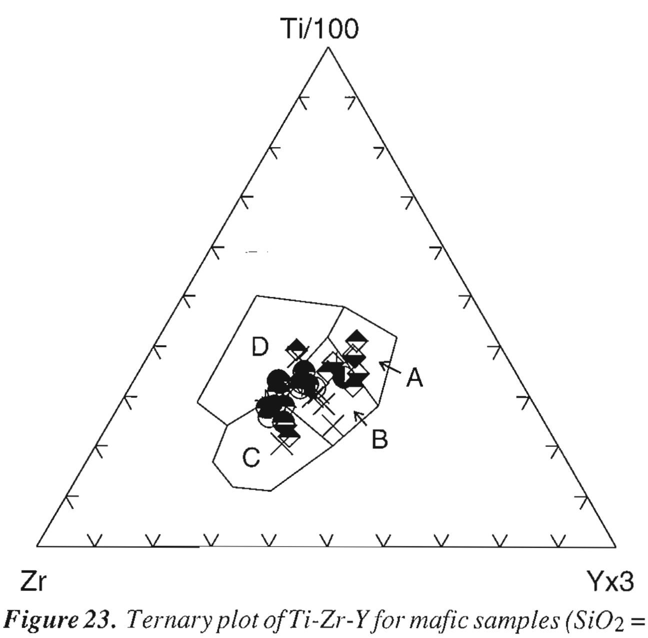

Figure 23. *Ternary plot of Ti-Zr-Y for mafic samples (SiO_2 = 54% or less, recalculated volatile-free) from the Broad River Group. Fields after Pearce and Cann (1973): A = low-potassium tholeiite; B = low-potassium tholeiite, calc-alkalic basalt, and ocean-floor basalt; C = calc-alkalic basalt; D = within-plate basalt. Legend as in Figure 18.*

volcanic-arc origin (Fig. 22), supported by the Ti-Zr-Y ratios of the mafic samples (Fig. 23). The felsic samples also have chemical characteristics indicative of a volcanic-arc origin (Fig. 24a, b).

Some samples show elevated Ni and Cr values, but no anomalous Cu, Pb, or Zn values were detected (Fig. 25), even in samples from the proximity of the Teahan base-metal deposit.

Unit Bdt

Unit Bdt is represented by 21 analyses, including 3 andesitic and dacitic tuffs, 5 dacitic to rhyolitic flows, and 13 basaltic flows. The latter are a distinctive component of unit Bdt, and form mappable subunits (Bdtb) in three areas north and west of Alma.

The andesitic crystal tuffs (samples 8803 and 8838) are basaltic andesites, with about 57% SiO_2, whereas the dacitic tuff (sample 8808) contains about 65% SiO_2. The five rhyolitic samples range from about 72 to 78% SiO_2 (recalculated volatile-free), whereas the basaltic samples range from true basalt to basaltic andesite, based on their range in SiO_2 contents. Overall, these samples show a range in chemical compositions similar to those in samples of similar SiO_2 content from other units of the Broad River Group. K_2O and Zr show scattered positive correlations with SiO_2 (Fig. 18a, c), whereas TiO_2 and V show reasonable negative correlations (Fig. 18b, d). Two basaltic samples contain high K_2O compared to other mafic samples; in thin section they are highly altered and contain abundant sericitized plagioclase. The samples are subalkalic, although two felsic samples have Nb/Y ratios close to alkalic values (Fig. 19). Calc-alkalic character is suggested by the TiO_2 and V trends (Fig. 18b, d), but the plot of TiO_2 against FeO^t/MgO suggests a tholeiitic trend for the basaltic samples of unit Bdtb (Fig. 21). In any case, a volcanic-arc setting is indicated by the suite as a whole (Fig. 22) and by the mafic samples which cluster in the arc-basalt fields on the Ti-Zr-Y diagram (Fig. 23). The felsic samples have Rb, Y, and Nb contents also consistent with an arc setting (Fig. 24a, b).

Metal contents in analyzed samples from unit Bdt (Fig. 25a-d) are generally low, but the most mafic samples have somewhat elevated Cr values (200-300 ppm), and one sample has a high Cu content.

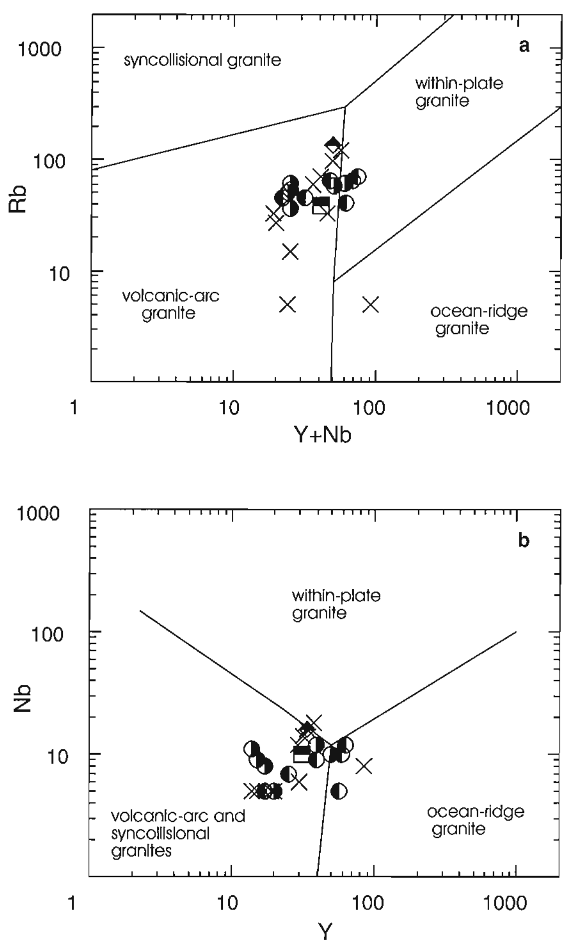

Figure 24. *Plots of **a)** Rb against Nb+Y and **b)** Nb against Y for felsic samples (SiO_2 = 65% or more, recalculated volatile-free) from the Broad River Group. Fields for syncollisional granites , volcanic-arc granites, within-plate granites, and ocean-ridge granites are from Pearce et al. (1984). Legend as in Figure 18.*

Unit Bts

Unit Bts is mainly sedimentary, and hence is represented by only one analyzed sample, a tuff of basaltic andesite composition with a SiO_2 content of 60% on a volatile-free basis. In thin section, this sample contains scattered quartz and plagioclase clasts, consistent with its andesitic composition, and an abundance of carbonate, consistent with the high LOI value (4.9%). The relatively high K_2O content (Fig. 18a) may reflect alteration, as the sample contains abundant sericite. Other chemical characteristics of the sample, including metal content, are generally similar to those of rocks of similar SiO_2 content from other units in the Broad River Group (e.g. Fig. 18-25).

Unit Bmf

All of the analyzed samples from unit Bmf represent the more mafic components of the unit, and most are basaltic flows or mafic tuffs (Appendix B). Eight of the samples (EB2 to EB19 from the published work of Dostal and McCutcheon (1990)) are from a small area in Lower Quiddy River (Fig. 3).

Overall, the samples show variation in composition similar to that in samples from unit Btp. Scatter in K_2O contents (Fig. 18a) is consistent with extent of alteration in the samples. Most mafic samples, especially those from the Quiddy River area, are low in K_2O, TiO_2, and Zr, in comparison with the basaltic samples from unit Bdtb (Fig. 18a, b, c), but similar to most mafic samples from unit Btp. The Quiddy River samples also have low Nb/Y and Zr/TiO_2 ratios (Fig. 19). These samples appear prominent on the figures because they constitute an anomalously large number of analyses from a small area; however, it should be noted that a few samples from other units have similar features, and the Quiddy River samples are within the range of variation of the rest of the Broad River Group. Taken as a whole, the samples portray a scattered positive correlation between TiO_2 and FeO^t/MgO ratio, suggesting a tholeiitic trend (Fig. 21). A positive correlation is also apparent between TiO_2 and Zr (Fig. 22), and many samples plot in the overlapping low-potassium tholeiite/calc-alkalic basalt/ocean-floor basalt field on the Ti-Zr-Y diagram (Fig. 23). The only felsic sample from the unit plots in the volcanic-arc granite fields (Fig. 24a, b). A high proportion of the samples have elevated Ni and especially Cr contents (up to 730 ppm), and scattered high Cu, Pb, and Zn values also occur (Fig. 25). On this basis, this unit appears to be an interesting target for exploration.

Unit Bmt

Unit Bmt is represented by five analyses, four from the Riverside–Albert area and one from the Fundy National Park coastal area. Sample 8904 is an amygdaloidal basalt, probably a flow, whereas the other two mafic samples (8150 and 8175) are both mafic tuffs. The two intermediate samples (8933 and 1177B) are andesitic tuffs. All five samples have low Nb contents and low Nb/Y ratios (Fig. 19). TiO_2 is relatively high in the andesitic samples (Fig. 18b), although V is much lower in those samples than in the basaltic samples. The similarity of TiO_2 contents in basaltic and andesitic samples suggests that the rocks may be calc-alkalic (Fig. 21), as does the position of the basaltic samples in the calc-alkalic basalt field on Figure 23, although the small number of samples precludes a definitive interpretation.

The basaltic samples show somewhat elevated values of Ni, Cr, and Cu (Fig. 25a, b, c), and andesitic sample 1177B has an anomalous high Zn content of 450 ppm (Fig. 25d).

Unit Bat

Unit Bat is represented by only two samples from basaltic flows The samples are chemically similar to mafic samples from other units, except one of the samples has a somewhat elevated Pb value of 22 ppm (Table C.1).

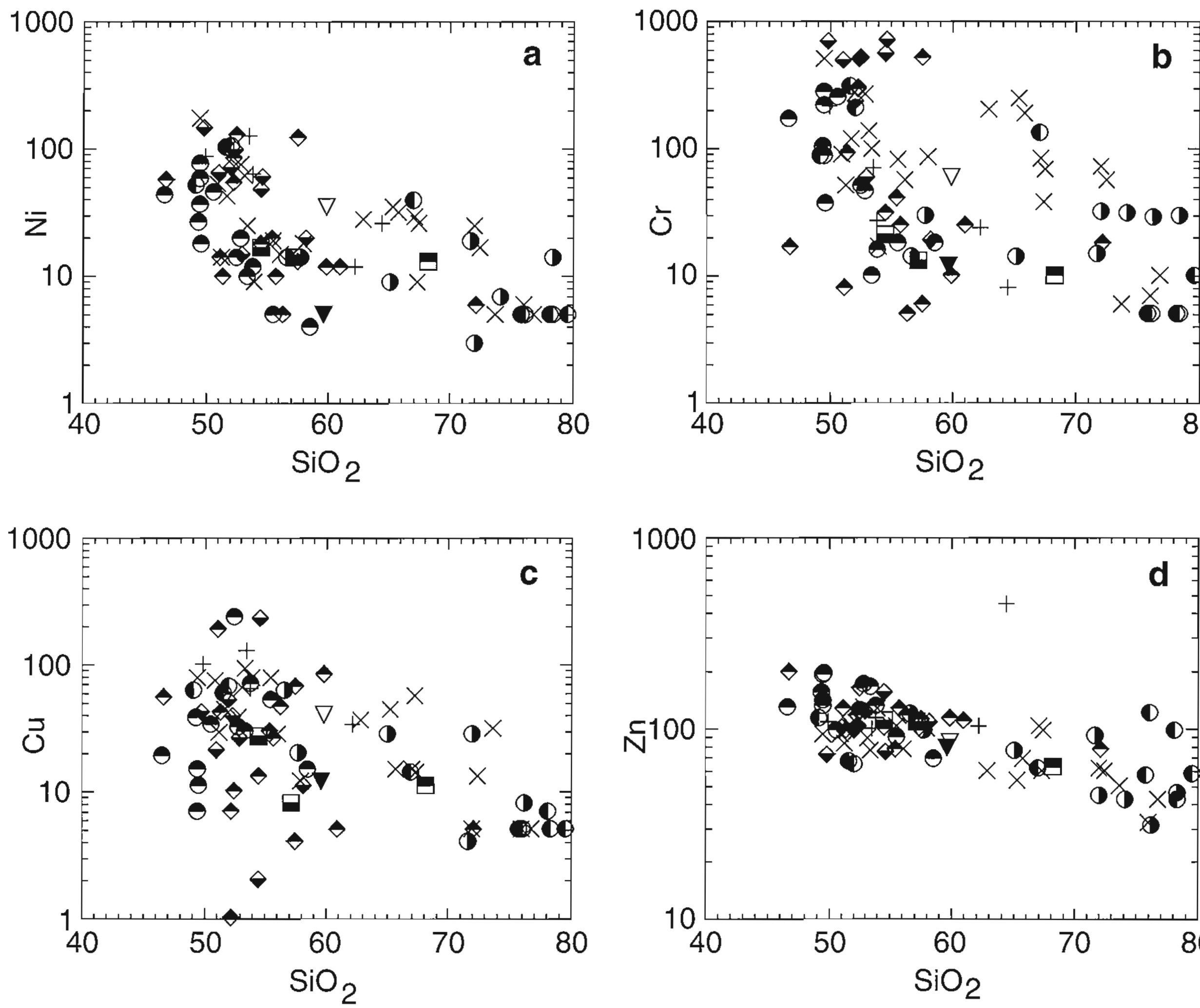

__Figure 25.__ Plots of __a)__ Ni, __b)__ Cr, __c)__ Cu, and __d)__ Zn against SiO_2 (recalculated volatile-free) for samples from the Broad River Group. Legend as in Figure 18.

Unit Bdr

Unit Bdr is represented by only one analyzed sample, a dacitic crystal tuff from Pollet River (Fig. 3). It is chemically similar to dacitic samples from other units, except for the somewhat elevated Pb value of 25 ppm (Table C.1).

Unit Bit

Only one sample was analyzed, an andesitic crystal tuff. It is chemically similar to andesitic samples from other units of the Broad River Group.

Circa *620 Ma plutons*

Overview

Circa 620 Ma plutonic rocks in the Caledonian Highlands are represented by 123 analyses from the Point Wolfe River, Kent Hills, Caledonia Road, Caledonia Brook, Alma, Goose Creek, Fortyfive River, Millican Lake, and Emerson Creek plutons (Table C.2). Sample locations (except for the Millican Lake and Emerson Creek plutons which are on Figure 16) are shown on Figure 15, and petrographic descriptions of analyzed samples are given in Appendix B. An overview of the data is presented first, followed by a discussion of specific chemical features displayed by each plutonic unit, and then the data are compared to those from the ca. 620 Ma volcanic rocks for an overall interpretation of petrogenetic relationships and tectonic setting.

Taken all together, the analyzed plutonic samples display a continuous range in SiO_2 contents from 45% to 75%, and many other chemical components show either positive or negative correlation with SiO_2 (e.g. Fig. 26a-d). Scatter in the trends is likely due, at least in part, to chemical mobility during alteration and metamorphism, and is discussed in subsequent sections for specific units. All of the units are subalkaline, as exemplified by the plot of Zr/TiO_2 vs. Nb/Y (Fig. 27), and the samples show typical calc-alkalic trends on the AFM diagram (Fig. 28) and TiO_2-FeO^t/MgO plot (Fig. 29). On the K_2O-SiO_2 diagram, the samples show a trend from the calc-alkalic to high-potassium calc-alkalic fields (Fig. 26a). They plot consistently in the arc field on the TiO_2-Zr diagram (Fig. 30). The number of mafic samples is small and they scatter across several fields on the Ti-Zr-Y discrimination diagram (Fig. 31). However, the much more numerous felsic samples plot in the arc fields on the Rb - Y+Nb and Y-Nb diagrams (Fig. 32a, b), except for some samples from the Caledonia Road Granitoid Suite and Kent Hills Pluton, discussed below.

Very few anomalous metal values were found in the analyzed samples (Fig. 33).

Point Wolfe River Pluton

The 45 analyzed samples from the Point Wolfe River Pluton represent all of the units in the pluton except the granitic porphyry. The samples cover a more or less continuous range of silica contents between about 55 and 75% (Table C.1). The lowest values are in the quartz dioritic and monzodioritic units, and highest values are in the Blueberry Hill and Old Shepody Road granites. Most other chemical components display strong correlation with SiO_2 content (e.g. Fig. 26a-d). The lithological units show chemical gradation from one to the other, consistent with a co-genetic relationship. The samples define a trend from the calc-alkalic to high-potassium calc-alkalic field, although four samples from the Pollet River granodiorite contain elevated K_2O contents, compared to other samples of similar SiO_2 content; in samples 632 and 1704A this appears to be related to intense sericitization, but in samples 1068A and 1119 it is reflected in a higher K-feldspar content and, hence, is a primary igneous feature. Samples from the Blueberry Hill granite have higher K_2O contents than samples from the Old Shepody Road granite of similar SiO_2 contents (Fig. 26a), consistent with the higher modal K-feldspar contents in the Blueberry Hill samples. Less mobile elements, such as TiO_2 and V, show a better correlation with SiO_2 (Fig. 26b, d), and are consistent with the interpretation that the units form a cogenetic suite linked by mafic mineral fractionation. Increase in Zr content suggests late crystallization of zircon, followed by its removal in the latest stages of evolution to result in a levelling off and then slight decrease in Zr content at about 70% SiO_2 (Fig. 26c). The relatively low Zr contents in the suite as a whole (less than 200 ppm) are consistent with origin in a volcanic-arc setting (Fig. 30).

The calc-alkalic trend on the AFM diagram (Fig. 28) is punctuated by a gap within the Pollet River granodiorite samples, which is less apparent in SiO_2 content (e.g. Fig. 26a). The felsic samples cluster quite closely in terms of Rb, Y, and Nb contents, which are consistent with a volcanic-arc setting (Fig. 32a, b).

Metallic elements show few anomalous values in the analyzed sample suite. Cr and Cu values are higher than Ni, and show negative correlation with SiO_2 (Fig. 33b, c); two samples (4527 from the Old Shepody Road granite and 8134 from the Pollet River granodiorite) have anomalous Cu contents (88 and 86 ppm, respectively). Pb values are mainly less than the detection limit (10 ppm), but range up to 15 ppm, and 5 samples have higher values (up to 27 ppm).

Goose Creek Leucotonalite

The series of small plutons that constitute the Goose Creek Leucotonalite are represented by five analyzed samples. They are characterized by high silica contents (71 to 75%), but low abundances of K_2O (Fig. 26a) and Rb (Fig. 32a), and high Na_2O, compared to the other units of similar SiO_2 content. They plot in the low-potassium field on the K_2O vs. SiO_2 diagram (Fig. 26a), but in most other chemical components, they do not show major differences from other high-silica, granitic units.

Fortyfive River Granodiorite

Seventeen samples from the three separate parts of the Fortyfive River Granodiorite were analyzed. They range from about 62 to 72% in SiO_2 content, and most other elements show good correlation with SiO_2, consistent with the samples representing a cogenetic suite related by fractional crystallization of plagioclase and amphibole. The range in SiO_2 content is similar to that in the Pollet River granodiorite unit of the Point Wolfe River Pluton, and overall the two units are chemically very similar (Fig. 26-33). However, samples of the the Fortyfive River Granodiorite tend to have higher K_2O contents than most samples of the Pollet River granodiorite (Fig. 26a), and on the AFM diagram, the Fortyfive River Granodiorite samples fill the gap in the Pollet River granodiorite suite (Fig. 28).

Metal contents are generally low, except for two samples (14 and 52) which show elevated values of Cu (Fig. 33c).

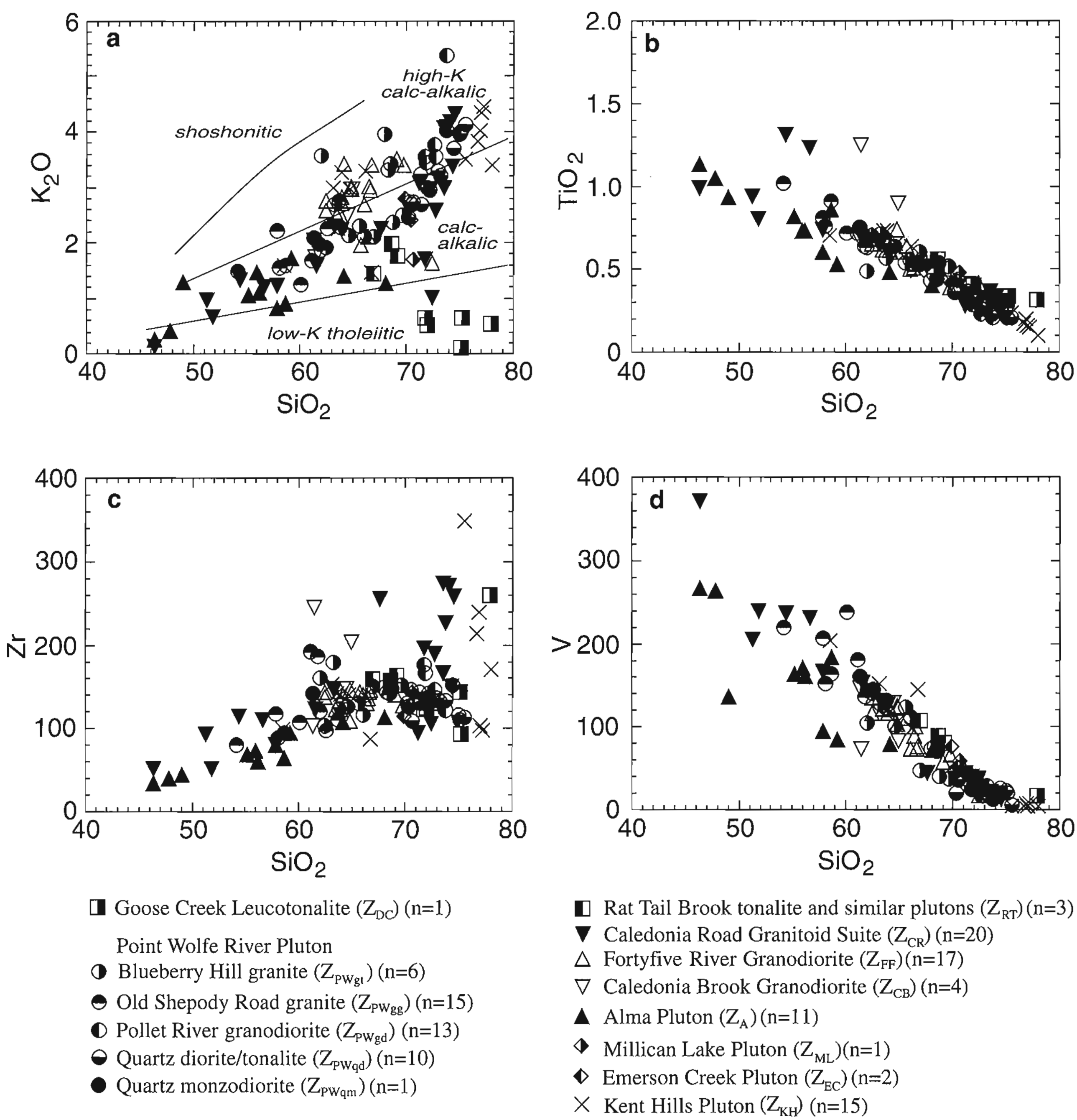

Figure 26. *Plots of **a)** K_2O, **b)** TiO_2, **c)** Zr, and **d)** V against SiO_2 (recalculated volatile-free as described in text) for samples from ca. 620 Ma plutons. Fields in a) from Wilson (1989) after Middlemost (1975).*

Kent Hills Pluton

The samples from the Kent Hills Pluton consist of a granodioritic group (including six samples from the main granodioritic part of the pluton and one from a small satellite pluton located near the Teahan deposit) and a granitic group from the northeastern margin of the pluton (six samples). The granodioritic samples range in SiO_2 content from 58 to 66%, and are chemically similar to the Fortyfive River Granodiorite, notably in their relatively high K_2O content (Fig. 26a). Other chemical features of the granodiorite are similar to those of other granodioritic units, and the samples fall on the same trends as the other units on various geochemical plots.

In contrast, the granitic samples contain 72 to 77% SiO_2, and, on average, represent the most silicic unit in the ca. 620 Ma plutons. Their K_2O contents lie within the high-potassium calc-alkalic field. However, their chemical compositions generally lie on the trends defined by other units, such as the Point Wolfe River Pluton and the granodioritic part of the Kent Hills Pluton, but are more evolved; TiO_2 and V contents, for example, are very low. However, they show a wide range in Zr contents, from about 100 to 350 ppm, and a corresponding wide range in Zr/TiO_2, in contrast to the Blueberry Hill granite of the Point Wolfe River Pluton, for example (Fig. 26c, 27). Their relatively higher Nb and Y contents trend into the within-plate fields (Fig. 32a, b), and their very

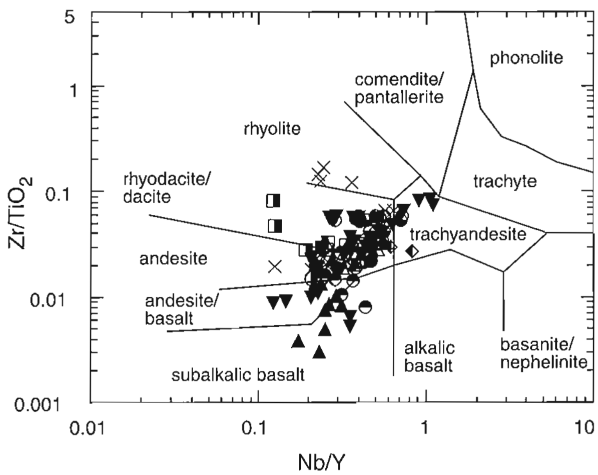

Figure 27. Plot of Zr/TiO2 against Nb/Y for samples from ca. 620 Ma plutons, with fields from Winchester and Floyd (1977). Legend as in Figure 26.

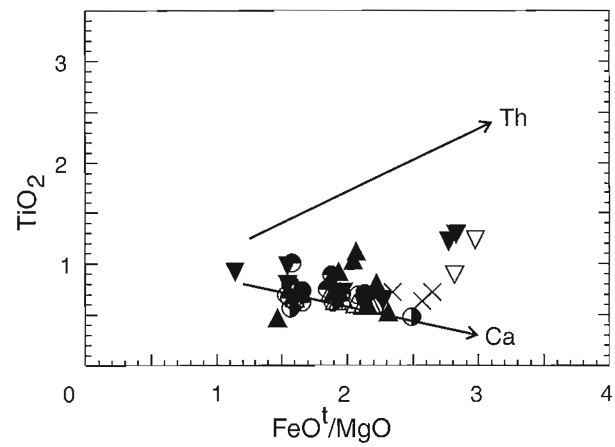

Figure 29. Plot of TiO2 against FeOt/MgO for samples with 65% or less SiO2 from ca. 620 Ma plutons. Trends for typical tholeiitic (Th) and calc-alkalic (Ca) suites are from Miyashiro (1974). Legend as in Figure 26.

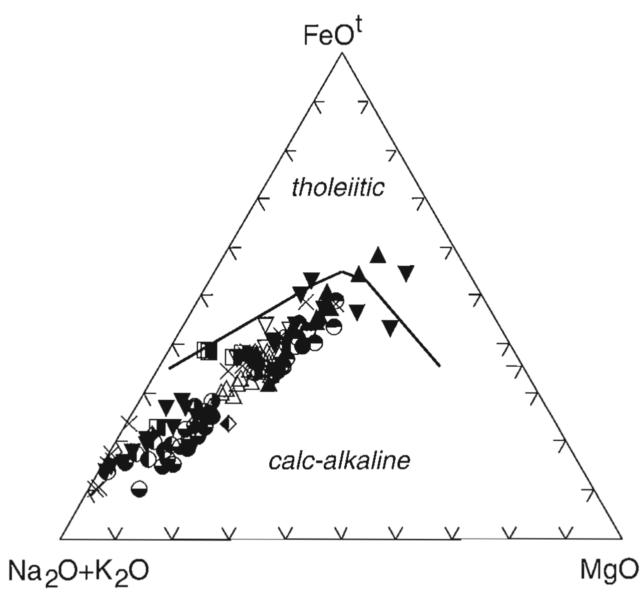

Figure 28. AFM diagram for samples from ca. 620 Ma plutons with tholeiitic/calc-alkalic dividing line from Irvine and Baragar (1971). Legend as in Figure 26.

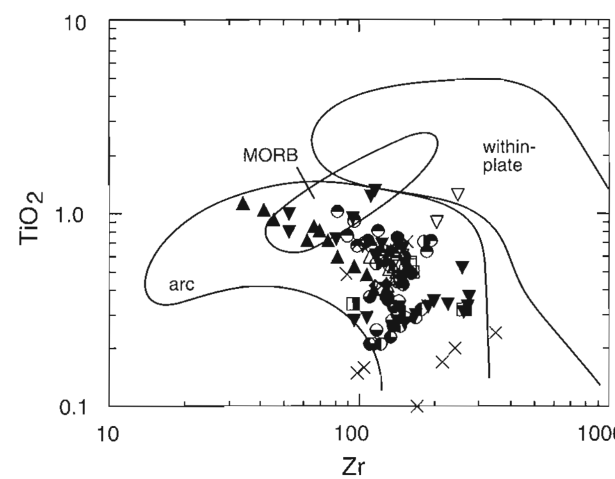

Figure 30. Plot of TiO2 against Zr for samples from ca. 620 Ma plutons. Fields for mid-ocean-ridge basalt (MORB), within-plate lavas, and arc lavas are from Pearce (1982). Legend as in Figure 26.

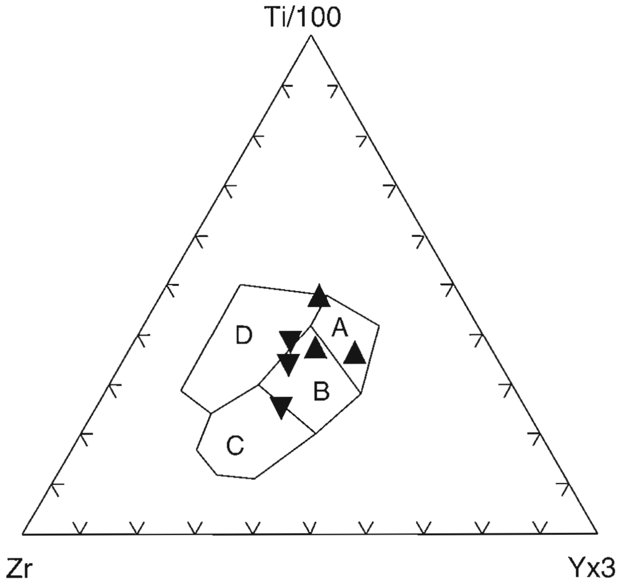

Figure 31. *Ternary plot of Ti-Zr-Y for mafic samples (SiO_2 = 54% or less, recalculated volatile-free) from ca. 620 Ma plutons. Fields after Pearce and Cann (1973): A = low-potassium tholeiite; B = low-potassium tholeiite, calc-alkalic basalt, and ocean-floor basalt; C = calc-alkalic basalt; D = within-plate basalt. Legend as in Figure 26.*

low MgO contents result in a trend along the A-F join on the AFM diagram (Fig. 28). It is possible that these granitic samples are a separate unit, perhaps unrelated to the ca. 620 Ma suites and part of the younger ca. 560-550 Ma plutonic suites, to which they show more chemical similarity. Shearing in the area precluded clear understanding of field relations.

None of the analyzed granodioritic samples (including the sample from the granodiorite body near the Teahan deposit) shows elevated metal values, except sample 8914, that contains elevated Cu and Pb contents of 214 and 96 ppm, respectively. The granitic samples also have low metal contents.

Rat Tail Brook Pluton

Three samples were analyzed from the tonalitic Rat Tail Brook Pluton. They contain 67 to 69% SiO_2, but have substantially lower K_2O contents than granodioritic samples of similar SiO_2 content from the Fortyfive River and Point Wolfe River plutons (Fig. 26a). However, their other chemical characteristics are similar to granodioritic samples from the other plutons, and they plot on the trends of those plutons. They do not show any anomalous metal values.

Alma Pluton

Eleven samples from the Alma Pluton show a wide range in silica contents from 45 to 67%, consistent with the range in modal composition from diorite/gabbro to granodiorite. Like field relations, the chemical data are consistent with cogenetic relationships among the rock types in the pluton, linked by crystal fractionation. Most elements show correlations with SiO_2, consistent with fractionation dominated by plagioclase and amphibole. The trend defined by these dominantly mafic samples on the TiO_2-SiO_2, TiO_2-FeO^t/MgO, and TiO_2-Zr plots (Fig. 26b, 29, 30) are diagnostic of a calc-alkalic suite formed in a volcanic-arc setting (e.g. Miyashiro and Shido, 1975; Shervais, 1982).

With the exception of diorite sample 60, which has a high Cu content of 150 ppm, the analyzed samples show low contents of metallic elements (Fig. 33).

Caledonia Road Granitoid Suite

The Caledonia Road Granitoid Suite is represented by 20 samples from the varied dioritic, granodioritic, and granitic units that constitute the suite. The SiO_2 contents reflect this wide range in rock type, and range from about 45 to 75% (Fig. 26). The chemical trends defined by these samples follow those of the other units, with the range more or less coinciding with the range of compositions displayed by all of the

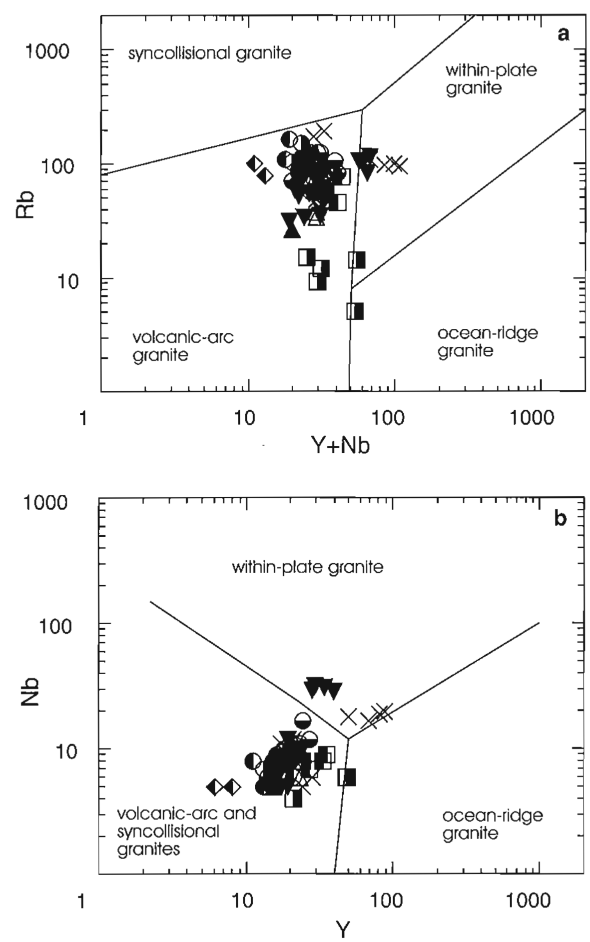

Figure 32. *Plots of **a)** Rb against Nb+Y and **b)** Nb against Y for felsic samples (SiO_2 = 65% or more, recalculated volatile-free) from ca. 620 Ma plutons. Fields for syncollisional granites, volcanic-arc granites, within-plate granites, and ocean-ridge granites are from Pearce et al. (1984). Legend as in Figure 26.*

other ca. 620 Ma plutonic units combined. Two felsic samples with low K_2O have tonalitic compositions similar to that of the Rat Tail Brook tonalite and approaching that of the Goose Creek Leucotonalite (Fig. 26a). Two mafic samples have relatively high TiO_2 contents (Fig. 26b). Zr contents in the felsic samples show wide variation, like that in the granitic samples from the Kent Hills Pluton. These samples also show a wide range in Nb/Y ratio, verging on alkalic values (Fig. 27), and some samples trend toward the within-plate field on Rb vs. Nb+Y and Nb-Y diagrams (Fig. 32a, b). Such trends are likely in highly evolved orogenic suites. The samples show a typical calc-alkalic trend on the AFM diagram (Fig. 28).

Ni, and especially Cr, contents in the three most mafic samples are elevated compared to levels in samples of similar SiO_2 content in the Alma Pluton. However, Cu, Pb, and Zn values are comparable to those in the Alma Pluton and are not anomalous.

Caledonia Brook Granodiorite

Four analyzed samples from the Caledonia Brook Granodiorite all contain about 60 to 65% SiO_2. The samples fall on the trend of other units in most cases, but two samples show elevated TiO_2 and Zr (Fig. 26b, c, 29, 30).

Emerson Creek and Millican Lake plutons

Chemical data are available for three samples, two from Emerson Creek Pluton from this study and one from the Millican Lake Pluton at Cape Spencer taken from Whalen et al. (1994). All three samples contain about 70% SiO_2 (Fig. 26), and are generally similar in their chemical characteristics to samples from the other ca. 620 Ma plutons with similar silica contents. However, two of the samples have lower Y contents (Fig. 32b), which result in somewhat high (compared to most other plutonic samples) Nb/Y ratios (Fig. 27).

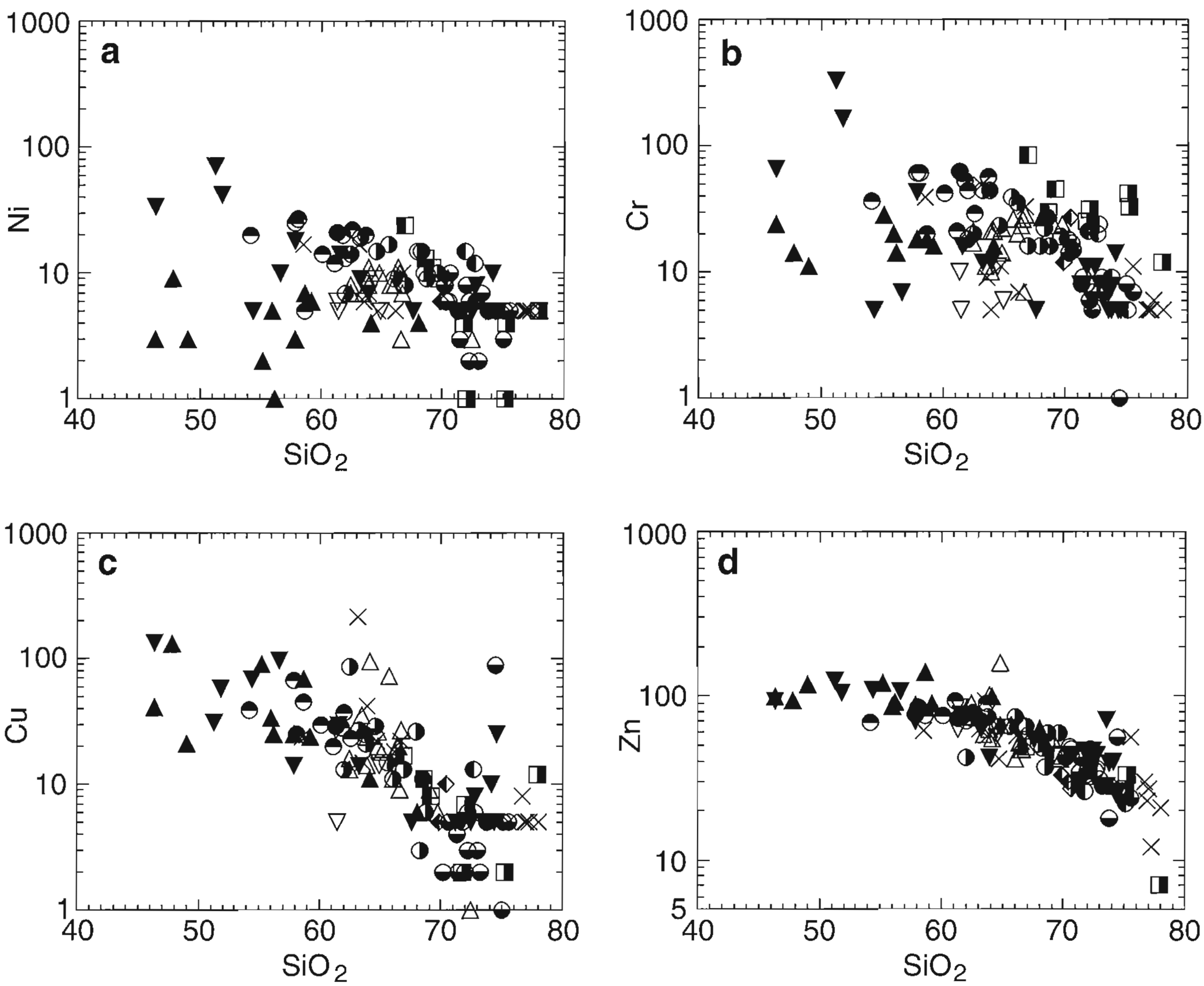

*Figure 33. Plots of **a)** Ni, **b)** Cr, **c)** Cu, and **d)** Zn against SiO_2 (recalculated volatile-free) for samples from ca. 620 Ma plutons. Legend as in Figure 26.*

Comparison between ca. 620 Ma plutonic and volcanic rocks

Overall, the plutons display chemical similarities to the volcanic rocks of the Broad River Group, but with much less scatter, and a more clear indication of calc-alkalic chemical affinity and a subduction-related tectonic setting. The data are consistent with the U-Pb dates which indicate that the volcanic and plutonic rocks are of similar age. Samples from the Broad River Group are biased toward mafic units, whereas the plutonic rocks are mainly intermediate to felsic. However, both are subalkaline (Fig. 19, 27), and volcanic samples display a calc-alkalic trend similar to that defined by the plutonic units (Fig. 18a and 26a; Fig. 21 and 29). A volcanic-arc setting is indicated by intermediate to felsic samples from both volcanic and plutonic units, with overlap into the within-plate fields as is common in more evolved continental volcanic-arc suites (e.g. Pearce et al., 1984). The abundance of intermediate and felsic rocks, both in the volcanic and plutonic suites, and the abundance of pyroclastic rocks, are indicative of a continental-margin subduction zone, such as that of the Andes (e.g. Pitcher, 1994). Both zircon inheritance (Bevier and Barr, 1990) and Nd isotopic data from a small subset of samples from these plutonic rocks (Whalen et al., 1994) are indicative of the involvement of older continental crust in the petrogenesis of these magmas, and hence are consistent with a continental margin setting.

Coldbrook Group

Overview

The mainly intermediate to felsic tuffs and flows interpreted to form the lower part of the Coldbrook Group are represented by 55 analyzed samples, including 17 from Currie and Eby (1990) (Table C.3). The samples are mainly from flows in these dominantly tuffaceous units. The basaltic and rhyolitic units interpreted to be in the upper part of the Coldbrook Group are represented by 61 analyzed samples, including 7 from Currie and Eby (1990) and 14 from Dostal and McCutcheon (1990). Sample descriptions are presented in Appendix B, and the chemical data are in Appendix C (Table C.3).

The samples as a group show a range in SiO_2 contents from about 47 to 80% (recalculated volatile-free) (Fig. 34). Consistent with their lithologies, the upper Coldbrook Group samples are more bimodal in their SiO_2 contents, whereas the lower Coldbrook samples are dominantly intermediate, with a slight silica gap at about 66% SiO_2. A compositional gap is also apparent in Zr/TiO_2 ratio in the rhyodacite/dacite field (Fig. 35). A plot of K_2O against SiO_2 (Fig. 34a) shows positive correlation, through the medium-potassium calc-alkalic field. The amount of scatter in intermediate and felsic samples from the Coldbrook Group is much less than that displayed by Broad River Group samples (Fig. 18a vs. 34a), but in both cases the mafic samples concentrate in the low-potassium field. The K_2O content appears to peak in samples with about 72 to 73% SiO_2, and then levels out or even decreases in the highest silica samples. TiO_2 shows strong negative correlation with silica for samples with more than 60% SiO_2, but there is some indication from the data that samples with less than 60% SiO_2 do not continue the negative trend, but instead show positive correlation at lower SiO_2 contents (Fig. 34b). This pattern suggests tholeiitic affinity for the Coldbrook Group (e.g. Shervais, 1982). The V-SiO_2 plot (Fig. 34d) may show a similar pattern. A plot of TiO_2 against FeO^t/MgO also suggests a tholeiitic trend (Fig. 37), although the AFM diagram (Fig. 36) is inconclusive.

Felsic samples from the Coldbrook Group have lower V contents than those from the Broad River Group (Fig. 34d vs. 18d). The Zr data also show significant differences between the two groups, with the Coldbrook Group samples overall having higher Zr contents, and showing a definite positive correlation between Zr and SiO_2, followed by a pronounced decrease in the most felsic samples (Fig. 34c vs. 18c). The decrease may reflect zircon fractionation.

A plot of TiO_2 vs Zr also shows very different patterns for the Coldbrook and Broad River groups, even in rocks of similar SiO_2 content, with the Coldbrook samples plotting toward, or in, the within-plate field (Fig. 38), in contrast to the Broad River samples, which scatter widely in the volcanic-arc field (Fig. 22). However, the ternary Ti-Zr-Y diagram for mafic samples (those with less than 54% SiO_2, as recalculated volatile-free) places most Coldbrook Group samples in the calc-alkalic or calc-alkalic/ocean-floor basalt/low-potassium tholeiite fields (Fig. 39), similar to the Broad River Group samples (Fig. 23). In contrast, felsic samples (those with more than 65% SiO_2 recalculated volatile-free) have within-plate characteristics (Fig. 40a, b) and differ significantly from the felsic samples of the Broad River Group (Fig. 24a, b).

Overall, the chemical data corroborate the distinction between the two groups based on structural, petrographical, and age differences. The Broad River Group is more clearly calc-alkalic and formed in a volcanic-arc setting. The mafic samples in the Coldbrook Group are tholeiitic, and the suite as a whole appears to have formed in a within-plate setting.

Unit Cgd

Fifteen analyses are available from the grey dacitic unit, eleven of which are from Currie and Eby (1990), who described most samples as flows. Like samples from the other lower Coldbrook Group units, they range from andesitic (SiO_2 as low as 54%) to rhyolitic (SiO_2 up to 75%), with a gap at about 66 to 68%. These samples follow a consistent trend between the basaltic and rhyolitic samples of the upper Coldbrook Group, and are clearly subalkaline (Fig. 35), and formed in a within-plate setting (Fig. 38, 40a, b).

Unit Clt

The lithic tuff unit of the lower Coldbrook Group is represented by eight analyzed samples. They fall into two groups, andesitic and rhyodacitic to rhyolitic (Fig. 34), but show no significant differences compared to other samples of similar SiO_2 contents.

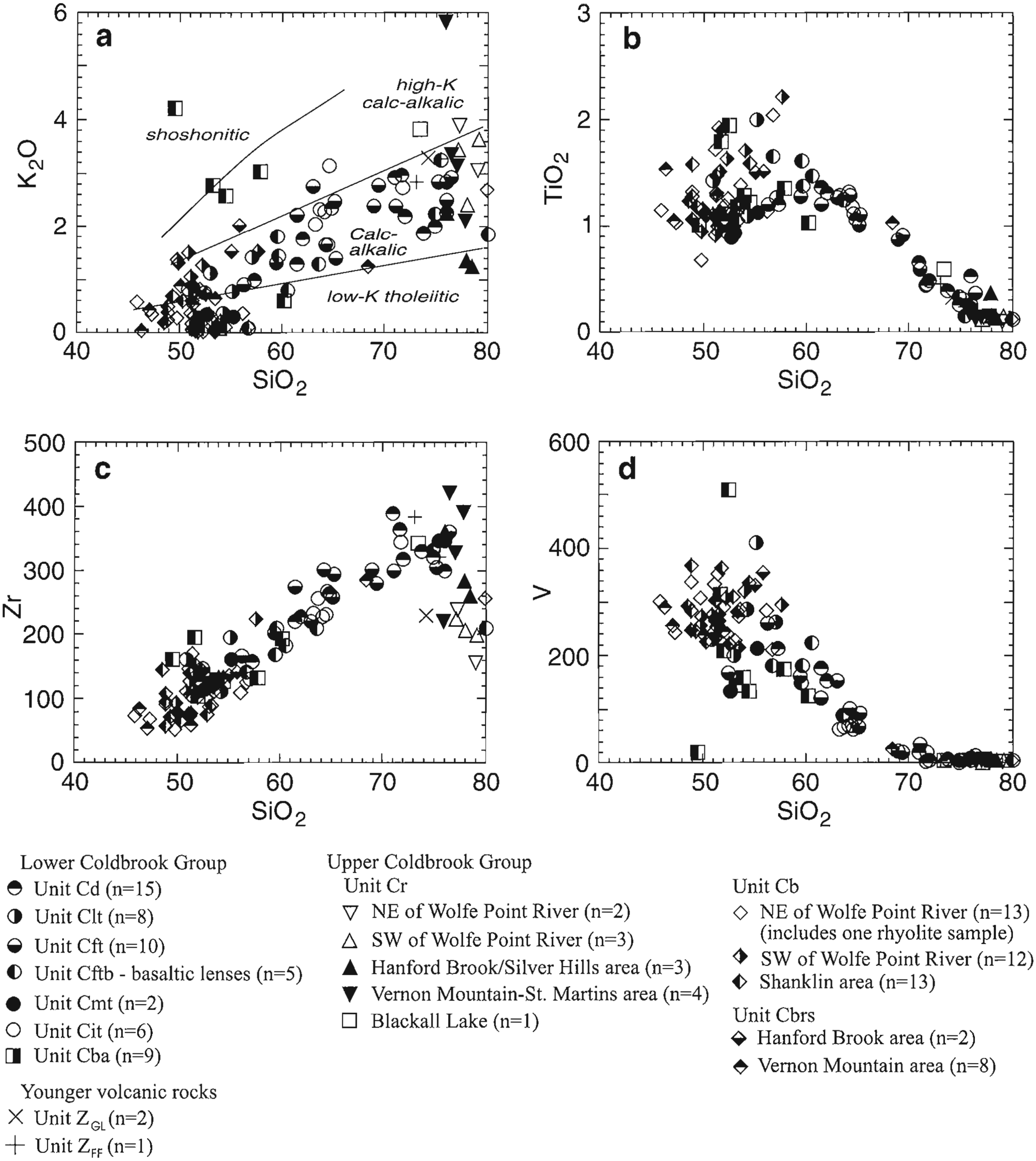

Figure 34. *Plots of **a)** K_2O, **b)** TiO_2, **c)** Zr, and **d)** V against SiO_2 (recalculated volatile-free as described in text) for samples from the Coldbrook Group. Fields in a) from Wilson (1989) after Middlemost (1975).*

Unit Cft

Ten samples were analyzed from the black felsic tuff unit of the lower Coldbrook Group. These dark-coloured rocks are mainly crystal tuffs, or lithic crystal tuffs, and their chemical compositions correlate well with their petrography. Those with SiO_2 contents between about 56 and 65% are andesitic tuffs dominated by plagioclase, whereas those with SiO_2 between about 72 and 76% are welded and display flow banding. No samples fall in the compositional range between about 65 and 72% SiO_2. The compositions follow the same trends as other samples from the lower Coldbrook Group, and felsic samples have a within-plate signature (Fig. 40a, b). No anomalous metal values were found (Fig. 41).

Unit Cftb

Five samples were analyzed from the mappable basaltic layers in unit Cft. These samples range from basalt to basaltic andesite, are chemically similar to basaltic rocks from the upper part of the Coldbrook Group, and generally plot with the other basaltic to andesitic samples on various chemical diagrams (e.g. Fig. 34a-d).

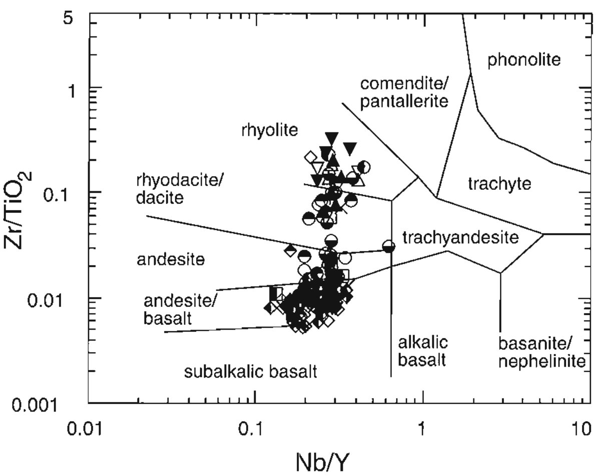

Figure 35. *Plot of Zr/TiO_2 against Nb/Y for samples from the Coldbrook Group, with fields from Winchester and Floyd (1977). Legend as in Figure 34.*

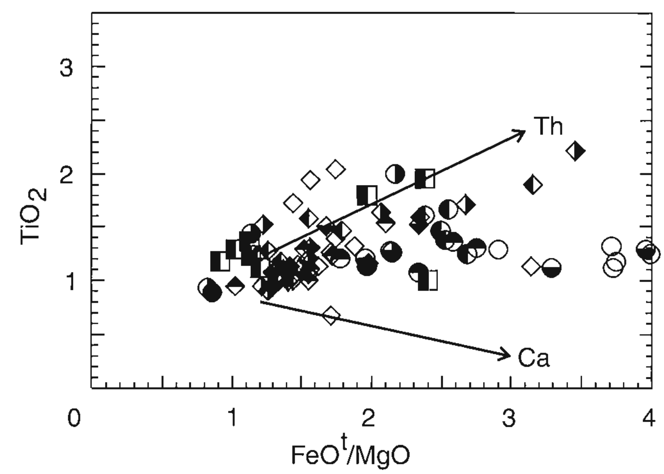

Figure 37. *Plot of TiO_2 against FeO^t/MgO for samples with 65% or less SiO_2 from the Coldbrook Group. Trends for typical tholeiitic (Th) and calc-alkalic (Ca) suites are from Miyashiro (1974). Legend as in Figure 34.*

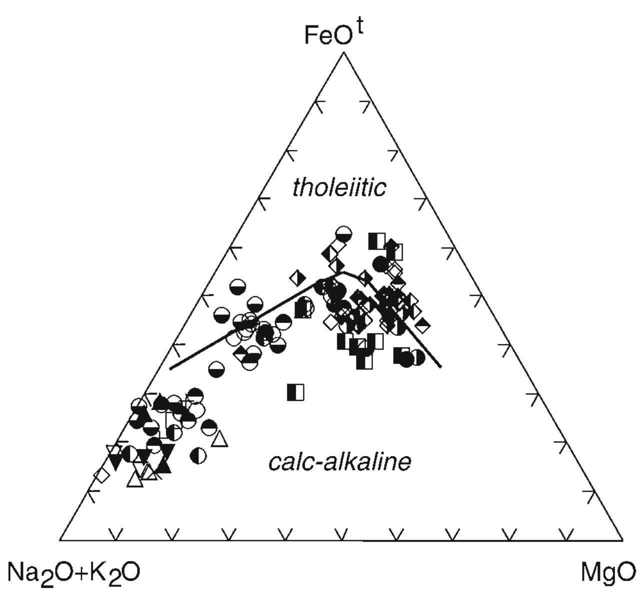

Figure 36. *AFM diagram for samples from the Coldbrook Group with tholeiitic/calc-alkalic dividing line from Irvine and Baragar (1971). Legend as in Figure 34.*

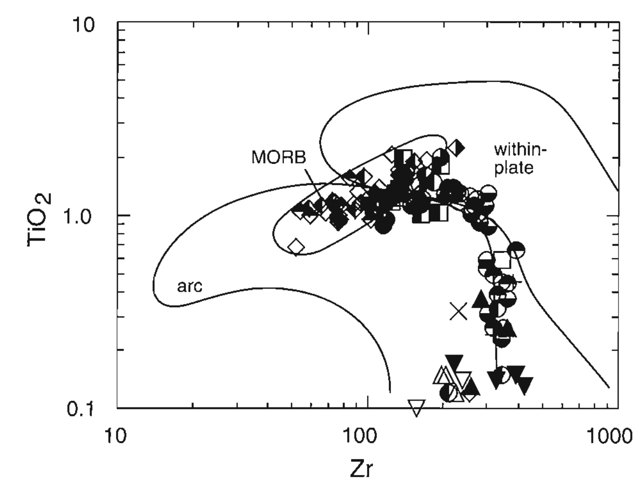

Figure 38. *Plot of TiO_2 against Zr for samples from the Coldbrook Group. Fields for mid-ocean-ridge basalt (MORB), within-plate lavas, and arc lavas are from Pearce (1982). Legend as in Figure 34.*

Unit Cmt

Two basaltic samples were analyzed from unit Cmt, and are mainly similar to basaltic samples from other units. However, both contain relatively high Ni and Cr, and sample 4609 contains the highest values of these elements among the analyzed samples from the Coldbrook Group (Fig. 41a, b).

Unit Cit

All six analyzed samples from tuffaceous unit Cit are from the Black River area. The two samples analyzed as part of the present study include an andesitic crystal tuff and a flow-banded (welded) tuff of rhyolitic composition. The other four samples are from Currie and Eby (1990) and are compositionally similar to andesitic crystal tuff of sample 6095. The compositions of these samples are generally indistinguishable from those of intermediate tuffs and flows in other units of the lower Coldbrook Group, although two of the samples from Currie and Eby (1990) have elevated Zn contents.

Unit Cba

Chemical analyses of nine samples from unit Cba (including five published by Eby and Currie, 1990) range from basaltic to andesitic. They fall into two groups in terms of K_20 content, one group with low values, and a second group with higher values. The latter four samples are all from Currie and Eby (1990); their petrographic descriptions do not provide evidence as to why such mafic samples would contain high K_2O values, and hence the significance of these data are unclear. The samples also contain elevated Ba and Rb values compared to other analyzed samples from the unit (Table C.3).

Overall, the samples from unit Cba have low V contents compared to other units in the Coldbrook Group (Fig. 34d), but do not appear anomalous in terms of other chemical features (e.g. Fig. 36-39, 41).

Unit Cr

Thirteen samples were analyzed, representing the various areas of rhyolitic unit Cr. In addition, sample 8126, from a rhyolite flow within unit Cb, was analyzed for comparison. These samples contain about 73 to 80% SiO_2, and a wide range in some chemical components such as K_2O and Zr (Fig. 34a, c) but a limited range in those elements which are components of mafic minerals such as TiO_2 and V (Fig. 34b, d). They are subalkaline, and plot mainly in the rhyolite field in terms of their Zr/TiO_2 ratio (Fig. 35). They

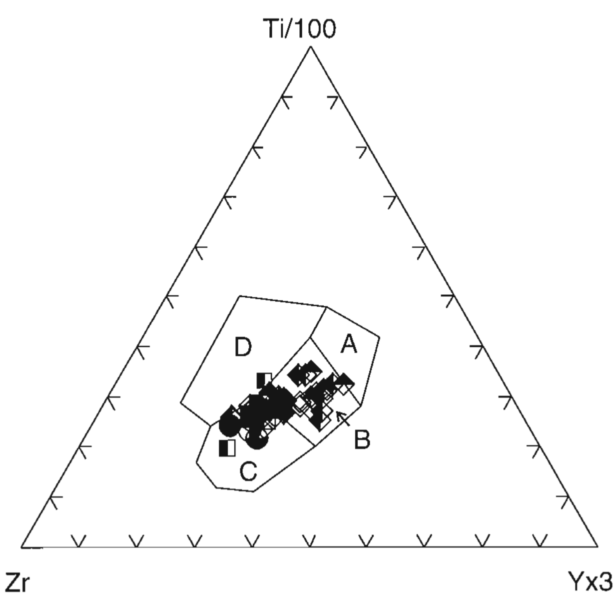

Figure 39. Ternary plot of Ti-Zr-Y for mafic samples (SiO_2 = 54% or less, recalculated volatile-free) from the Coldbrook Group. Fields after Pearce and Cann (1973): A = low-potassium tholeiite; B = low-potassium tholeiite, calc-alkalic basalt, and ocean-floor basalt; C = calc-alkalic basalt; D = within-plate basalt. Legend as in Figure 34.

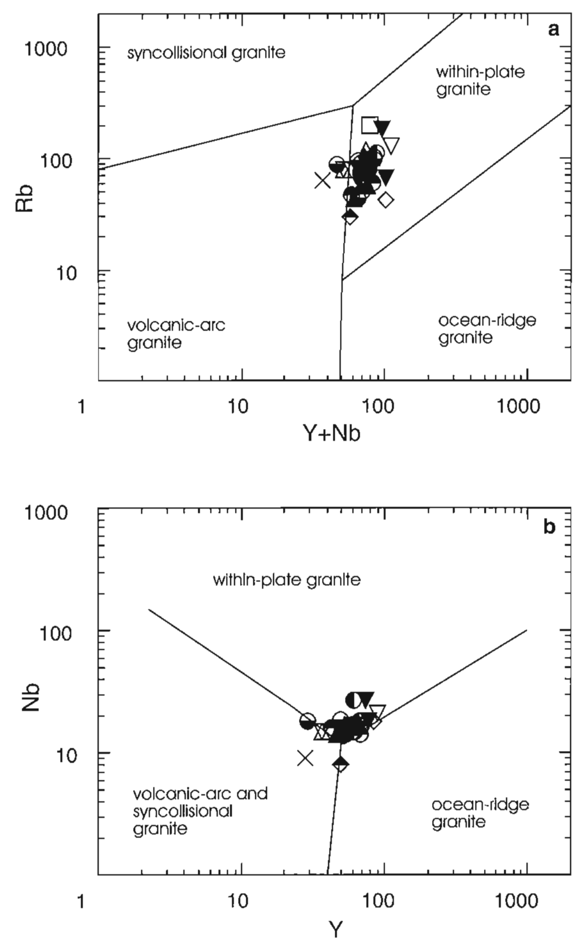

*Figure 40. Plots of **a**) Rb against Nb+Y and **b**) Nb against Y for felsic samples (SiO_2 = 65% or more, recalculated volatile-free) from the Coldbrook Group. Fields for syncollisional granites, volcanic-arc granites, within-plate granites, and ocean-ridge granites are from Pearce et al. (1984). Legend as in Figure 34.*

have relatively high Nb and Zr indicative of a within-plate origin. They do not appear to show any consistent variation through the unit, although the database may not be large enough to reveal such differences if they do exist.

Unit Cb

A relatively large number of samples (38) were analyzed from basaltic unit Cb because of the potential usefulness of basaltic flows, even when altered, in indicating chemical affinity and tectonic setting (e.g. Winchester and Floyd, 1977; Floyd and Winchester, 1978). The degree of alteration is indicated not only by the petrographic features described previously, but also by the relatively high and variable LOI values (up to 6%). The recalculated SiO_2 values show a basaltic to andesitic range (47-56%), and the samples cluster quite closely in the andesite/basalt field on the Zr/TiO_2 vs. Nb/Y discrimination diagram (Fig. 35). The samples show a positive correlation of TiO_2 with FeO^t/MgO ratio (Fig. 37) and with Zr (Fig. 38), indicative of tholeiitic affinity (Miyashiro, 1974). No systematic differences were noted along strike in the unit from southwest to northeast; for example, the samples from the southwest (Shanklin area), which tend to be less altered/metamorphosed than samples from the rest of the unit, and which mainly contain relict clinopyroxene, have K_2O values similar to those in the more altered northeastern part of the unit (Fig. 34a) and a similar range in TiO_2 values (Fig. 34b).

Both Ni and Cr show considerable variation, and three samples (4037a, 4609, and 7081) show elevated values of these elements (Fig. 41a, b). Sample 4037a also contains high Pb and Zn. Cu values exceed 100 ppm in several samples.

Unit Cbrs

Seven basaltic samples were analyzed from unit Cbrs, as well as one sample from an interlayered dacitic flow (sample 6528), and an additional two analyses are available from Dostal and McCutcheon (1990). These samples show chemical, as well as petrographic, features similar to those of the basaltic rocks in unit Cb, and the samples are essentially indistinguishable on the various chemical diagrams.

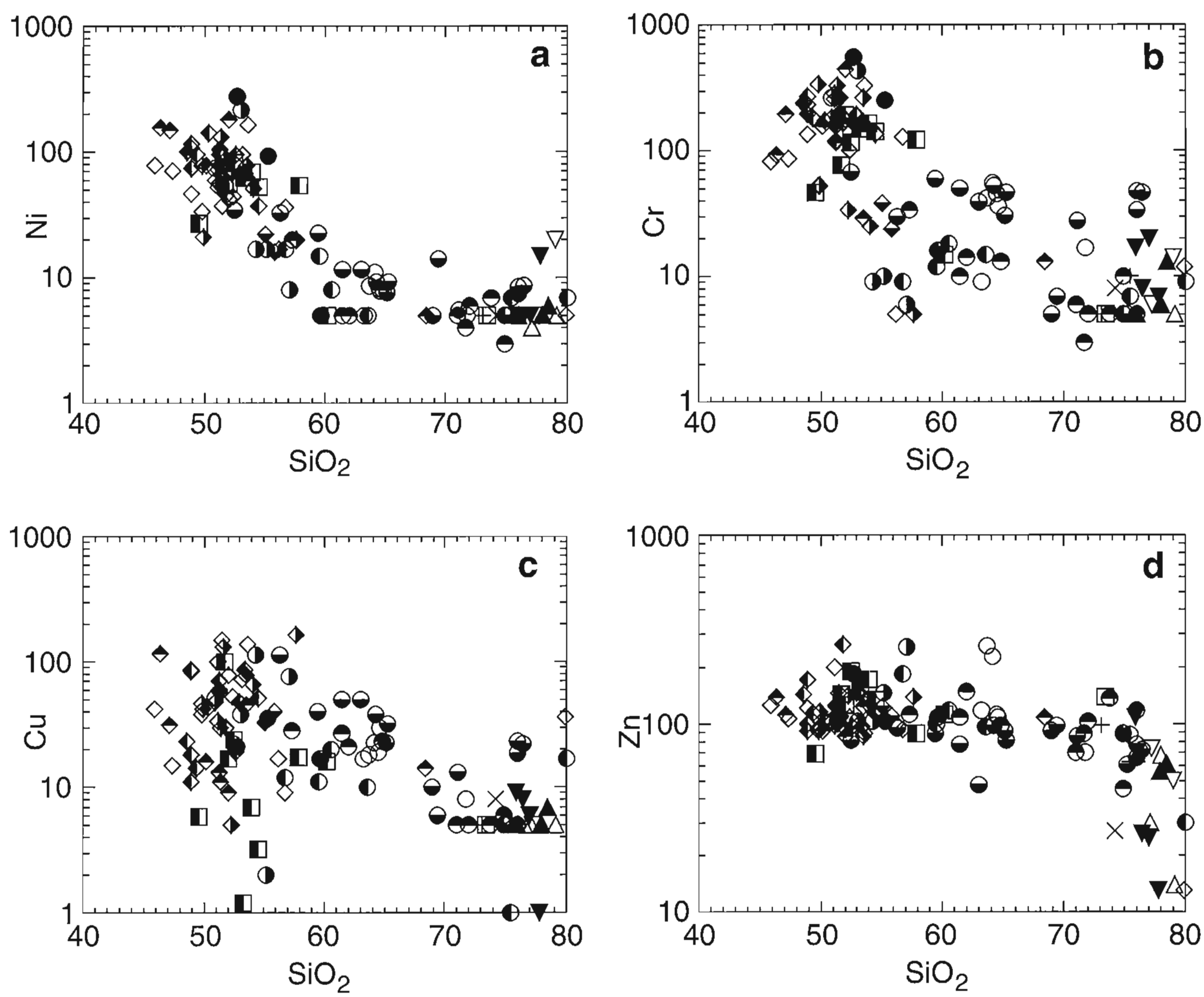

Figure 41. Plots of a) Ni, b) Cr, c) Cu, and d) Zn against SiO_2 (recalculated volatile-free) for samples from the Coldbrook Group. Legend as in Figure 34.

Circa *560-550 Ma plutons*

Overview

The ca. 560-550 Ma plutons are represented by 85 analyses, mainly from the Mechanic Settlement and Bonnell Brook plutons (Appendix C, Table C.4). Petrographic descriptions of the analyzed samples are presented in Appendix B. The samples are bimodal in their composition; peridotitic, gabbroic, and dioritic samples range in SiO_2 content (recalculated volatile-free) from about 42 to 65%, whereas granitic samples show a more narrow range, from about 72 to 78% (Fig. 42a-d). In order to emphasize comparisons of compositionally similar units, the data are discussed below in mafic and felsic groupings, rather than by individual pluton.

Peridotitic, gabbroic, and dioritic samples

Samples from the Mechanic Settlement Pluton range in silica content (recalculated volatile-free) from about 42% in the peridotitic samples to 65% in a porphyritic diorite sample

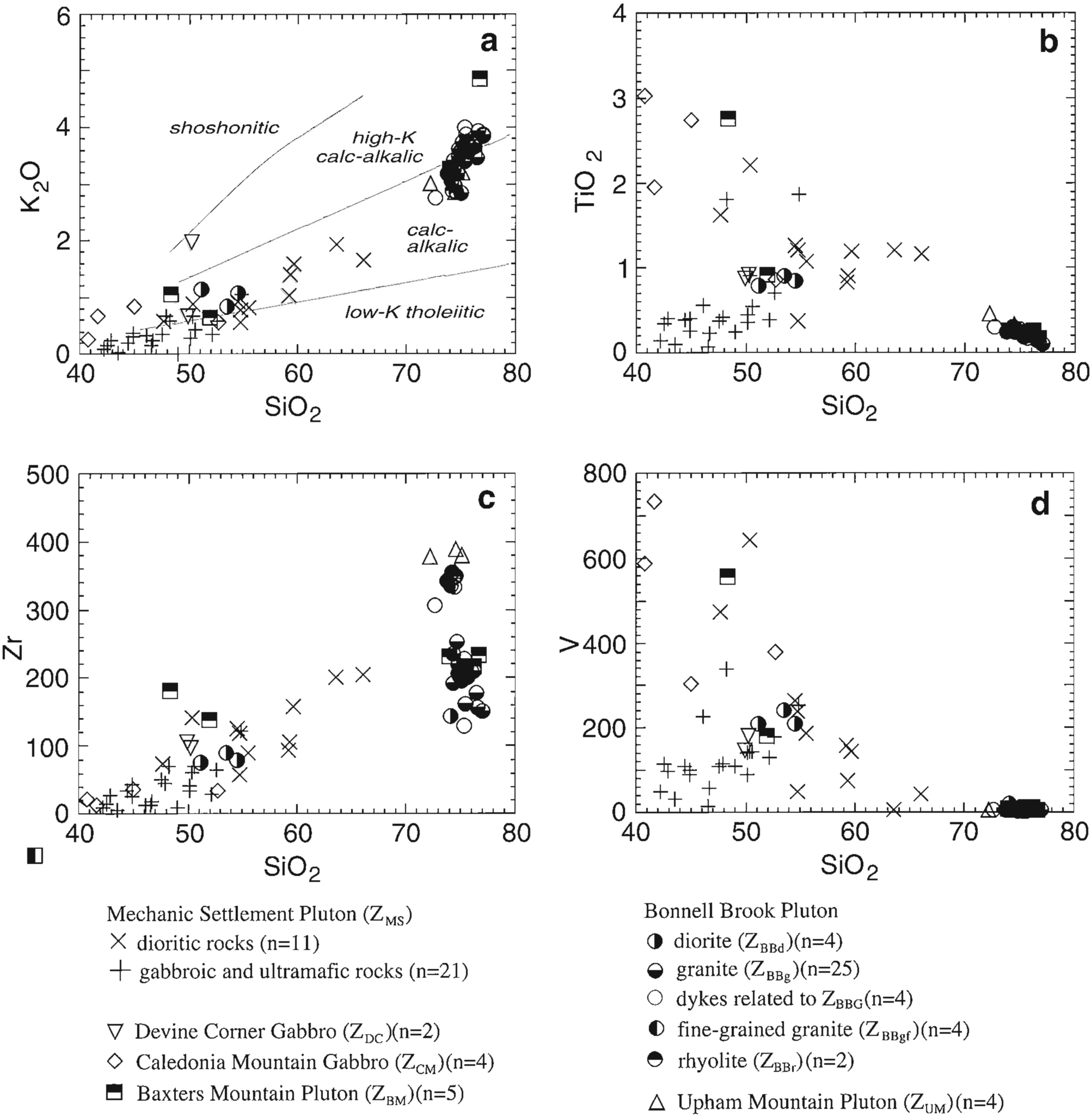

Figure 42. *Plots of **a)** K_2O, **b)** TiO_2, **c)** Zr, and **d)** V against SiO_2 (recalculated volatile-free as described in text) for samples from ca. 560-550 Ma plutons. Fields in a) from Wilson (1989) after Middlemost (1975).*

(Table C.4). They are mainly subalkaline, although a few samples scatter into the alkalic field (Fig. 43). This scatter results from the very low Nb values in some samples (at or below 5 ppm, the detection limit of the analytical method), and hence this spread in Nb/Y ratios is not likely to be meaningful. The AFM diagram (Fig. 44) shows an iron-enrichment trend, characteristic of tholeiitic suites, although dioritic samples scatter into the calc-alkalic field. On the K_2O vs SiO_2 plot (Fig. 42a), the trend appears calc-alkalic, and the gabbroic samples (45-54% SiO_2) plot in calc-alkalic basalt fields. However, the positive correlation of TiO_2 and SiO_2 (Fig. 42b) and FeO^t/MgO (Fig. 45) are typical of tholeiitic suites. The wide scatter on the Ti-Zr-Y diagram (Fig. 47) reflects the low values of TiO_2 and Zr, especially in the ultramafic samples. This diagram is not a useful discriminant for tectonic setting in these rocks.

The samples show a wide range in Ni and Cr values, with a strong negative correlation with SiO_2 (Fig. 49a, b). The high Ni and Cr, as well as scattered and, in some cases, high Cu values (Fig. 49c) reflects the economic potential of this pluton (Paktunc, 1989a, b).

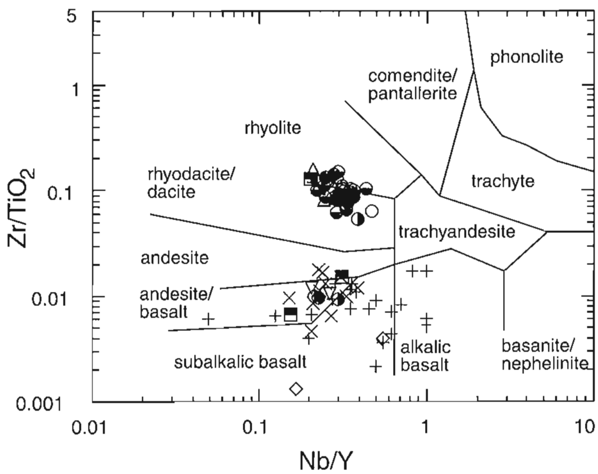

Figure 43. Plot of Zr/TiO2 against Nb/Y for samples from ca. 560-550 Ma plutons, with fields from Winchester and Floyd (1977). Legend as in Figure 42.

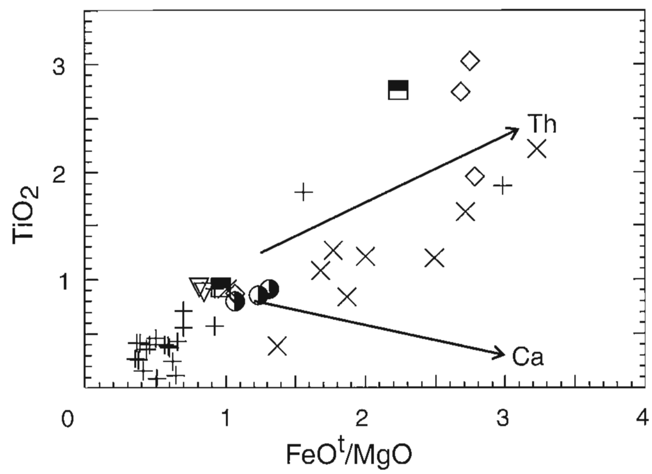

Figure 45. Plot of TiO2 against FeOt/MgO for samples with 65% or less SiO2 from ca. 560-550 Ma plutons. Trends for typical tholeiitic (Th) and calc-alkalic (Ca) suites are from Miyashiro (1974). Legend as in Figure 42.

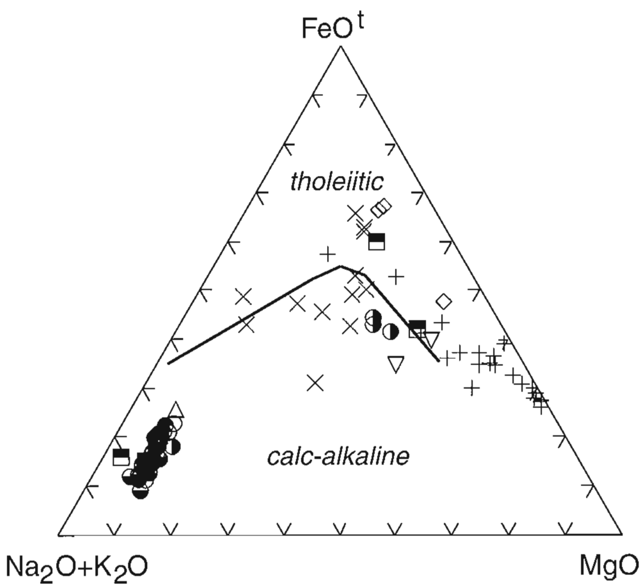

Figure 44. AFM diagram for samples from ca. 560-550 Ma plutons with tholeiitic/calc-alkalic dividing line from Irvine and Baragar (1971). Legend as in Figure 42.

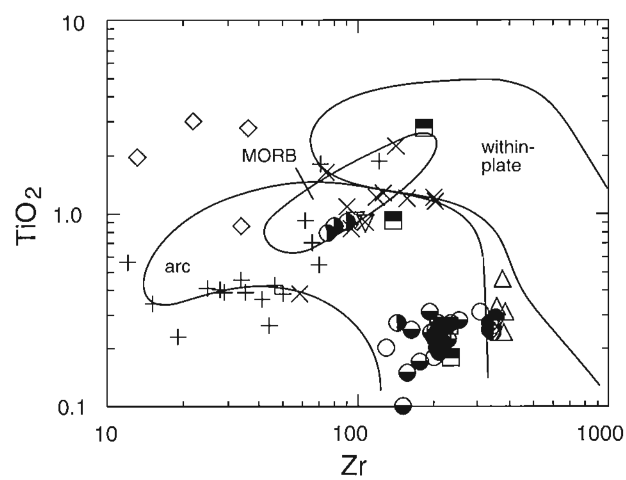

Figure 46. Plot of TiO2 against Zr for samples from ca. 560-550 Ma plutons. Fields for mid-ocean-ridge basalt (MORB), within-plate lavas, and arc lavas are from Pearce (1982). Legend as in Figure 42.

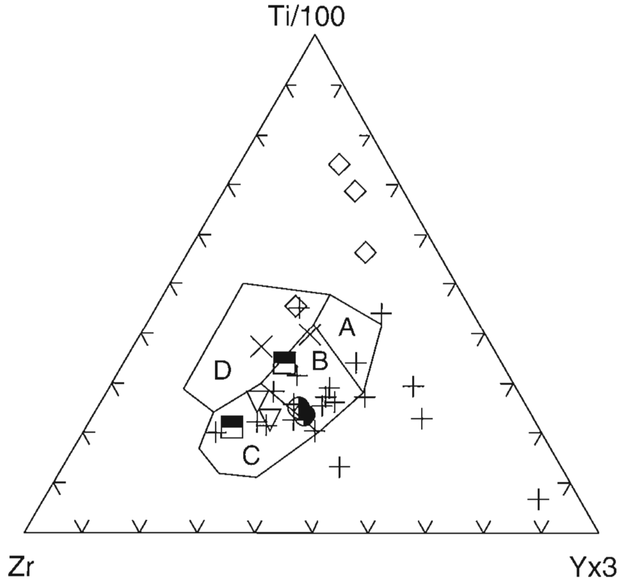

Figure 47. Ternary plot of Ti-Zr-Y for mafic samples (SiO_2 = 54% or less, recalculated volatile-free) from ca. 560-550 Ma plutons. Fields after Pearce and Cann (1973): A = low-potassium tholeiite; B = low-potassium tholeiite, calc-alkalic basalt, and ocean-floor basalt; C = calc-alkalic basalt; D = within-plate basalt. Legend as in Figure 42.

The gabbroic and dioritic rocks of the Devine Corner, Bonnell Brook, and Baxters Mountain plutons are generally similar in composition to the gabbroic and dioritic samples from the Mechanic Settlement Pluton (e.g. Fig. 42), consistent with the interpretation that all of these plutons are cogenetic and related in their origin and tectonic setting. These other units also show elevated Ni and Cr values in some cases.

The Caledonia Mountain gabbro shows some similarities, but also differences when compared to these other plutons, based on four samples analyzed. The three most mafic samples, in particular, have higher K_2O, TiO_2, and V (Fig. 42a, b, d, 46a, b). They contain higher FeO^t relative to MgO (Fig. 44, 45). Most interestingly, they also show low Ni and Cr, compared to the Mechanic Settlement Pluton samples (Fig. 49a, b). Blackwood (1991), in a detailed petrological study of the Caledonia Mountain Pluton, noted this depletion in Ni and Cr, and concluded that economic concentrations of these elements may exist at a deeper level in the pluton.

Granitic samples

Analyzed samples from granitic parts of the Bonnell Brook, Upham Mountain, and Baxters Mountain plutons contain about 74% SiO_2 (Fig. 42). They vary in K_2O content in the high potassium field from about 3 to 4%, with the exception of one syenogranitic sample from the Baxters Mountain Pluton with nearly 5% K_2O (Fig. 42a). Overall, the range in K_2O content is consistent with the range in K-feldspar in these rocks, which vary in composition from monzogranite to syenogranite. Many elements, such as TiO_2 and V (Fig. 42b, d) show little variation, but Zr shows a wide range (Fig. 42c), probably as a result of zircon fractionation. On the Zr/TiO_2-Nb/Y diagram (Fig. 43), the samples cluster at the boundary between the rhyodacite/dacite and rhyolite fields. They show a calc-alkalic trend near the alkali corner on the AFM diagram (Fig. 44). On the Rb-Nb+Y diagram (Fig. 48a), the samples form a cluster mainly in the within-plate field. However, they do not display typical features of A-type granites — only 4 samples (one from Bonnell Brook, one from Baxters Mountain, and two from Upham Mountain) have Ga/Al x 10^4 ratios greater than 2.6, the boundary between A-type and other granitoid suites proposed by Whalen et al. (1987). They do not display values of indicator elements such as Zr, Zn, or Na_2O+K_2O as high as those in typical A-type granitoid suites, although the values are generally higher than those in evolved I- or S-type granites (Barr and White, 1996a). Overall, the granites may be transitional to A-type.

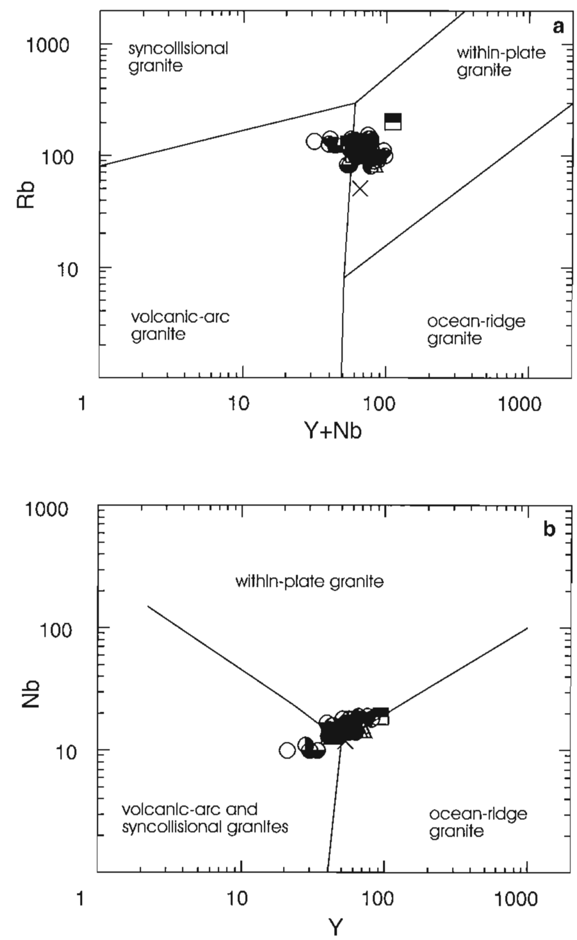

*Figure 48. Plots of **a)** Rb against Nb+Y and **b)** Nb against Y for felsic samples (SiO_2 = 65% or more, recalculated volatile-free) from ca. 560-550 Ma plutons. Fields for syncollisional granites, volcanic-arc granites, within-plate granites, and ocean-ridge granites are from Pearce et al. (1984). Legend as in Figure 42.*

As is normal in felsic rocks, Ni, Cr, and Cu contents are low, but Pb and Zn values show more variation, with Pb up to 30 ppm and Zn to 90 ppm (Fig. 49a-d).

Comparison of ca. 560-550 Ma volcanic and plutonic units

The ca. 560-550 Ma plutonic units in the Caledonian Highlands do not provide much assistance in interpreting the various chemical diagrams because the plutons, like the upper volcanic units, are essentially bimodal. However, their chemical similarity to the basalt and rhyolite samples of the upper Coldbrook Group supports the interpretation, based on field relations, that the plutons are comagmatic with the basalt and rhyolite. The bimodality of these rocks supports the within-plate setting suggested by at least some of the chemical criteria.

Most of the evidence suggests that the Coldbrook Group and comagmatic plutons did not form in a subduction zone, and a within-plate extensional setting seems more compatible with most characteristics of the rocks. It is possible that the magmas inherited the subduction-like signatures from their source rocks, in the infrastructure of an older ca. 620 Ma volcanic arc.

Other units

Grassy Lake formation (unit O_G)

Two dacitic samples from the Grassy Lake formation contain 70-73% SiO_2 and are generally similar in composition to samples of similar silica content in the Coldbrook Group (e.g. Fig. 34a-d). The younger age of these samples would not be predicted on the basis of petrological features.

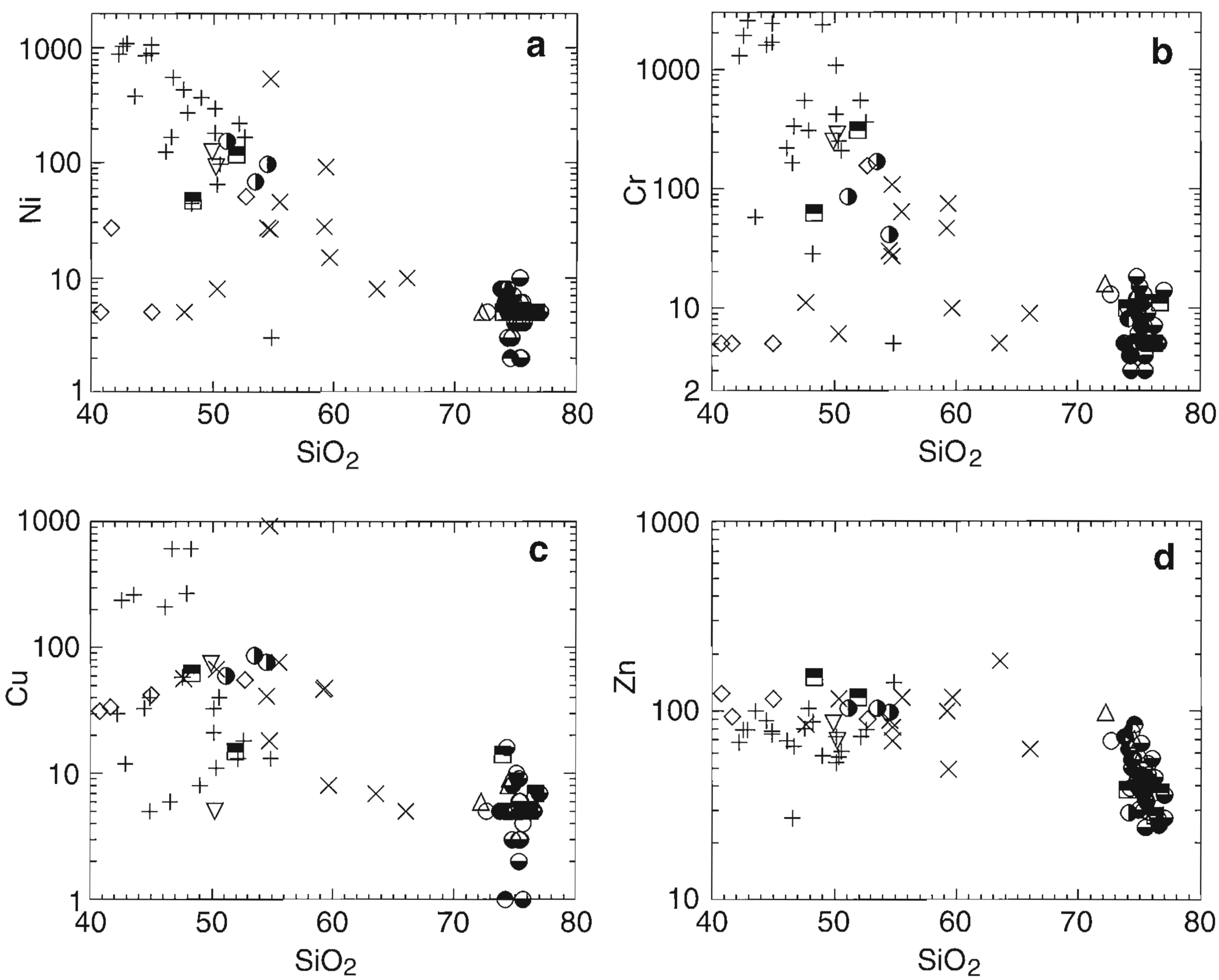

Figure 49. *Plots of **a)** Ni, **b)** Cr, **c)** Cu, and **d)** Zn against SiO_2 (recalculated volatile-free) for samples from ca. 560-550 Ma plutons. Legend as in Figure 42.*

Fairfield formation (unit D_F)

A rhyolitic sample from the Fairfield formation contains about 74% SiO_2 and shows some chemical differences from Coldbrook group rhyolites of similar silica content, for example, lower Zr and lower Y and Nb (Fig. 41a, b). It appears to have more volcanic-arc and less within-plate character, which may reflect the nature of the crustal source in this part of the Caledonian Highlands.

DEFORMATION AND METAMORPHISM

Introduction

The identification and characterization of structural features in the Caledonian Highlands are based on overprinting criteria, metamorphic grade, and geochronology. The area is divided into six structural domains with contrasting structural geometries and histories (Fig. 50-54). Domains I and II comprise the ca. 620 Ma Broad River Group and associated plutonic units in the northeastern part of the highlands. The Broad River Group has been metamorphosed to greenschist facies everywhere, and locally, five generations of deformation can be distinguished (designated D_{B1}-D_{B5}). Domains III and IV include the ca. 550 Ma Coldbrook Group and related plutonic units in the southwestern part of the highlands. The Coldbrook Group is typically unmetamorphosed (area designated domain III), except in the northeast along contacts with the Broad River Group, where it reaches chlorite grade (area designated domain IV). Structures in domain III are the result of one major episode of deformation (D_{CIII-1}), whereas domain IV has at least three deformational events (designated D_{CIV-1} to D_{CIV-3}). Domain V is a narrow zone of intense Carboniferous deformation in rocks assigned to the Broad River Group and associated ca. 620 Ma plutons in the Cape Spencer area, and is characterized by greenschist-facies metamorphism. Domain VI includes rocks and structures in the pre-600 Ma Hammondvale metamorphic suite. It is characterized by a major episode of high-pressure metamorphism and related structures.

The Broad River and Coldbrook groups in domains II, III, and IV are further divided into smaller subdomains in order to better define the character of regional-scale structures and the significant spatial variations observed in structural style (Fig. 51, 52).

Broad River Group (domains I and II)

Style of deformation and metamorphism

Primary sedimentary and volcanic layering in the Broad River Group is here termed 'S_{B0}'. In this and subsequent fabric and event designations, the subscript 'B' refers to the Broad River Group and associated plutons. The main regional deformation (D_{B1}) was accompanied by greenschist-facies metamorphism (M_{B1}) and the development of a penetrative phyllitic to slaty foliation (S_{B1}), generally consisting of the planar orientation of minerals. Syntectonic metamorphic mineral assemblages include albite+chlorite+epidote±actinolite±calcite±opaque minerals in mafic volcanic rocks, sericite±muscovite±chlorite±epidote in felsic volcanic rocks, muscovite+sericite±epidote±chlorite±biotite in siliciclastic sedimentary rocks, and albite+epidote+chlorite±muscovite±actinolite±titanite in plutonic rocks. Foliation S_{B1} is generally subparallel to lithological contacts and to primary sedimentary and volcanic layering (S_{B0}). It is developed in all lithological units, with the exception of some larger igneous bodies and some felsic flows that still retain igneous textures, although partially replaced by greenschist-facies minerals.

S_{B0} and S_{B1} locally produce an intersection lineation (L_{B1}), commonly displayed as colour streaks on S_{B1}. In lapilli tuffs and conglomeratic sedimentary rocks, the intersection lineation is defined by elongate clasts. Locally, in some fine-grained wacke and mafic units, L_{B1} takes the form of pencil lineations.

D_{B1} also resulted in rare outcrop-scale, tight to isoclinal, steeply inclined folds (F_{B1}) of pre-existing compositional layering (S_{B0}). These folds almost exclusively formed in fine-grained sedimentary and volcanic rocks. In some of the less deformed felsic flows, original flow folding is preserved, but the orientations of these features were not systematically recorded during this study. The lack of abundant F_{B1} folds in the Broad River Group is possibly due to the strong transposition of S_{B0} into S_{B1} and/or the overprinting by mylonitic fabrics parallel to S_{B1} (*see* below). Because of this lack of information, it is difficult to conclusively establish that S_{B1} is axial planar to F_{B1}.

A pre-M_{B1} event is recognized, and related to contact metamorphism around plutonic units in the Broad River Group. Although most of the effects of this metamorphism have been obliterated by D_{B1} and later events, rare low-strain enclaves still preserve hornfelsic textures, especially near the southeastern margin of the ca. 615 Ma Kent Hills Pluton. Metavolcanic samples in this contact zone contain the peak assemblage cummingtonite+augite+hornblende+biotite±apatite that is characteristic of the hornblende-hornfels facies (e.g. Yardley, 1989).

A second deformational event (D_{B2}) produced a series of folds (F_{B2}) that vary in size from microscopic to outcrop-scale features. They are distinguished from F_{B1} folds because they folded both S_{B1} and L_{B1}, but it is unclear if they represent a completely separate event or a late phase of D_{B1} folding. These folds are generally asymmetric, open to tight, and steeply inclined to upright. Tiny ridges on some S_{B1} surfaces resemble intersection lineations, but in thin section they are seen to be the result of microcrenulations of sericite and/or muscovite, and to mimic the orientation of larger F_{B2} folds. Associated with some of the smaller folds are relatively steep crenulation cleavages that parallel the axial surfaces of F_{B2} folds.

A third deformational event (D_{B3}) produced a set of small, open to tight, asymmetric Z- and S-shaped kink folds (F_{B3}), with a moderately developed kink-band cleavage parallel to the axial surfaces of these folds. Conjugate pairs of kink bands are less common.

Evidence for a D_{B4} event is restricted to the southeastern part of the Broad River Group in domain II (Fig. 51) where S_{B0} and S_{B1} have been refolded into regional, open to tight, folds (F_{B4}) with a basin-and-dome-like configuration. Sporadic, uniformly oriented kink folds occur throughout domain II and are interpreted to represent a minor event (D_{B5}) .

Mylonitization

Mylonitization in the Broad River Group appears to have occurred in at least two episodes. The earliest record of mylonitic deformation is interpreted to have been related to D_{B1}, but before or during M_{B1} metamorphism, because many of these zones have been extensively recrystallized during greenschist-facies metamorphism. These zones are best preserved along the southeastern margin of the Point Wolfe River Pluton and within the Caledonia Road Granitoid Suite, but are also recognized locally in volcanic and sedimentary rocks of the Broad River Group. In the plutonic units, the mylonitic texture is preserved as coarsely recrystallized ribbon quartz, asymmetric feldspar crystals, and amphibole augen that produce a moderately developed mineral lineation. The regional significance and sense of movement of these mylonite zones are unknown, although structural relationships suggest a relatively high-angle, dip-slip to thrust component.

The second mylonitic deformation occurred after M_{B1} metamorphism and appears to have been much more widespread. In granitoid rocks, the mylonitic foliation is platy in appearance and preserves a well developed stretching lineation defined by asymmetric feldspar crystals, amphibole crystals, and elongate quartz ribbons. Textures in the volcanogenic sequence include extremely flattened volcanic fragments and the development of ultramylonite to phyllonite. Although movements in this zone have not been determined in detail, structural relations suggest a strike-slip to an oblique strike-slip component, probably with a right-lateral sense of movement.

Although the older mylonites are extensively recrystallized compared to the younger set, it cannot be shown conclusively that these mylonites did not form at the same time. However, the lack of correlation between the structural patterns (e.g. stretching lineations, Fig. 50) implies a separate and distinct kinematic framework.

Structural geometry

Domain I

Structural data from domain I are displayed on stereonets on Figure 50. Poles to S_{B1} in stratified and igneous rocks form well defined clusters with an average foliation that strikes consistently northeast and dips moderately to the northwest (032°/49°NW and 030°/55°NW). Poles to S_{B0} also form a well defined cluster that is subparallel to S_{B1} (034°/42°NW); however, these poles form an incipient girdle distribution about a shallow southwest-plunging axis (229°/15°). The fairly consistent S_{B0} orientations in domain I could indicate that D_{B1} folding is largely isoclinal. The presence of outcrop-scale isoclinal F_{B1} folds supports this interpretation.

Intersection lineations (L_{B1}) form a moderately northwest-plunging cluster (328°/38°) with a slight girdle distribution. The dispersal of intersection lineations is interpreted to be due to later folding (F_{B2}) about a subhorizontal axis trending northeast-southwest (238°/01°). Measured axes of these folds are subparallel and form a well defined, shallow, southwest-plunging axis (224°/12°) that confirms a F_{B2} folding event. F_{B2} folds are generally steeply inclined to the southeast with axial planes that are subparallel to S_{B1}.

Kink folds (F_{B3}) are common in the more phyllitic and slaty rocks and, based on the stereographic pattern, form a conjugate set of shallow-plunging, westerly (258°/24°) and northwesterly (323°/24°) fold axes. The associated kink planes parallel the axial planes and have steep east-west to north-south trends.

The coplanarity of the younger and older mylonitic structures makes it impossible to differentiate between the two sets on the basis of foliation geometry alone. For this reason, all recognized mylonitic foliations are plotted on the same stereographic projection (Fig. 50). It clearly shows that both mylonitic episodes are characterized by similar northeast-striking, steeply northwest-dipping foliations (029°/64°NW), although slightly steeper than S_{B1}. Stretching lineations in the recrystallized mylonite are locally present on the foliation plane and cluster around a moderately plunging axis trending north to northwest (339°/40°). Stretching lineations in the younger mylonites typically plunge shallowly to the southwest (242°/17°). Mylonitic foliations are rarely folded, but, where present, such folds are generally small isoclinal structures. It is not known if their formation was synchronous with mylonitic deformation or if they represent a younger folding event.

Domain II

Structural data from domain II are displayed on stereonets on Figure 51. Subdomain IIA is the most northeasterly part of domain II and is characterized by regional-scale, open, upright, symmetrical antiforms. Poles to S_{B1} and S_{B0} form a broad girdle of points defining shallow, southwest-plunging fold axes (220°/18° and 215°/12°, respectively). The mean poles to foliation and bedding define clusters on the girdle with shallow, southwest- and south-dipping features (149°/19°SW and 108°/13°S, respectively). Steeply dipping S_{B1} and S_{B0} planes are not common in this subdomain.

Subdomain IIB, southwest of subdomain IIA (Fig. 51), is characterized by a complexly folded outcrop pattern with open, upright to inclined, synformal and antiformal structures. The complexity of the fold patterns is reflected in the scatter on the stereographic projections. However, poles to S_{B1} and S_{B0} define subparallel girdle distributions with shallow, east- to east-southeast-plunging fold axes at 100°/20° and 112°/24°, respectively. As in subdomain IIA, the mean poles to S_{B1} and S_{B0} define clusters on the girdle with shallow orientations of 014°/20°E and 020°/24°E, respectively.

Subdomain IIC (Fig. 51) is also a complexly folded area with an overall open, upright, symmetrical, antiformal outcrop pattern. Although poles to bedding are scattered, S_{B1} and S_{B0} define girdle distributions that are subparallel about shallow, southwest-plunging axes (236°/20° and 232°/18°, respectively). The mean poles to S_{B1} and S_{B0} define clusters on the girdle with shallow, west- and south-dipping features (173°/22°SW and 105°/24°S, respectively).

Subdomain IID is the most southwesterly part of domain II and covers the area south of the Point Wolfe River Pluton (Fig. 51). This area is characterized by open to tight, upright, symmetrical folds with a broad, regional-scale, synformal structure. Poles to S_{B1} form a girdle distribution about a northeast-plunging axis (042°/27°). Poles to S_{B0} are more scattered but still form a broad girdle subparallel to S_{B1} with a fold axis at 030°/30°. Steep S_{B1} and S_{B0} orientations are more common in this subdomain than in the other subdomains of domain II.

Due to the limited number of measurements from subdomains IIA to IID, the L_{B1} and F_{B2} data from all four subdomains are plotted together on one stereographic projection (Fig. 51). L_{B1} forms three well defined clusters trending at 316°/13°, 215°/20°, and 104°/23°, and a minor cluster at 019°/19°. F_{B2} fold axes do not define a clear pattern on the stereographic projection, although many are subhorizontal to

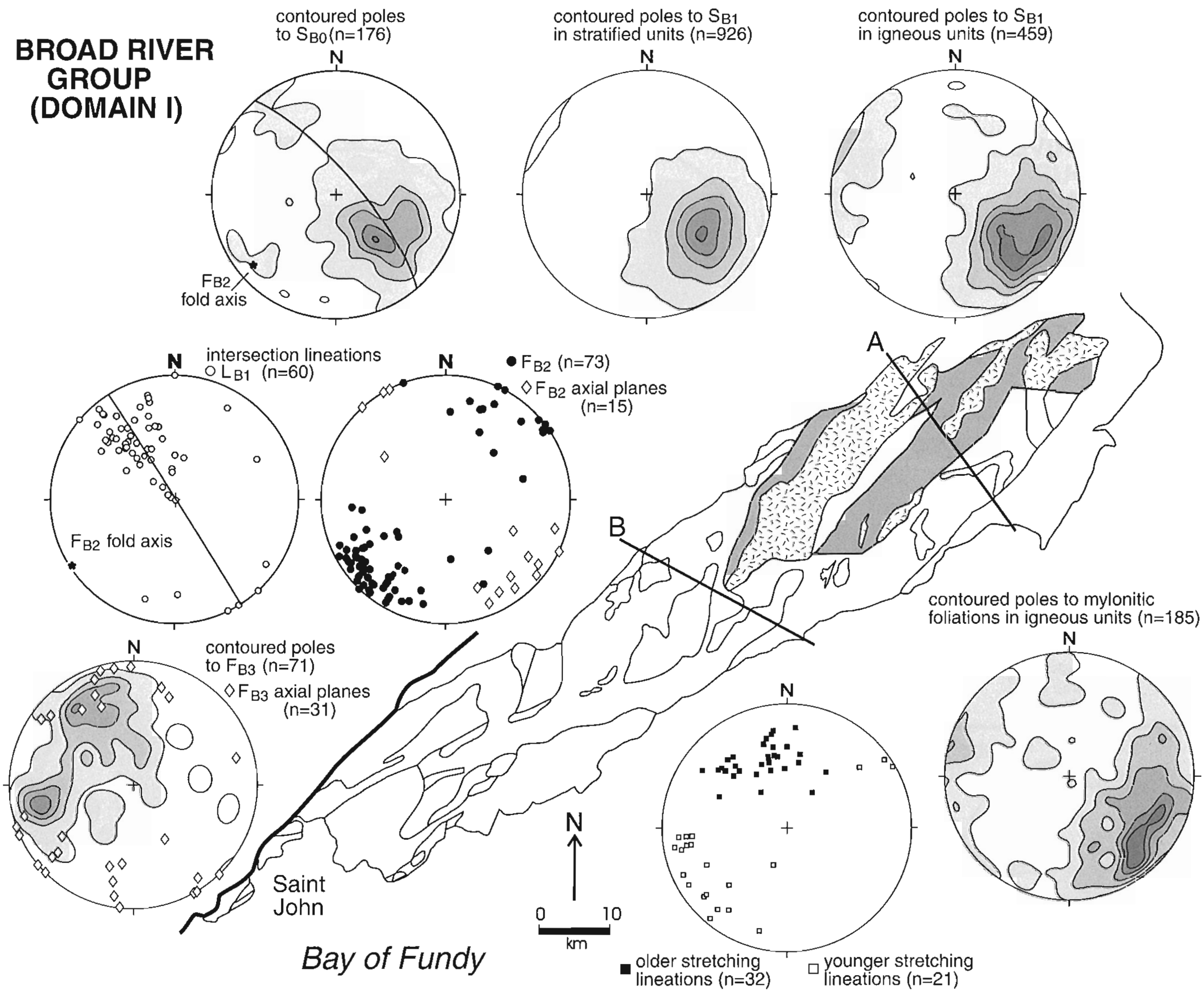

Figure 50. Stereographic projections displaying structural data from domain I, which includes the northern part of the Broad River Group (shaded on figure) and associated plutons (slash pattern on figure). Other contacts on the figure are simplified from Figures 3 and 9. Lines A and B indicate positions of cross-sections in Figure 54. Contours on stereonets represent 1, 2, 3, 4, and greater than 5% per 1% area; darkest shading indicates highest contour area. S, F, and L terminology is explained in the text.

shallowly northeasterly plunging. In domain I, L_{B1} is a regionally northwest-plunging lineation that is locally folded by subhorizontal, northeast-trending F_{B2} folds. In contrast, both L_{B1} and F_{B2} have been refolded by regional folds in domain II. F_{B3} kink folds are not easily distinguished from F_{B2} folds in domain II, but, where present, appear to be refolded along with L_{B1} and F_{B2}, suggesting that the regional folds in domain II are probably F_{B4}. The complexity of the superimposed F_{B4} folding makes interpretation of these pre-existing linear structures difficult.

Kink folds are common and typically plunge shallowly to the southwest at 247°/27°. The associated kink planes parallel the axial planes and have a steep northeasterly trend. The kinks have a relatively uniform orientation, unlike F_{B3} kinks, and hence are interpreted to be the result of a younger event (D_{B5}).

Summary and interpretation

The main fabric in the Broad River Group and associated plutonic units is the principal foliation (S_{B1}) that strikes northeast-southwest. The foliation along the coast of the Bay of Fundy dips moderately to the southeast; however, 4 to 5 km to the northwest, the dip of the foliation becomes progressively horizontal and then more northwesterly. Based on these orientations and local stratigraphic control, the overall structure of the Broad River Group is interpreted as an isoclinal recumbent F_{B1} fold, overturned to the southeast and locally refolded by major upright F_{B4} folds in the southeast (*see* Fig. 54).

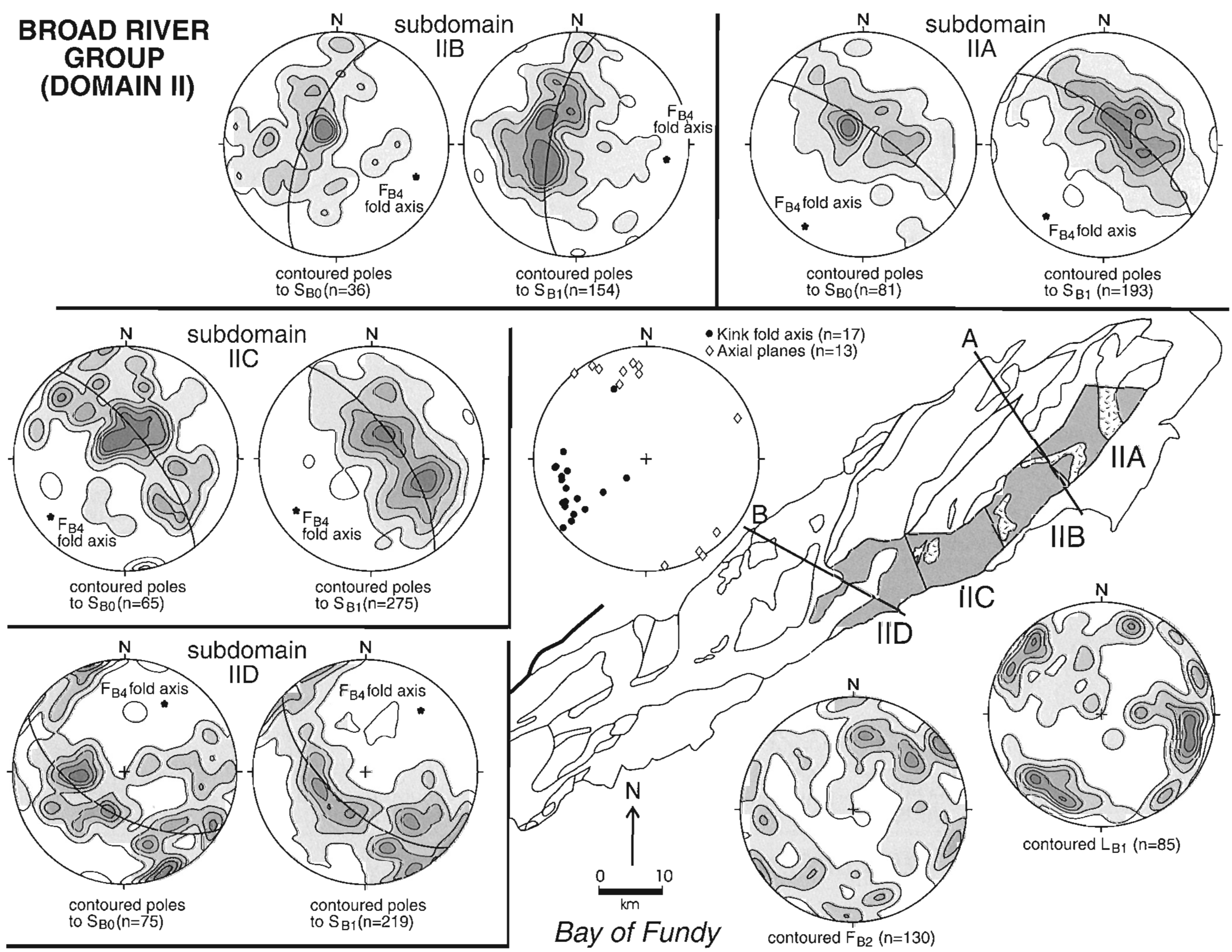

Figure 51. Stereographic projections displaying structural data from domain II, which includes the southern part of Broad River Group (shaded on figure) and associated plutons (slash pattern on figure). Other contacts on the figure are simplified from Figures 3 and 9. Lines A and B indicate positions of cross-sections in Figure 54. Contours on stereonets represent 1, 2, 3, 4, and greater than 5% per 1% area; darkest shading indicates highest contour area. S, F, and L terminology is explained in the text.

An inconsistency with this interpretation is that the intersection lineations (L_{B1}) are perpendicular to the inferred fold axis trending northeast-southwest (*see* domain I). However, this geometrical relationship is consistent with mylonitic textures developed in sheath folds. If the regional recumbent fold was related to mylonitization, it suggests southeastward thrusting, which would explain the moderate northwest-plunging stretching lineations observed in many of the plutonic units. In this case many of the similar-trending intersection lineations observed in the volcanic and sedimentary rocks may be stretching lineations. If F_{B2} folds are related to late phases of D_{B1} deformation, then the asymmetry of F_{B2} folds also suggests a southeasterly directed emplacement of the recumbent fold. However, detailed kinematic studies are needed in this area to substantiate this interpretation.

Coldbrook Group (domains III and IV)

Style of deformation and metamorphism

Primary sedimentary and volcanic layering in the Coldbrook Group are here designated S_{C0}. In this and subsequent fabric and event designations, the subscript 'C' refers to the Coldbrook Group, and '3' and '4' refer to domains III and IV, respectively. The style of deformation and metamorphism varies dramatically from west to east in the Coldbrook Group. The main regional deformation (D_{C3-1}) in the west (subdomains IIIA and IIIB) was inhomogeneous and not associated with metamorphism. In these subdomains, S_{C3-1} is not well developed but, where present, is marked by a flattening of volcanic fragments or a closely spaced pressure-solution cleavage in coarser grained rocks. In some fine-grained rocks, a single penetrative slaty fabric may be present, resulting from new growth of white mica, the alignment of pre-existing detrital minerals, or a development of pressure solution seams. Locally this cleavage is anastomosing. L_{C3-1} intersection lineations are poorly developed. Zones of more intense cleavage development, which are locally present along the boundaries of different lithological units, are probably a response to competency contrasts or later shearing. Rare, outcrop-scale, open folds in subdomain IIIB are interpreted to be related to D_{C3-1}.

The main regional deformation in the eastern part of the Coldbrook Group is considerably more intense and structurally distinct. For this reason, this area is assigned to a separate domain IV, subdivided into subdomains IVA and IVB. In these subdomains the main deformation (D_{C4-1}) was accompanied by regional chlorite-grade metamorphism (M_{C4-1}), with the development of a penetrative slaty to phyllitic foliation (S_{C4-1}) that consists of the planar orientation of muscovite and chlorite. S_{C4-1} is generally subparallel to primary sedimentary and volcanic layering, but locally it intersects S_{C0} at a high angle. This produces minor intersection lineations (L_{C4-1}), displayed as colour streaks on S_{C4-1}. The S_{C4-1} fabric is typically overprinted by younger mylonitic or phyllonitic textures, especially in subdomain IVB (*see* below), although even in this subdomain the earlier structures are locally preserved in low-strain zones.

In subdomain IVC, D_{C4-1} also resulted in rare, outcrop-scale, tight to isoclinal folds (F_{C4-1}). As in the Broad River Group, these folds are best developed in sedimentary rocks. In some of the less deformed felsic flows, original flow folding is preserved; these features were not measured systematically during this study.

In subdomain IVA, S_{C4-1} is locally deformed by D_{C4-2} into small, symmetric, open, and upright to steeply inclined folds (F_{C4-2}). These folds are rarely observed in subdomains IVB. All of these earlier structural features in subdomain IVA are folded by a younger D_{C4-3} regional event with similar structural features as those in domain II of the Broad River Group, suggesting that these areas were deformed during the same event.

Evidence for contact metamorphism is obvious in rocks around the ca. 560-550 Ma Mechanic Settlement Pluton (subdomain IIIB). Sedimentary rocks adjacent to the pluton contain the assemblage cordierite+biotite+chlorite+muscovite, whereas mafic volcanic rocks contain hornblende+biotite±chlorite. These assemblages are characteristic of the lower temperature part of the hornblende-hornfels facies (e.g. Yardley, 1989). The relatively narrow contact zone around this pluton is due to its rapid cooling after emplacement (Grammatikopoulos et al., 1995).

Mylonitization

Evidence for mylonitization in the Coldbrook Group is largely restricted to the area of the boundary with the Broad River Group in subdomain IVB and to a lesser extent in subdomain IVA. It appears to have occurred after peak chlorite-grade metamorphism (M_{C4-1}) because many of the mylonitic textures are not recrystallized. Textures in the volcanogenic sequence include a strong, flaggy, muscovite-chlorite foliation with phyllonite formation. In this zone, volcanic fragments and phenocrysts are extremely flattened and small, centimetre-scale, asymmetric, kink folds are common. Although the sense of movement in this zone has not been determined in detail, the asymmetry of the kink folds suggests a strike-slip component, probably with a right-lateral sense of movement similar to that recorded in the younger mylonites in the Broad River Group.

Structural geometry

Subdomain IIIA

Structural data from subdomain IIIA and the other subdomains of the Coldbrook Group are displayed on Figure 52. S_{C0} in this subdomain strikes northeast to east-northeast and is steeply to moderately inclined. Poles to S_{C0} form a broad girdle of points defining the F_{C3-1} fold axis (068°/23°). S_{C3-1} consistently dips steeply southeast and trends northeast-southwest; poles cluster on a stereonet projection with an average orientation of 061°/73°SE. No folds were observed in this subdomain.

Subdomain IIIB

Subdomain IIIB encompasses the area west of the Broad River Group in the central part of the Caledonian Highlands (Fig. 52). It is separated from the Broad River Group along its eastern contact by a steep northeast-trending fault. Subdomain IIIB is characterized by volcanic and sedimentary strata that strike northeast-southwest and are steeply to shallowly inclined. Poles to S_{C0} form a broad girdle of points defining the F_{C3-1} fold axis (220°/20°). S_{C3-1} is generally steeply dipping and strikes northeast-southwest; poles cluster on a stereographic projection with an average orientation of 042°/90°.

L_{C3-1} intersection lineations are rare and F_{C3-1} folds are not common. F_{C3-1} fold axes form a scattered distribution on a stereonet projection, perhaps because some measurements were inadvertently taken from flow folds, as opposed to tectonic folds.

Subdomain IVA

Subdomain IVA encompasses a block of the Coldbrook Group in the area southeast of the Bonnell Brook Pluton (Fig. 52). A fault separates subdomain IVA from the Broad River Group in this area, and is interpreted to represent a major thrust surface on which the Coldbrook Group was thrust over the Broad River Group. However, the southwestern boundary appears to be a younger, steep, northeast-trending fault. Subdomain IVA is characterized by variably oriented S_{C0} and S_{C4-1}. However, poles to S_{C4-1} form a girdle distribution about a northeast-plunging axis (046°/29°). Poles to S_{C0} are more scattered but still form a broad girdle subparallel to S_{C4-1}, with a fold axis at 041°/46°.

F_{C4-2} fold axes are widely dispersed in this subdomain and do not rigorously define a girdle distribution; the dispersal of these folds, S_{C0}, and S_{C4-1} is interpreted to be the result of later folding. The structural configuration in subdomain IVA parallels that in domain II (subdomain IID).

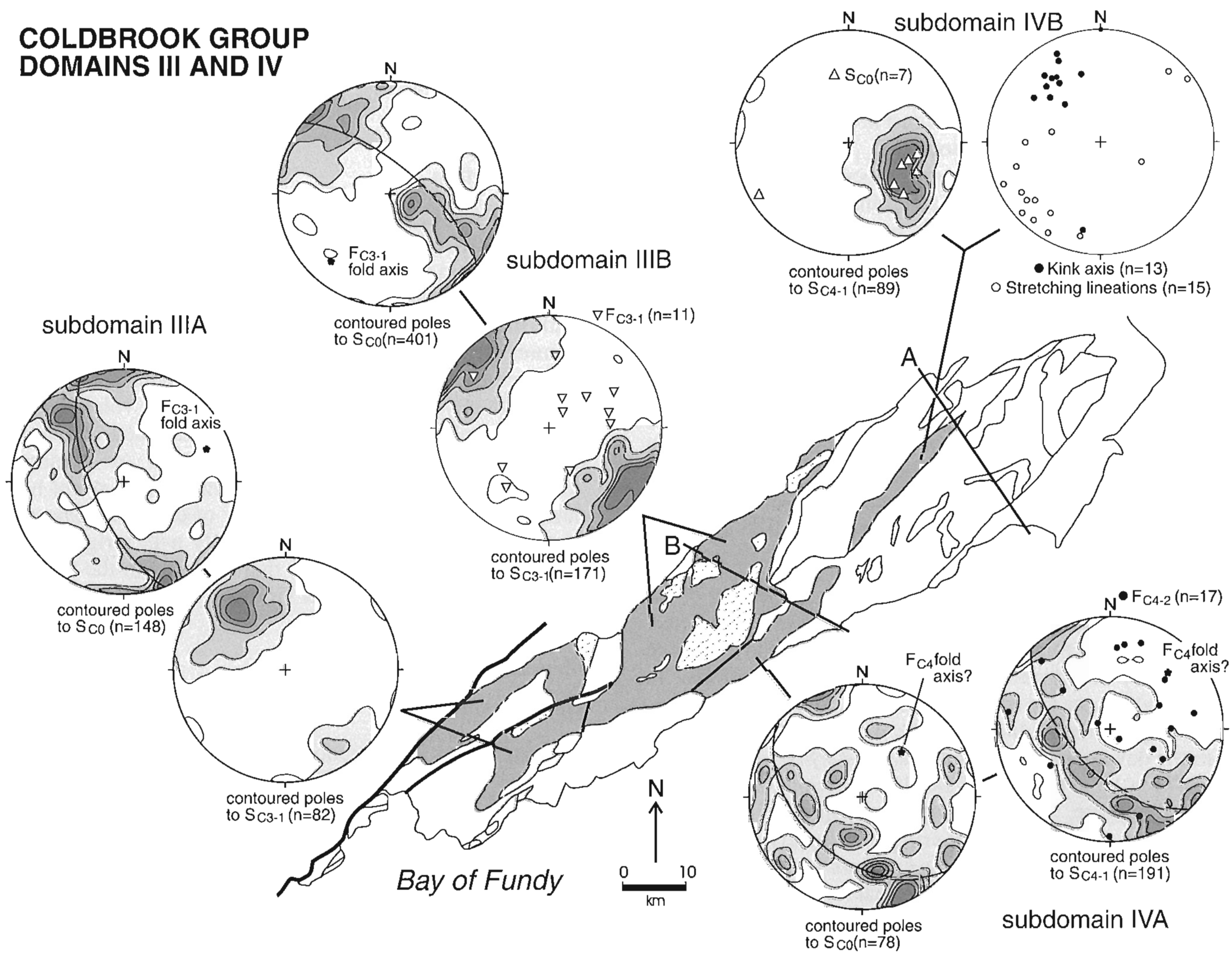

Figure 52. Stereographic projections displaying structural data from domains III and IV in the Coldbrook Group (shaded on figure) Other units are simplified from Figures 3 and 9. Lines A and B indicate positions of cross-sections in Figure 54. Contours on stereonets represent 1, 2, 3, 4, and greater than 5% per 1% area; darkest shading indicates highest contour area. S, F, and L terminology is explained in the text.

Subdomain IVB

Subdomain IVB coincides with a narrow sliver of the Coldbrook Group along the southeastern margin of the Point Wolfe River Pluton (Fig. 52). Poles to S_{C4-1} in these mylonitic and phyllitic rocks form a well defined cluster with an average foliation that strikes consistently northeast and dips moderately to the northwest (025°/61°NW). Rare S_{C0} poles are subparallel to S_{C4-1} (032°/50°NW). Stretching lineations are shallow and southwest plunging (average 222°/15°). Kink-fold axes form a moderately northwest-plunging cluster (325°/31°). The structural features in subdomain IVB are similar in orientation to the younger mylonitic structures in domain I of the Broad River Group.

Summary and interpretation

Based on stratigraphy and the outcrop distribution of units, the main area of the Coldbrook Group (subdomain IIIB) is interpreted to be a large, upright, relatively horizontal, anticlinal (F_{C3-1}) structure (Fig. 54b). A poorly developed, steep, axial planar cleavage (S_{C3-1}) is associated with the fold. The conformably overlying Cambrian–Ordovician Saint John Group in the Hanford Brook area flanks the northwestern limb of the anticline and also displays this poorly developed cleavage.

Although no minor folds were observed in subdomain IIIA, the distribution of units in this area suggests that it has been folded into a regional, gently southwest-plunging, steeply northwest-inclined syncline. The associated steeply southeast-dipping cleavage (S_{C3-1}) is interpreted to be axial planar. The unconformably overlying Cambrian–Ordovician Saint John Group in this area is folded into a large isoclinal syncline overturned to the northwest (Richards, 1971; Wardle, 1978) and generally mimics the structure in the Coldbrook Group (domain IIIA). The structural fabrics in subdomains IIIA and IIIB of the Coldbrook Group parallel those in the overlying Saint John Group, indicating that these units were deformed together, and placing a maximum age of Lower Ordovician on the deformation.

In contrast to subdomains IIIA and IIIB, the main fabric preserved in subdomains IVA and IVB of the Coldbrook Group is a penetrative slaty to phyllitic foliation, in which younger mylonitic fabrics form an integral part in subdomain IVB. These subdomains lie within, and display structural fabrics similar to those in, the Broad River Group, which suggests that these subdomains of the Coldbrook Group and the older Broad River Group were deformed together during the same deformational event(s).

Cape Spencer area (domain V)

The Cape Spencer domain is a relatively narrow, northeast-trending belt of Precambrian volcanic and plutonic rocks, and Cambrian and Carboniferous sedimentary rocks, along the coast of the Bay of Fundy southeast of Saint John (Fig. 53). Fabrics and events in the Cape Spencer domain are here identified by the subscript 'CS'. Four distinct episodes of deformation were documented in the Cape Spencer domain by Watters (1993b). According to Watters (1993b), the main regional deformation (D_{CS1}) involved thrusting which was accompanied by subgreenschist-facies metamorphism (M_{CS1}) and the development of a penetrative phyllitic to slaty foliation (S_{CS1}), in both the Precambrian and Cambrian–Carboniferous units. Syntectonic metamorphic mineral assemblages include albite+chlorite+epidote+quartz±calcite± opaque minerals in the mafic volcanic rocks, sericite±chlorite± epidote in the felsic volcanic rocks, albite+epidote+chlorite+ sericite±muscovite±calcite in plutonic rocks, and sericite+ chlorite±calcite±epidote in sedimentary rocks. The foliation is typically subparallel to lithological contacts and primary sedimentary and volcanic layering (S_{CS0}) and is developed in all rock types.

Structural data from the Cape Spencer domain are displayed on stereographic projections in Figure 53. In addition to thrusting, D_{CS1} also resulted in regional-scale, northeast-trending, shallow-plunging recumbent folds which verge to the northwest. Poles to S_{CS0} form a northwest-southeast girdle distribution defining the F_{CS1} fold axis (049°/10°), with a main cluster of points representing moderately southeast-dipping beds (033°/51°SE). In the field, S_{CS1} is axial planar to these folds and dips moderately to the southeast. Poles to S_{CS1} show a similar distribution as poles to S_{CS0}, with an incipient northwest-southeast girdle distribution about a shallow northeast-plunging fold axis (046°/04°), and a cluster of poles (041°/40°SE) corresponding to moderately southeast-dipping foliations.

The girdle distribution of S_{CS1} is due to refolding by D_{CS2}. S_{CS1} is folded into open to close folds, which locally contain an axial planar, subhorizontal,, crenulation cleavage (S_{CS2}). These are, in turn, deformed by a set of kink bands representing D_{CS3} (cf. Watters, 1993b). Foliation measurements taken in this study did not differentiate between S_{CS1} and S_{CS2}, and therefore this stereographic projection may be a composite of these two features.

The fourth episode of deformation is related to movement on northeast-trending, southeast-dipping normal faults (Watters, 1993b).

Hammondvale metamorphic suite (domain VI)

The Hammondvale metamorphic suite occurs in a fault-bounded block located along the northwestern margin of the Caledonian Highlands in the Hammondvale area (Fig. 53, 54b). It consists of albite- and garnet-porphyroblastic mica schists with minor marble and amphibolite. The main mineral assemblage in the mica schist is quartz+muscovite+albite±garnet±biotite±K-feldspar±epidote. The mica schists have well developed schistosity (S_{H1}) and a local mineral lineation (L_{H1}) that is interpreted to be a stretching lineation. S_{H1} is defined by alignment of muscovite±biotite, whereas the lineation is defined by recrystallized quartz ribbons and asymmetric porphyroblasts. Marble is well banded (S_{H1}) with thin muscovite-rich layers, and contains the mineral assemblage calcite+muscovite +apatite+titanite+opaque minerals±chlorite. Amphibolite is also well banded (S_{H1}), alternating between hornblende- and plagioclase-rich layers, and contains the assemblage hornblende+albite+titanite. Quartz occurs only as inclusions in albite porphyroblasts.

Structural data from the Hammondvale metamorphic suite are displayed on Figure 53. Poles to S_{H1} form a well-defined cluster with an average foliation that strikes consistently northeast and dips steeply to the northwest (019°/78°NW); these poles also form an incipient girdle distribution about a shallow south-southwest plunging axis (205°/27°). S_{H1} is locally crenulated and, as in the case of L_{H1}, measurements are few and their significance is unclear.

Metamorphic conditions, as determined by White (1995), are consistent with high-pressure/low-temperature metamorphism, as is typically associated with major tectonic boundaries.

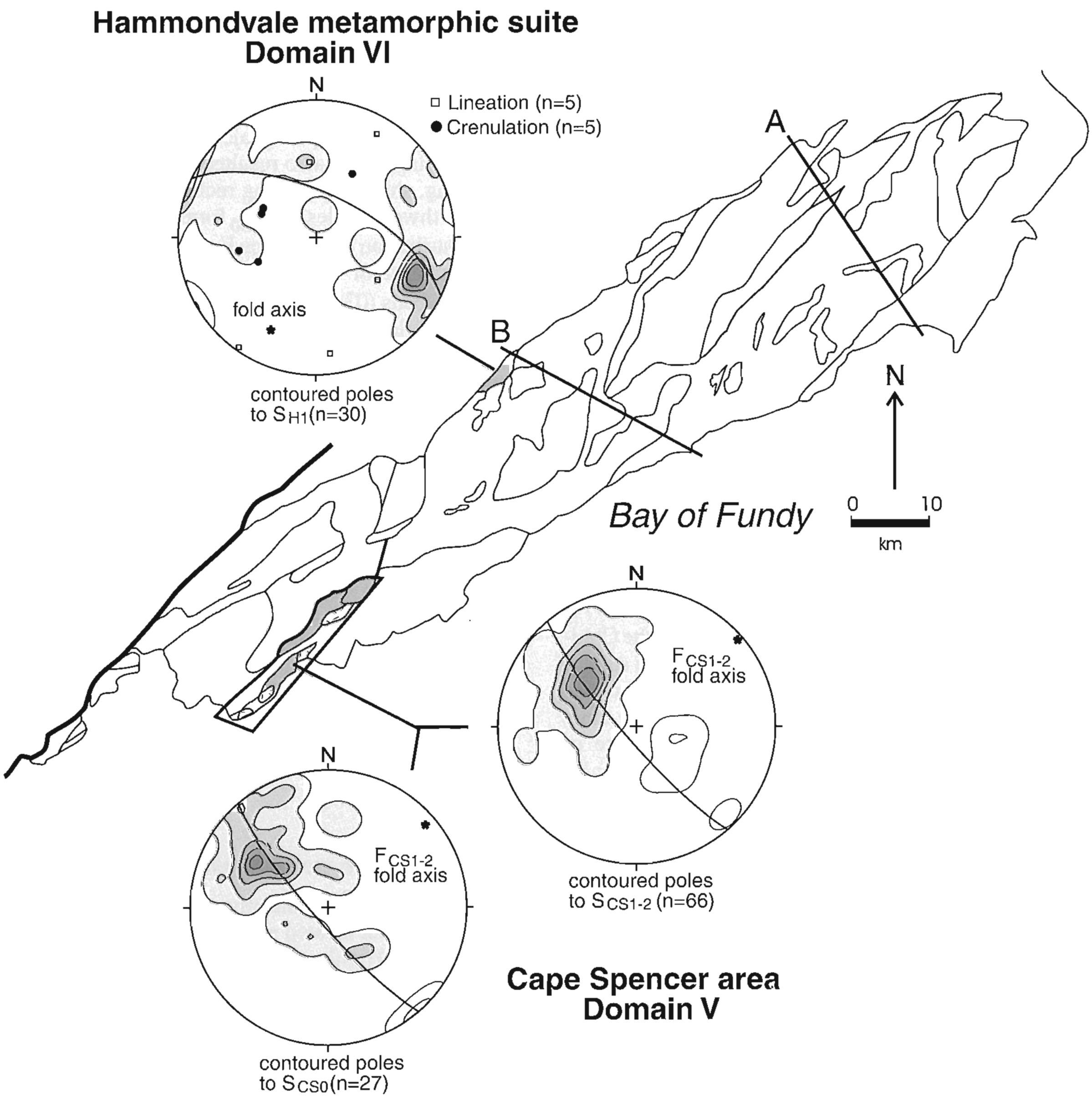

Figure 53. Stereographic projections displaying structural data from domain V (Cape Spencer area) and domain VI (Hammondvale metamorphic suite). Other units are simplified from Figures 3 and 9. Lines A and B indicate positions of cross-sections in Figure 54. Contours on stereonets represent 1, 2, 3, 4, and greater than 5% per 1% area; darkest shading indicates highest contour area. S, F, and L terminology is explained in the text.

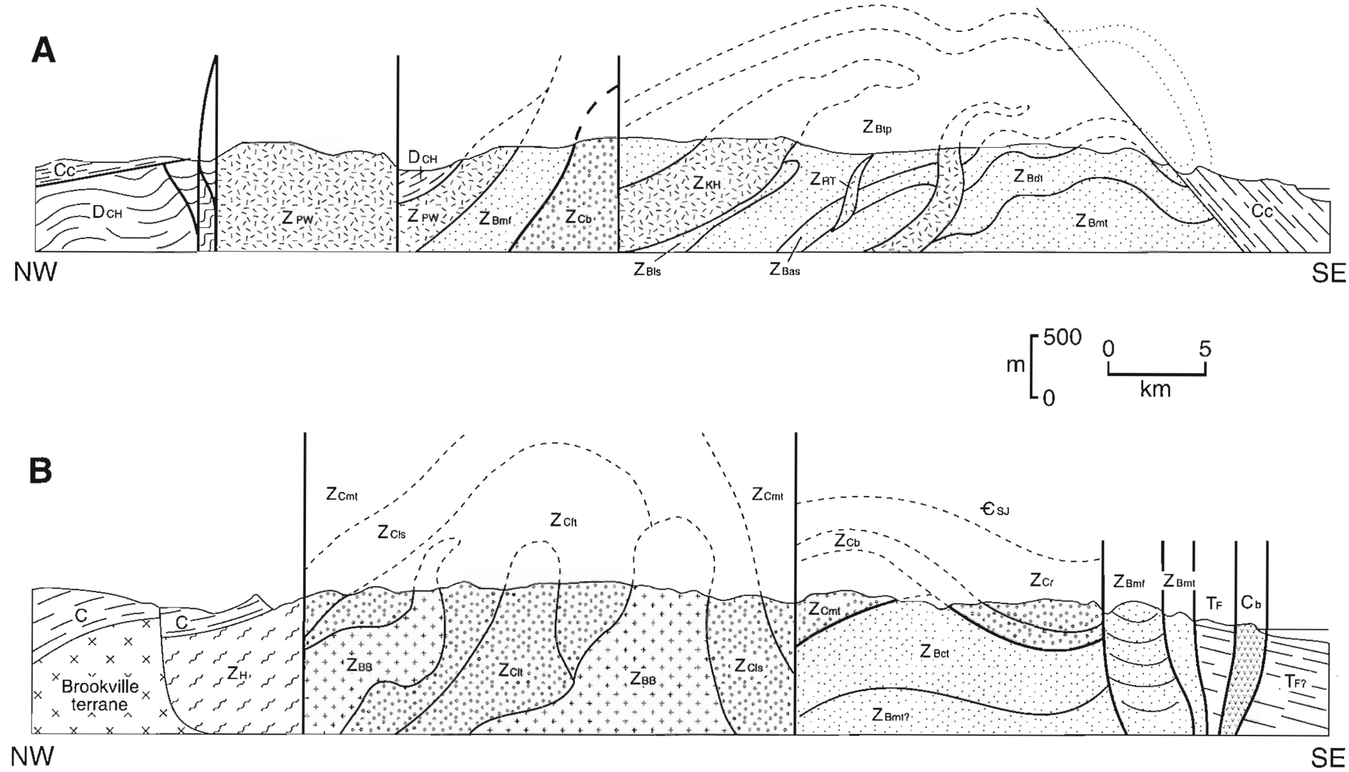

*Figure 54. Northwest to southeast cross-sections along lines **A** and **B** as shown on Figures 50-53. Unit designations as on Figures 3, 9, 15, and 16 and Open File 3615.*

Tectonic interpretation and implications

Introduction

Previous interpretations of the structural evolution of the Caledonian Highlands were based on limited Rb-Sr and K-Ar whole-rock analyses (e.g. Ruitenberg et al., 1973, 1979). As a result, most of the volcanic and associated sedimentary rocks were considered to be part of single Late Precambrian suite intruded by Ordovician and Carboniferous plutons. In this framework, rocks in the Caledonian Highlands were considered to have been mildly deformed during the Acadian Orogeny (Middle Devonian), but a younger (Early Carboniferous), more intense deformation was interpreted to have been responsible for the majority of the structures. The younger event formed a belt of intense penetrative deformation along the Bay of Fundy, referred to as the Fundy Cataclastic Zone (e.g. Ruitenberg et al., 1973; 1979). This belt coincides with the Cape Spencer area, Broad River Group, and subdomains IVA and IVB of the Coldbrook Group of this study.

As a result of this study, a much different and more complex interpretation of the structural features of the Caledonian Highlands has emerged. Crystallization ages for the plutonic and volcanic rocks of the Caledonian Highlands, combined with overprinting structural relationships described above, provide time constraints on deformation and metamorphism (Fig. 55). In addition, the latest Devonian and Carboniferous sedimentary rocks that flank the highlands constrain the minimum age of regional deformation and metamorphism, as they have been folded and faulted, but show no evidence of penetrative deformation and metamorphism, and contain numerous strongly deformed clasts derived from the highlands (C. St. Peter, pers. comm., 1995).

Neoproterozoic events

Volcanic rocks of the Broad River Group yielded U-Pb (zircon) ages that range from ca. 618 to 600 Ma, and the spatially associated plutons have ages of ca. 625 to 615 Ma (Table 1; Fig. 55). Parts of the Broad River Group preserve evidence for contact metamorphism associated with the ca. 620 Ma plutons. The main regional metamorphism (M_{B1}) and penetrative deformation (D_{B1}) in the Broad River Group were synchronous with the development of a regional isoclinal recumbent fold (F_{B1}). Apparently related to this folding event were zones of mylonitization and a late folding event (D_{B2}) that resulted in asymmetric folds (F_{B2}). These events appear to have predated deposition of the ca. 560-550 Ma Coldbrook Group, much of which (domain III) is unmetamorphosed and relatively undeformed.

The Hammondvale metamorphic suite yielded $^{40}Ar/^{39}Ar$ muscovite cooling ages of ca. 617-603 Ma (White, 1995) that indicate a minimum age for regional high-pressure/low-temperature metamorphism and deformation in this unit. However, the relationship of this unit to the other units of the Caledonian Highlands is not clear. The muscovite ages are similar to ages obtained from detrital muscovite from the

Saint John Group (Dallmeyer and Nance, 1990), suggesting that the Hammondvale metamorphic suite may have been a source for muscovite in the Saint John Group. However, where presently exposed, the suite lacks quartzite and hence does not appear to be a source for the quartzite pebbles in various conglomeratic units in the Caledonian Highlands.

Early to Middle Paleozoic events

The ca. 560-550 Ma Coldbrook Group (domain III) and the overlying Cambrian to Lower Ordovician Saint John Group appear to have been folded together in event D_{C3-1}. The timing of this event is poorly constrained, but occurred prior to the deposition of the unconformably overlying Late Devonian to Carboniferous Horton Group. Age spectra for detrital muscovite from the lower part of the Saint John Group display lower temperature increments that yield ages of ca. 400 Ma, interpreted by Dallmeyer and Nance (1990) to reflect a low-grade thermal overprint. This interpretation is consistent with the presence of a penetrative regional cleavage in these samples; detrital muscovite grains have been rotated into alignment with this fabric. The ca. 400 Ma age is considered to indicate the minimum age of D_{C3-1} deformation in domain III of the Coldbrook Group.

Other parts of the Coldbrook Group that occur in close association with the Broad River Group (subdomains IVA and IVB) display a completely different style of deformation. The main deformation in these subdomains (D_{C4-1}) was accompanied by regional chlorite-grade metamorphism associated with a penetrative foliation similar in orientation to that in the adjacent and presumably underlying Broad River Group, suggesting that these units were deformed and metamorphosed together (i.e. events D_{B3} and M_{B2} are the same as D_{C4-1} and M_{C4-1}, respectively). The age of this event may have been Silurian, based on $^{40}Ar/^{39}Ar$ whole-rock ages of ca. 430-410 Ma for phyllite samples from the Broad River Group in this area (Dallmeyer and Nance, 1994). Although Ordovician (ca. 460 Ma) and Devonian (ca. 370 Ma) volcanic activity occurred in the highlands (Table 1), it appears to have been spatially restricted and probably did not provide enough heat to reset the argon system.

The ca. 430-410 Ma muscovite cooling ages in the Broad River Group are fairly similar to the low-temperature ages of ca. 400 Ma obtained by Dallmeyer and Nance (1990) for detrital muscovite from the Saint John Group, as noted above. Hence the deformation in the Saint John and Coldbrook groups in domain III (D_{C3-1}) may have been approximately coeval with and related to the more major events in domain IV. However, the difference in intensity of deformation and metamorphism between the two areas suggests that they were not spatially close at that time.

Along the Bay of Fundy coast, the regionally folded foliation patterns in the Broad River Group (D_{B4} in domain II) are identical to those in the Coldbrook Group (D_{C4-3} in subdomain IVA). This similarity suggests that, after chlorite-grade metamorphism, these areas were deformed together. Because this was not a fabric-producing event, the muscovite ages were not reset. This event occurred after ca. 400 Ma but

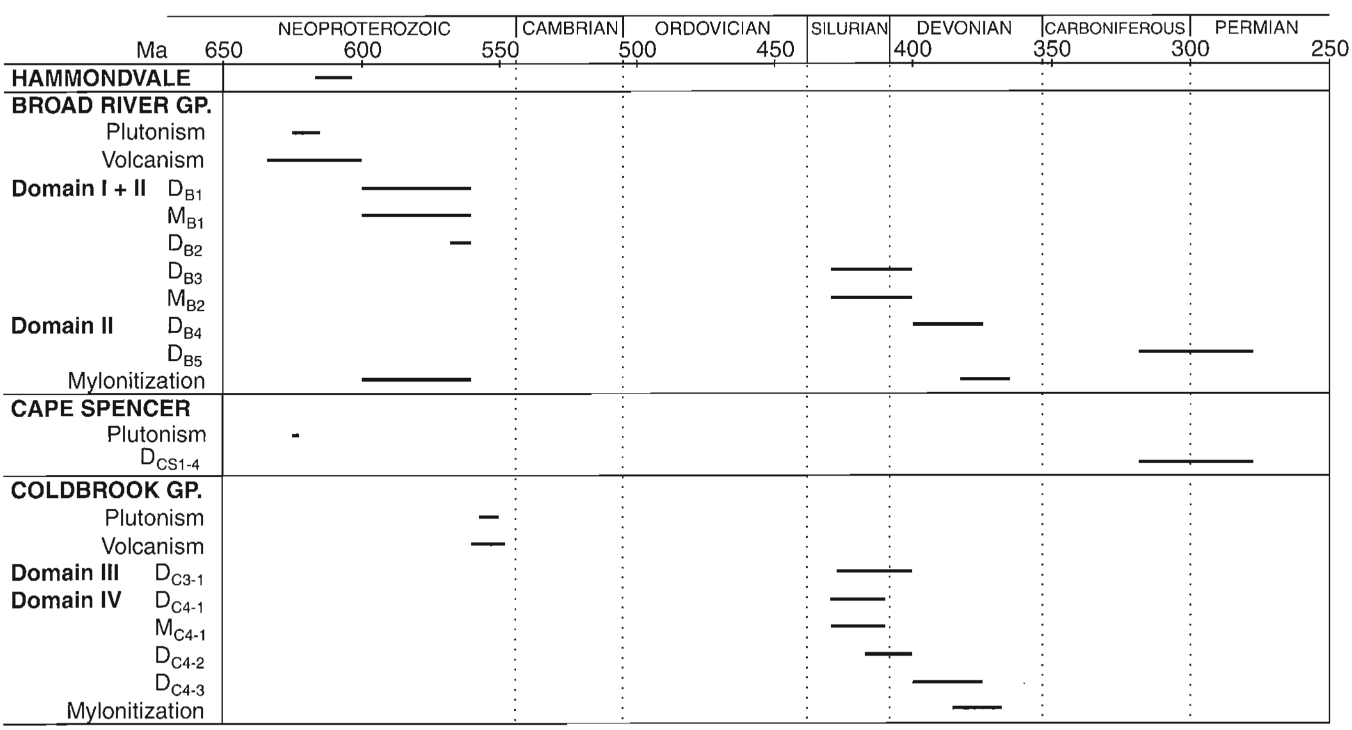

Figure 55. Time-space diagram for Neoproterozoic units in the Caledonian Highlands, showing inferred timing of igneous, deformational, and metamorphic events, as discussed in the text.

probably before ca. 375 Ma, because the folds are crosscut by late Middle Paleozoic mylonites (*see* below), and may have been related to the juxtaposition of the Meguma terrane with the 'Avalon' terrane along the Cobequid–Chedabucto Fault.

Late Middle Paleozoic mylonitization

Mylonitization, evidence for which is observed throughout most of subdomain IVB of the Coldbrook Group and domain I of the Broad River Group, appears to have occurred after chlorite-grade metamorphism and the regional $D_{B4}/D_{C4\text{-}3}$ folding event. This is largely based on their overprinting of D_{B4} and $D_{C4\text{-}3}$ fabrics and the preservation of many primary textures within the mylonite zones. The oldest rocks that overlie some of these mylonite zones are part of the Visean Windsor Group (ca. 350 Ma). The age of the mylonite is interpreted to be broadly similar to the inception age of the Maritimes Basin, in particular deposition of the Horton Group in the Moncton Subbasin (cf. St. Peter, 1993). The Moncton Subbasin is interpreted to have opened in a dextral oblique to strike-slip environment, although much of the kinematic evidence on the faults at the initial basin margins have been obliterated by multiple later displacements (St. Peter, 1993). Limited evidence from mylonite zones in the Broad River and Coldbrook groups indicates a dextral oblique to strike-slip sense of movement (e.g. Moroz, 1994), supporting the interpretation of St. Peter (1993).

Late Paleozoic thrusting

Volcanic and associated granitic rocks in the Cape Spencer area are similar to units in the Broad River Group, and a granitic pluton from this area has been dated at ca. 623 Ma (Watters, 1993b) confirming this comparison. Associated with these older rocks are the Cambrian Cape Spencer Formation (McLeod et al., 1994) and the lower Westphalian (ca. 315 Ma) Balls Lake and Lancaster formations, which are interpreted to unconformably overlie the older units (Watters, 1993b).

The main regional deformation (D_{CS1}) and metamorphism (M_{CS1}) affected all the rocks exposed in the Cape Spencer area, and can be traced southwest of Saint John where it also affected rocks as young as Westphalian (Nance, 1987b; White, 1995). This is confirmed by $^{40}Ar/^{39}Ar$ muscovite and illite cooling ages of ca. 318-277 Ma (Dallmeyer and Nance, 1990; Watters, 1993b). Deformation in this area is directly related to movement on the Avalon–Meguma terrane boundary. Movement on this boundary was right-lateral on mainland Nova Scotia (Mawer and White, 1987; Keppie and Dallmeyer, 1987) and probably dextral reverse with northwestward-directed thrusting where it curves southwestward in the Bay of Fundy (Nance, 1987b). Hornblende from veins in granulite-mylonite blocks in megabreccia associated with the Cobequid Fault in Nova Scotia have yielded ca. 335 Ma cooling ages and these blocks occur as clasts in the overlying Riversdale Group that postdates ca. 315-310 Ma (Gibbons et al., 1996). These observations suggest that right-lateral deformation associated with the terrane boundary in Nova Scotia was broadly synchronous with thrusting in southern New Brunswick.

Late kink folds in the Broad River Group (D_{B5}; Fig. 55) may also be related to this thrusting event (D_{CS1}).

In the Cape Spencer area, effects of earlier (pre-D_{CS1}) deformation are evident only in the Precambrian igneous units, where mylonitic textures are locally preserved. Also, clasts of similar mylonitic granitoid lithologies occur in Westphalian conglomerates, the matrix of which display D_{CS1} fabrics (Watters, 1993b). This earlier deformation may have been related to the late Middle Paleozoic mylonitization in the Broad River and Coldbrook groups.

Late Paleozoic brittle faults

Brittle faults in the Caledonian Highlands are typically long, linear features and only a minimum number are shown on Open File 3615; they are drawn only where direct evidence for their presence, such as fault gouge, was observed. Faults are concentrated at formation boundaries and are commonly vertical. Although displacement indicators were not usually observed, based on slickensides and offset features, both dip-slip and strike-slip motions have occurred, but it is not clear if these motions were of the same age or had a range of ages.

As in the Cape Spencer area, these brittle northeast-trending faults are interpreted to be related to juxtaposition of the Meguma terrane with the Avalon terrane (cf. St. Peters, 1993). Extension that accompanied the Triassic–Jurassic opening of the present Atlantic Ocean probably reactivated many northeast-trending faults as normal dip-slip faults with downthrow displacement to the southeast, and new southwest-trending faults were formed (e.g. Roberts and Williams, 1993; Watters, 1993b).

ECONOMIC GEOLOGY

Introduction

A variety of mineral showings and deposits in the Caledonian Highlands were described previously by Ruitenberg et al. (1979), and additional information is available in assessment files of the New Brunswick Department of Natural Resources. Although examination of mineral occurrences was beyond the scope of this project, the petrological and structural information presented in this report make it clear that the Caledonian Highlands is a geologically complex area that has not yet received the level of basic geological investigation and mineral exploration that is warranted by its economic potential. Specific examples of and evidence for this potential are described below.

Base-Metal Sulphides

The most well known sulphide deposits in the Caledonian Highlands are Teahan and Lumsden, which were interpreted by Ruitenberg et al. (1979) as deformed stratiform pyrite-copper-zinc-lead sulphide deposits. The Broad River Group hosts both of these deposits, as well as most other occurrences such as those in the Quiddy River and Goose Creek areas described by Ruitenberg et al. (1979), and also by McLeod (1987). Moroz (1994) completed a study of the Teahan and Lumsden deposits, including ore petrology and fluid inclusions. He found that mineralization in both deposits is dominated by pyrite, low-iron sphalerite, and chalcopyrite. In addition, the Teahan deposit contains minor galena, silver telluride, and electrum, and the Lumsden samples contain minor enargite. He suggested that the Teahan deposit is located in a major shear zone, and is a vein-type deposit, a model which may also be applicable to the Lumsden deposit. Moroz (1994) suggested that these deposits may be similar in origin to the Cape Spencer deposits (e.g. Watters, 1993b).

This study draws attention to the previously unrecognized large extent of the Teahan unit (unit Btp of the Broad River Group), and also to the favourable tectonomagmatic setting of both the Broad River and Coldbrook groups for base-metal and gold deposits; i.e, a volcanic-arc setting with voluminous felsic volcanic and interlayered sedimentary rocks. Scattered high metal values in representative samples from a variety of units selected for analysis as part of this project are evidence for mineralization potential. The abundance and wide distribution (mainly in the Broad River Group) of pyrite-rich felsite units (especially in map units Bdt and Bmf) are particularly encouraging. Associated, relatively high-level plutonic rocks, with a wide range in compositions from gabbroic through very felsic, are also favourable exploration targets. These favourable lithological units have been subjected to major shearing and deformation, both ductile and brittle, providing major opportunities for redistribution and concentration of metals; for example, in the veins described by McLeod (1987) and the gold deposit in the Cape Spencer area described by Watters (1993b).

Mineralization potential in gabbroic and ultramafic plutons

An important development that highlighted the economic potential in the Caledonian Highlands was the recognition of the Mechanic Settlement Pluton as a layered mafic-ultramafic intrusion with potential for PGE and Ni-Cr mineralization (Paktunc 1988, 1989a, b; Wells 1992). Paktunc (1989a) described platinum-group element (PGE) and sulphide minerals in feldspathic peridotite and olivine gabbronorite. PGE minerals reported were vysotskite ((Pd,Ni)S), merenskyite ((Pd,Pt) $(Te,Bi)_2$), michenerite ((Pd,Pt)BiTe), sperrylite ($PtAs_2$), stillwaterite (Pd_8As_3), and hollingworthite ((Rh,Pt,Pd)AsS; electrum (AuAg) and native gold were also reported, as well as chalcopyrite, pyrrhotite, and pentlandite. Although Wells (1992) assessed the pluton as subeconomic in terms of these components, relatively little of the pluton is exposed, and it may be more extensive under Carboniferous cover to the north (Nickerson, 1994).

The Caledonia Brook pluton is also a layered gabbroic body with some petrological similarities to the Mechanic Settlement Pluton. As a result of his petrological studies, Blackwood (1991) concluded that the part of the pluton now exposed has low levels of platinum-group elements and base metals. However, he suggested that an early sulphide segregation from the magma may be responsible for these low values, and hence that economic concentrations of these elements may be present at deeper levels.

Similar, smaller gabbroic bodies are widespread in the Caledonian Highlands, the largest other body being the Devine Corner Gabbro. The wide distribution of these units, and the anomalous values of Ni and Cr found in many of the mafic samples (both plutonic and volcanic) analyzed during this project, show potential for significant Ni-Cr-Cu-PGE mineralization in the Caledonian Highlands.

TECTONIC SETTING

Comparison with previous interpretations of tectonic setting

On the basis of chemical data from mainly two areas in the Caledonian Highlands, Dostal and McCutcheon (1990) suggested that the rocks formed above a northwest-dipping subduction zone, which they assumed to have an age of 630-600 Ma. Their 'central belt' samples appear to be from basaltic units in the upper Coldbrook Group and, like samples from those units analyzed as part of this study, plot rather ambiguously in overlapping calc-alkalic basalt/island-arc tholeiitic basalt/mid-ocean-ridge basalt fields on most tectonic setting discrimination diagrams. The 'eastern belt' samples of Dostal and McCutcheon (1990) are mainly from a small area in the Broad River Group (Lower Quiddy River) and do not appear to be representative of the group as a whole. Dostal and McCutcheon (1990), and subsequently Keppie and Dostal (1991), used these data to suggest a zonation in the volcanic rocks of the Caledonian Highlands, resulting from a northwest-dipping subduction zone. However, the model did not take into account the different ages of the rocks used in the study, and in the case of the 'eastern belt', are not representative of the belt. Hence, this model for tectonomagmatic evolution is no longer viable.

Based on their chemical data, Currie and Eby (1990) interpreted the Coldbrook Group to have formed in a subduction-related ensialic arc. Their data are mainly from units here included in the lower part of the ca. 560-550 Ma Coldbrook Group, with some samples from the upper basalt and rhyolite units. None of their samples are from the Broad River Group, although Currie and Eby (1990) assumed their samples to be representative of ca. 620 Ma volcanism in the Caledonian Highlands. This assumption led them to compare their data to other ca. 620 Ma volcanic units in the Avalon terrane, such as the Harbour Main Group of Newfoundland and the Jeffers Group of the Cobequid Highlands, a comparison that now appears to be inappropriate. However, the data of Currie and Eby (1990) constitute an important component of the chemical database for the newly defined Coldbrook Group.

Previously, McLeod (1987) recognized contrasts in chemical composition between the eastern and central parts of his Big Salmon River–Goose River map area, which approximately coincide with the Broad River and Coldbrook groups of this study. Using mainly major-element data, he suggested that the difference may be related to contrasting calc-alkalic and continental tholeiitic character. In the area to the north and east, on the basis of some of the data presented here, Barr and White (1988c) interpreted the Broad River Group (their 'sequence A'), and associated plutons, to have formed in a continental-margin arc setting, whereas the Coldbrook Group (their 'sequence B'), and associated plutons, formed during subsequent extension within the older subduction zone complex. These preliminary interpretations are consistent with the larger database presented here, although ambiguity remains with respect to the tectonic setting of the Coldbrook Group.

Magmatic evolution and tectonic model

Petrochemical features of the Broad River Group and associated ca. 620 Ma plutonic rocks are consistently indicative of origin in a continental-margin magmatic arc (Fig. 56a). In contrast to previous suggestions (e.g. Dostal and McCutcheon, 1990), no reliable evidence has been found to indicate arc polarity. The apparent interlayering of coarse, quartz-rich sedimentary layers with the volcanic units indicates that older crustal rocks were exposed to erosion during the evolution of the arc, and the abundance of intermediate and felsic rocks suggests the presence of thick continental crust. These volcanic-arc rocks were regionally metamorphosed at low grade (greenschist facies) and deformed, presumably due to continued subduction and possibly collision, prior to formation of the Coldbrook Group and associated plutons at 560-550 Ma. Some evidence from U-Pb dating (Bevier and Barr, 1990) suggests that volcanism may have continued in the Broad River Group, at least locally, to ca. 600 Ma, but there is no evidence that it continued beyond that time. It, therefore, appears likely that there was a hiatus in igneous activity between 600 and 560 Ma in the part of the Avalon terrane preserved in the Caledonian Highlands. The reason for the cessation of subduction by 600 Ma is unclear. Collision with the now-adjacent Brookville terrane is unlikely because there is little evidence in the Brookville terrane for such an event (White and Barr, 1996). However, collision with another Avalonian area (perhaps now represented by the Hammondvale metamorphic suite) is an alternative possibility.

No compelling evidence was found to suggest that the Coldbrook Group represents a volcanic-arc complex. It appears more likely that the older, ca. 620 Ma arc complex was undergoing extension by 560 Ma when the rocks of the lower Coldbrook Group were formed. Alternatively, this volcanism may have occurred in an area juxtaposed against the Broad River Group by collision and/or transcurrent faulting (Fig. 56b). This model is consistent with a transtensional environment for the ca. 560 Ma volcanism, debris flows, and sedimentation, in a subaerial setting. By 550 Ma, however, the two areas were juxtaposed, with rifting in the Broad River Group, as well as the older parts of the Coldbrook Group itself (Fig. 56c). Rifting was accompanied by bimodal volcanism and plutonism, as well as continental-type (fluvial) sedimentation. Continued rifting and subsidence resulted in marine deposition in the Cambrian, as documented, for example, by Tanoli and Pickerill (1988).

Subsequent igneous activity in the Caledonia terrane was apparently minor, and formed only small areas of dacitic tuff in the Ordovician, rhyolite in the Devonian, and possibly basalt in the Carboniferous (Barr et al., 1994). Deformation was mainly related to transcurrent faulting, and produced major mylonite and protomylonite zones through the central highlands, as described in the section titled 'Deformation and Metamorphism'. These movements may be reflected in the Silurian–Devonian thermal disturbance in the Broad River Group detected by Dallmeyer and Nance (1994), and may have been related to juxtaposition with other terranes (such as Brookville) to the northwest. Toward the coast, the rocks show shearing and mylonitization apparently related to Carboniferous interaction with the Meguma terrane to the southeast (e.g. Nance, 1987b). None of the faulting appears to have

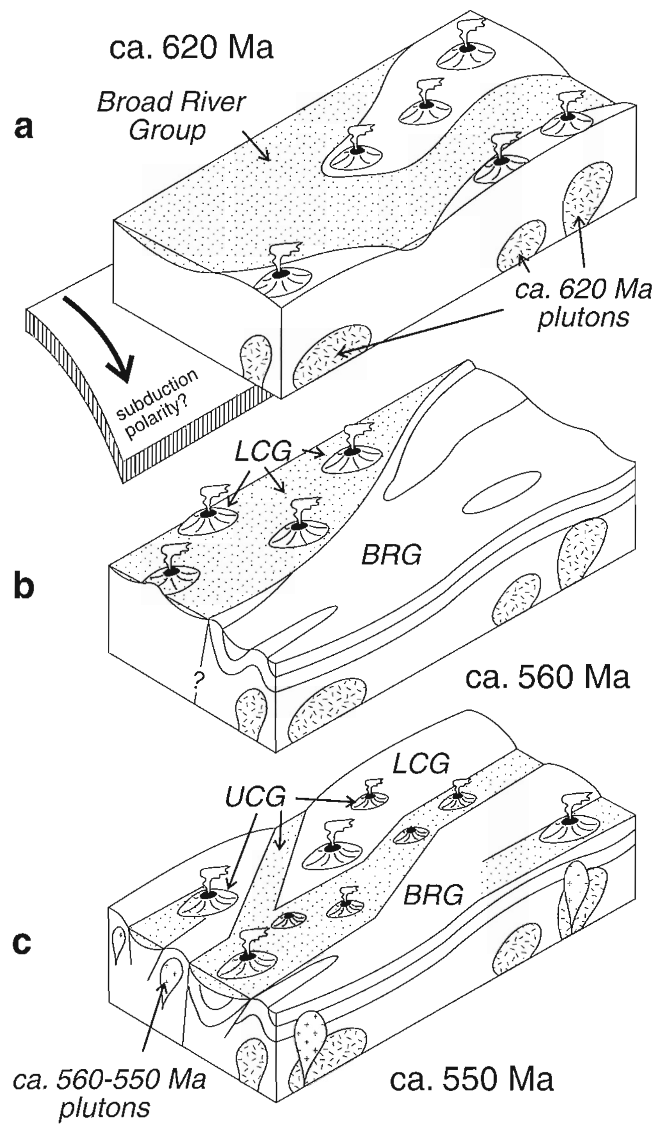

Figure 56. A possible model for Late Neoproterozoic tectonic evolution in the Caledonian Highlands; see text for discussion. LCG, lower Coldbrook Group; UCG, upper Coldbrook Group; BRG, Broad River Group.

had significant vertical motion because there is little variation in the level of erosion across the highlands. An exception is the Hammondvale metamorphic suite, composed of high-pressure rocks that may represent part of the infrastructure of the Caledonia terrane.

Regional comparisons

The Broad River Group and associated plutons have time-correlative units throughout the Avalon terrane, and are typical of the Late Precambrian magmatism considered characteristic of Avalon. In the eastern part of the Avalon terrane in Newfoundland, dates of ca. 630-600 Ma are reported from volcanic rocks of the Harbour Main Group and associated Holyrood Pluton (Krogh et al., 1988). Farther west, similar ages have been reported from other volcanic and plutonic units (O'Brien et al., 1996; Barr and Kerr, 1997).

In the Mira terrane of southeastern Cape Breton Island, ca. 620 Ma volcanic and plutonic rocks occur in the East Bay Hills, Coxheath Hills, and Sporting Mountain belts (Bevier et al., 1993; Barr et al. 1996). Like the Broad River Group, they are calc-alkalic and formed in a continental-margin subduction zone, interpreted to dip to the southeast (Barr, 1993; Barr et al. 1996).

In northern mainland Nova Scotia, volcanic and plutonic rocks in the Antigonish and Cobequid highlands may be similar in age to the Broad River Group, although reported ages are mainly younger at ca. 618-605 Ma (Doig et al., 1991; Murphy et al., 1992b). Also, the rocks are not so clearly indicative of a volcanic-arc setting, with characteristics ranging from within-plate tholeiitic to calc-alkalic (Murphy et al., 1992b).

The ca. 560-550 Ma Coldbrook Group and associated plutons appear to be somewhat unique in the Avalon terrane, at least in the northern Appalachian Orogen. Although units of similar age occur in the Avalon terrane in Newfoundland, they are mainly alkaline to peralkaline (O'Brien et al., 1996), unlike the Coldbrook Group. The Coldbrook Group appears to be somewhat younger than units of the Fourchu and Main-à-Dieu groups in the Coastal belt of southeastern Cape Breton Island (Bevier et al., 1993), although parts of the Main-à-Dieu Group are lithologically similar to the Coldbrook Group, and both units may represent rocks formed during postsubduction extension. In contrast, the petrochemical characteristics of the Fourchu Group suggest that it was formed during subduction at ca. 575 Ma (Barr, 1993; Barr et al., 1996).

The presence of volcanic and plutonic rocks with ages of ca. 560-550 Ma have not yet been confirmed by U-Pb dating in northern mainland Nova Scotia or the Boston area. Thus it appears that the latest Precambrian tectonomagmatic evolution in the Avalon terrane may have been much more variable than either the earlier history, or the subsequent Cambrian history which appears to have been markedly uniform throughout the terrane (e.g. Landing, 1996a).

The tectonic evolution and regional correlations of the Caledonia terrane are important for exploration models in the Caledonian Highlands. Base-metal deposits (e.g. Teahan, Lumsden) in the Caledonian Highlands have generally been compared with the Stirling deposit in southeastern Cape Breton Island (e.g. Ruitenberg et al., 1979); however, the results of our study indicate that these deposits are not similar in age, tectonic setting, or metallogeny (Moroz, 1994), and that different exploration models should be applied in the Caledonian Highlands.

CONCLUDING STATEMENT

Previous interpretations of the geology of the Caledonian Highlands were based on the assumption that variations in rock type are the result of internal variations in environment in a volcanic-arc setting, combined with variably intense localized and regional deformation. Recognition that the volcanic and sedimentary rocks in the Caledonian Highlands do not belong to a single stratigraphic assemblage is a major advance in the understanding the geological evolution of the area. Nevertheless, many problems and inconsistencies remain in the interpretations presented here. They may best be resolved by detailed investigations in specific areas within the overall framework established by the present project.

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APPENDIX A
Terminology

Volcanic and sedimentary rocks

Various classification schemes and terminology are used for volcanic rocks (e.g. Schmid 1981; Fisher and Schmincke, 1984; Cas and Wright, 1987). For the volcanic and volcaniclastic rocks of the Caledonian Highlands, any genetic classification is difficult to apply consistently because of the degree of deformation in many samples. In the case of flows, general compositional terms (e.g. basalt, andesite, dacite, rhyolite) are used, based on modal mineralogy and chemical composition, if available. For volcaniclastic rocks, a descriptive classification based on grain size of pyroclasts (e.g. lapilli, ash) is used in naming rocks, following Schmid (1981). The nature of the pyroclasts is indicated by the modifiers 'crystal' or 'lithic'. As for flows, compositional terms (e.g. basaltic) are used as modifiers, based on modal mineralogy and chemical composition, if available.

Rocks of mixed pyroclastic and epiclastic character are indicated by the modifier 'tuffaceous', as recommended by Schmid (1981). Epiclastic rocks are named according to the sedimentary rock nomenclature (e.g. Ehlers and Blatt, 1982).

Plutonic rocks

Plutonic rocks are named on the basis of modal mineralogy using the classification of Streckeisen (1976).

APPENDIX B

Petrographic descriptions

Introduction

This appendix provides brief petrographic descriptions of samples for which chemical analyses are listed in Appendix C. Hence, they are reasonably representative of igneous rocks of the Caledonian Highlands. The samples are listed by map unit, in the same sequence as in the chemical data tables of Appendix C. Descriptions for samples from Currie and Eby (1990) are taken from Table A1 (Currie and Eby, 1990, p. 1430). Samples from Dostal and McCutcheon (1990) do not include petrographic descriptions; however, as noted by Dostal and McCutcheon (1990, p. 86), all of the samples are mafic, and have recrystallized to greenschist or subgreenschist mineral assemblages. Some samples contain relict subophitic and porphyritic textures, and a few contain relict clinopyroxene. They are composed mainly of actinolite, chlorite, epidote, and sodic plagioclase, with minor amounts of quartz, iron-titanium oxides, titanite, and carbonate minerals.

NTS coordinates (easting, northing) are given in parentheses, except for samples from Dostal and McCutcheon (1990), Currie and Eby (1990), Grammatikopoulos (1992), and Moroz (1994). Approximate sample locations are shown on Figures 3, 9, 15, and 16.

Abbreviations used are as follows: f.g., fine grained; m.g., medium grained; c.g., coarse grained; hyp., hypidiomorphic; allot., allotriomorphic; gran., granular; plag, plagioclase; opx, orthopyroxene; cpx, clinopyroxene.

The petrographic terms used below are in accordance with the definitions in Bates and Jackson (1980). The term saussurite is used very broadly to describe typically fine-grained polymineralic mixtures (mainly albite, epidote, sericite, clay minerals, and carbonate) that have replaced or partly replaced plagioclase.

B.1 Broad River Group

Unit Bls

8155 - (365705, 5078773); laminated tuff; sparse plagioclase and quartz clasts in a very f.g. well layered groundmass of quartz, feldspar, epidote, chlorite, and biotite

8179 - (366857, 5078779); felsic crystal tuff; feldspar and embayed quartz crystals in a f.g. strongly foliated groundmass of quartz, feldspar, epidote, chlorite, and sericite

8861 - (357435, 5071638); mafic tuff; mylonitic; abundant chlorite, epidote; pyrite stringers

8873 - (359737, 5075419); crystal tuff; well foliated; quartz and feldspar clasts in a very f.g. sericite-rich groundmass

8943 - (366768, 5082045); andesitic crystal tuff; quartz and feldspar porphyroblasts in a f.g. well foliated groundmass with abundant chlorite and sericite

8948 - (365892, 5079662); dacitic to rhyolitic crystal tuff; scattered quartz and plagioclase crystals in a cryptocrystalline felsic groundmass with abundant sericite

RM297 - felsic ash tuff; cryptocrystalline, abundant epidote and sericite

RM298 - basalt; very f.g.; abundant epidote; amygdules filled by epidote and chlorite

RM301 - mafic, lithic lapilli tuff; amygdaloidal basaltic clasts; abundant epidote and chlorite

Unit Btp

044 - (341973, 5058914); andesitic tuff; f.g.- m.g. plagioclase crystals with interstitial chlorite and epidote

8112 - (349797, 5065750); chloritic schist/andesitic lithic crystal-lapilli metatuff; f.g. well foliated; flattened cavities may have been amygdules; scattered plagioclase phenocrysts and rare relict embayed quartz; elongate recrystallized intermediate to felsic lithic lapilli

RM33 - mafic crystal tuff; f.g.-m.g. plagioclase crystals in a mixture of chlorite, epidote, actinolite, and minor quartz

RM62 - felsic ash tuff; foliated f.g. to cryptocrystalline mixture of feldspar, quartz, epidote, and chlorite

RM73 - mafic tuff; f.g. to cryptocrystalline mixture of plagioclase, chlorite, epidote, and unidentifiable material

RM78 - dacitic crystal tuff; crystals of embayed quartz, amphibole, and altered plagioclase in a f.g. to cryptocrystalline groundmass of epidote, chlorite, amphibole, and feldspar

RM84 - mafic, lithic lapilli tuff; varied basaltic and andesitic lapilli; abundant actinolite, chlorite, epidote, and cryptocrystalline material

RM85 - (345596, 5064056); dacitic crystal tuff; abundant crystals of quartz and feldspar in a f.g. felsic groundmass with abundant epidote and some chlorite

RM106 - andesitic, crystal lithic tuff; abundant plagioclase, amphibole, and andesitic lithic fragments in a f.g. altered groundmass

RM108 - dacitic, lithic crystal tuff; mainly plagioclase, quartz, amphibole crystals in a f.g. foliated groundmass with abundant chlorite and epidote; scattered dacitic lithic lapilli; cavities with prehnite and pumpellyite

RM114 - mafic crystal tuff; f.g., foliated; plagioclase, actinolite, chlorite, epidote, and prehnite

RM121 - mafic crystal tuff; f.g., foliated; plagioclase, quartz, chlorite, and epidote

RM124 - felsic crystal tuff; crystals of quartz and feldspar in a f.g. foliated groundmass with abundant carbonate stringers, chlorite, epidote, quartz, and feldspar

RM131 - felsic tuff; f.g. to cryptocrystalline quartz and feldspar ribbons; scattered plagioclase crystals; abundant carbonate

RM133 - mafic crystal tuff; f.g. foliated plagioclase, quartz, actinolite, chlorite, epidote, and carbonate

RM152 - basalt; f.g. foliated mixture of plagioclase, epidote, chlorite, carbonate, quartz

RM162 - (348690, 5064697); dacitic crystal tuff; plagioclase and quartz crystals in a f.g. foliated groundmass of epidote, chlorite, and carbonate

RM174 - crystal tuff/arkose; layered; f.g. quartz and feldspar crystals in a f.g. foliated groundmass of actinolite, epidote, and chlorite.

RM176 - crystal tuff/arkose; similar to RM174 but finer grained

RM179 - crystal tuff; similar to RM176 but crenulated as well as foliated, and with abundant carbonate lenses and stringers

RM206A - basalt or basaltic tuff; f.g. intergranular with plagioclase crystals in a foliated groundmass of actinolite, epidote, chlorite, and prehnite

RM219 - mafic, crystal lithic tuff

Unit Bdt

035 - (344236, 5052351); felsic crystal tuff; scattered feldspar crystals in a microcrystalline felsic groundmass; scattered felsic lithic lapilli; moderately intense alteration (sericite, epidote)

080 - (347841, 5055412); felsic crystal tuff; lapilli of quartz, K-feldspar, and plagioclase (locally with granophyric rims) in a cryptocrystalline groundmass with sericitic stringers

566 - (345778, 5057611); felsic lithic tuff; rhyolitic clasts and matrix; abundant epidote and sericite; could be autobreccia

573 - (345694, 5055282); felsic lithic tuff; sparse rounded dacitic and rhyolitic clasts in a sericitized ash groundmass; scattered iron oxides

600 - (340977, 5050218); rhyolite; flow-banded; abundant feldspar and smaller quartz crystals in a f.g. sericitic (originally felsic ash) groundmass

8803 - (353408, 5060813); basaltic andesite; f.g. intergranular; saussuritized plagioclase surrounded by chlorite/epidote groundmass; minor quartz

8808 - (354433, 5060028); dacitic, lithic crystal lapilli tuff; abundant plagioclase crystals; well foliated; secondary epidote and chlorite

8838 - (351751, 5056949); andesitic, crystal lapilli tuff; abundant plagioclase crystals (intensely saussuritized) in a groundmass of chlorite, epidote, and cryptocrystalline secondary minerals

Unit Bdtb (basaltic lenses/layers in unit Bdt and BSS)

085 - (343563, 5050198); basalt; f.g. pilotaxitic; abundant chlorite, some carbonate and epidote; patches of abundant hematite

155C - (342467, 5049073); basalt/andesite; f.g. intergranular, with mafic minerals replaced by epidote and chlorite; epidote veinlets; abundant scattered hematite

182 - (346442, 5050221); basalt; f.g., intensely altered to saussurite, epidote, chlorite, and hematite

188 - (346398, 5050440); basalt; m.g. intergranular; similar to 182 but coarser grained

191 - (345297, 5049371); basalt; f.g. intergranular with flow-aligned plagioclase laths, interstitial chlorite, and abundant opaque minerals; amygdules filled with epidote and albite; veinlets of epidote and albite

577A - (345995, 5054239); metabasalt; relict f.g. intergranular texture; plagioclase laths intergrown with mainly chlorite, epidote, and carbonate

578B - (346028, 5054345); metabasalt lithic tuff; basaltic clasts in a basaltic groundmass of plagioclase phenocrysts and laths, chlorite, and epidote; chlorite-filled amygdules; may be an autobreccia

603 - (340927, 5050471); metabasalt/andesite; f.g. cryptocrystalline groundmass with abundant chlorite and epidote; sparse flow-aligned plagioclase laths (microphenocrysts); abundant fine opaques (hematite)

1016 - (346698, 5053389); basalt; f.g. groundmass of plagioclase laths, chlorite, granular epidote, and scattered opaque minerals; flattened chlorite-filled amygdules

1377 - (347450, 5052672); basalt/andesite; f.g., flow-aligned plagioclase laths; intergranular epidote and chlorite

1378 - (347225, 5052258); basalt; f.g., massive 'greenstone'; very altered, with abundant epidote and chlorite, and sericitic veinlets

1712 - (347121, 5052227); basalt; f.g.intergranular and porphyritic, with abundant plagioclase phenocrysts; amygdules filled with epidote, carbonate, and feldspar

1835 - (337166, 5051679); andesite or andesitic crystal tuff; m.g. intergranular, porphyritic with abundant plagioclase phenocrysts; interstitial chlorite, epidote, and carbonate

Unit Bts

8845 - (359946, 5064283); andesitic to dacitic, crystal lithic lapilli tuff; abundant quartz and plagioclase clasts; minor mica clasts; abundant cryptocrystalline dacitic lapilli; well foliated groundmass contains abundant chlorite, epidote, and carbonate

Unit Bmf

006 - (339497, 5060145); andesitic flow(?); f.g. intergranular plagioclase with interstitial chlorite, carbonate, and epidote

1142A - (333525, 5053057); basaltic, lithic crystal lapilli tuff; plagioclase and plagioclase-rich lithic clasts in a f.g. groundmass with abundant chlorite, epidote, and carbonate

1343B - (341283, 5061762); basaltic tuff; cryptocrystalline with abundant epidote and chlorite; well foliated

1344A - (340470, 5062380); basalt; very f.g. intergranular with abundant chlorite and epidote; amygdules filled by epidote, chlorite, and albite

1754B - (338641,5065788); basalt; f.g. plagioclase and amphibole in intergranular texture; scattered amygdules with m.g. plagioclase and amphibole; scattered opaque grains; looks contact metamorphosed

4510 - (331063, 5048939); basalt; m.g. intergranular, with abundant relict clinopyroxene; may be a younger dyke?; moderately saussuritized plagioclase and abundant opaques

5008 - (326383, 5044464); mafic to intermediate crystal tuff; abundant plagioclase and mafic crystals (now chlorite + epidote) with minor quartz and K-feldspar crystals, and rare lithic clasts, in f.g. chlorite/feldspar/epidote matrix

5098 - (318731, 5036085); pillow basalt; f.g. altered intergranular, with abundant chlorite, epidote, and carbonate; amygdules filled with carbonate, quartz, and epidote; former pyroxene(?) phenocrysts replaced by epidote

5099 - (319409, 5036202); pillow basalt; f.g. altered intergranular, with abundant chlorite, epidote, and carbonate. Amygdules filled mainly with epidote; abundant carbonate in veins and interstices. Weakly foliated or sheared

8896 - (353078, 5077073); mafic tuff; sparse plagioclase crystals in a strongly foliated groundmass of feldspar, chlorite, epidote, and quartz

8899 - (352028, 5075672); mafic tuff; very f.g.; similar to 8896; epidote-rich

8913 - (350902, 5074526); crystal tuff; scattered quartz and plagioclase crystals in a f.g., strongly foliated groundmass of mainly quartz, muscovite, and epidote

8929 - (348567, 5072594); basaltic tuff; f.g. with abundant epidote and chlorite; cavities filled by epidote and carbonate; abundant albite and quartz

8959 - (361741, 5080806); mylonitic mafic tuff (epidote, chlorite, quartz ribbons, plagioclase, minor muscovite)

EB25 - basalt from Dostal and McCutcheon (1990)

Quiddy River section of unit Bmf

EB02, 06, 09, 11, 12, 15, 18, 19 - basalt (analyses from Dostal and McCutcheon, 1990)

Unit Bmt

1177B- (340429, 5044508); mafic tuff; f.g., well foliated; abundant chlorite, sericite, and quartz

8150 - (367827, 5075425); metatuff?; mixture of chlorite, quartz, carbonate, and albite; no relict igneous texture

8175 - (365601, 5072354); mafic metatuff or flow?; foliated; very altered; abundant epidote, chlorite, albite, and sericite

8904 - (363871, 5068800); basalt; m.g. intergranular; plagioclase with abundant interstitial epidote, chlorite, and carbonate; amygdules with carbonate and chlorite

8933 - (367218, 5073645); andesitic crystal tuff; m.g. plagioclase and epidote crystals in f.g. well foliated groundmass of plagioclase, chlorite, quartz, and epidote

Unit Bat

1691 - (329943, 5064388); mafic tuff or flow; f.g. intergranular; abundant plagioclase, chlorite, amphibole, biotite, and carbonate; may be contact metamorphosed

1751 - (333660, 5069701); andesitic tuff(?); f.g. equigranular quartz and feldspar, with abundant biotite, chlorite, epidote, and opaque minerals; may be contact metamorphosed

Unit Bdr

1122A - (337169, 5071896); dacitic tuff; scattered plagioclase crystals in f.g., well foliated groundmass of feldspar, quartz, chlorite, and epidote

Unit Bit

6158 - (277873, 5014244); andesitic crystal tuff?; very altered, with abundant chlorite, epidote, carbonate, polygonal quartz, and sericite; no relict igneous texture

B.2. Circa *620 Ma plutons*

Alma Pluton (Z_A)

024 - (343502, 5053911); diorite; m.g. hyp. granular; intensely saussuritized plagioclase and less altered amphibole, with abundant apatite and opaque minerals

029 - (345456, 5052797); quartz diorite; m.g. hyp. granular; intensely saussuritized plagioclase, chloritized amphibole/biotite, and minor interstitial quartz

034 - (343838, 5052292); quartz diorite; f.g.- m.g. hyp. granular; intensely saussuritized plagioclase and less altered amphibole; finer grained than 029, and with more mafic minerals, and more apatite

037 - (344523, 5052290); quartz diorite; like 029; very altered, abundant apatite and opaque grains

060 - (345612, 5056506); diorite; m.g. allot. gran.; cumulate-like texture of plagioclase with interstitial amphibole; abundant opaque phases and apatite

087 - (345013, 5049768); quartz diorite/tonalite; m.g. hyp. gran.; intensely saussuritized plagioclase and chloritized amphibole and biotite;

088 - (344623, 5050569); diorite; similar to 029, but contains more apatite and less quartz

176 - (345831, 5051654); tonalite; similar to 087

186 - (346518, 5050738); tonalite; similar to 087 and 176, but with more interstitial quartz

531 - (344926, 5055979); quartz diorite; m.g. hyp. gran.; intensely saussuritized plagioclase; relatively fresh hornblende, chloritized biotite; 15% interstitial quartz; scattered opaques; accessory apatite

572 - (345656, 5056204); tonalite; m.g. hyp. gran.; intensely saussuritized plagioclase; chloritized biotite; 30% interstitial quartz; scattered opaques; abundant epidote

Caledonia Brook Granodiorite (Z_{CB})

8071 - (363479, 5076540); biotite-hornblende granodiorite; m.g.-c.g. allot. gran.; plagioclase, amphibole, and biotite with interstitial quartz and K-feldspar; moderately intense alteration to saussurite, epidote, and chlorite

8072 - (363660, 5080130); biotite-hornblende granodiorite; similar to 8071

8882 - (362736, 5076483); biotite-hornblende granodiorite; similar to 8071 but more deformed, with interstitial aggregates of sutured quartz grains

8884 - (362277, 5077248); hornblende-biotite granodiorite; m.g. hyp. gran.; plagioclase, biotite, and amphibole with interstitial quartz and K-feldspar; abundant titanite; contains small enclaves of f.g. biotite-hornblende diorite

Caledonia Road Granitic Suite (Z_{CR})

8068 - (364019, 5073588); granite; m.g. deformed and recrystallized; perthitic alkali feldspar and plagioclase augen surrounded by f.g. quartz aggregates

8070 - (363542, 5076297); diorite; m.g. hyp. gran.; intensely saussuritized plagioclase; amphibole partly replaced by chlorite; abundant epidote

8141C- (364217, 5074562); granite; m.g.-c.g. allot. inequigranular; mainly alkali feldspar with chessboard texture and interstitial quartz; minor biotite mainly altered to chlorite and epidote

8145 - (366610, 5076956); granite; similar to 8141c; relatively abundant accessory titanite

8171 - (368696, 5078381); granite; protomylonite; augen of plagioclase and K-feldspar and elongate quartz, with scattered bands of biotite, epidote, and chlorite

8850 - (360821, 5065326); quartz diorite; m.g. intergranular texture, with amphibole partly replaced by chlorite and epidote; quartz is interstitial

8860 - (360844, 5072728); granodiorite; m.g. hyp. gran.; plagioclase and amphibole with 20% interstitial quartz and minor K-feldspar; plagioclase is extensively altered to saussurite

8870 - (360752, 5074301); quartz diorite; m.g. hyp. gran.; plagioclase and amphibole with minor interstitial quartz; intensive alteration to saussurite, epidote, and chlorite

8871 - (360484, 5074485); granite; similar to 8171 but less deformed; large quartz grains similar to Old Shepody Road unit of Point Wolfe River pluton; moderately intense alteration (saussurite, sericite, chlorite, epidote)

8880 - (362200, 5073588); granite; protomylonite like 8171

8886 - (359677, 5069533); quartz diorite; similar to 8850

8888 - (360520, 5070541); granite; similar to 8871

8909 - (361523, 5073005); granite; protomylonitic, similar to 8171

8937 - (365397, 5075283); granite; m.g. allot. gran.; probably protolith of 8171; minor biotite and accessory titanite

8940 - (365096, 5076380); diorite; mylonitic; augen of amphibole is a f.g., foliated, and very altered groundmass

8941 - (364984, 5076621); granite; mylonitic, with ribbons of quartz separated by bands of highly saussuritized feldspar and mafic minerals

8942 - (364716, 5076942); quartz diorite; m.g. allot. inequigranular; appears recrystallized; abundant amphibole and biotite; interstitial polycrystalline and sutured quartz

8950 - (370119, 5077400); quartz diorite; similar to 8850

8952A - (370493, 5077772); biotite tonalite; m.g. hyp. gran.; abundant biotite and no amphibole; accessory titanite and apatite; interstitial quartz and minor K-feldspar

8956 - (369237, 5077901); granodiorite; mylonitic; similar to 8941 but with more abundant recognizable biotite in the mafic bands

Emerson Creek Pluton (Z_{EC})

6107 - (285805, 5020876) granodiorite; m.g.-c.g. hyp. gran.; plagioclase and chloritized biotite with interstitial orthoclase and quartz; abundant fractures and sericitic alteration

8017 - (287133, 5021869); granodiorite; similar to 6107 but more altered; abundant carbonate in interstices and veinlets

Millican Lake Pluton (Z_{ML})

82074- (271375, 5008460); c.g. leucocratic tonalite, strongly sheared and altered to illite and hematite; from Whalen et al. (1994) (Millican Lake Pluton at Cape Spencer)

Fortyfive River Granodiorite (Z_{FF})

009 - (343258, 5055939); granodiorite; m.g. allot. gran.; intensely altered (saussurite, epidote, chlorite)

014A - (340694, 5053877); granodiorite; similar to 009, but somewhat coarser grained

050C - (344569, 5058994); granodiorite; similar to 009 but less altered; retains relict amphibole

051 - (344614, 5058649); granodiorite/tonalite; m.g. hyp. gran.; abundant amphibole; interstitial quartz and very minor K-feldspar; plagioclase is moderately saussuritized; abundant epidote and chlorite throughout

052 - (344491, 5058586); tonalite/granodiorite; similar to 051 but more altered; very little K-feldspar

090 - (347966, 5061146); tonalite/granodiorite; coarser grained but otherwise similar to 052

133 - (339092, 5051988); tonalite/granodiorite; strongly cataclased

518 - (341834, 5057158); similar to 090; very abundant coarse epidote patches and veinlets

521 - (343411, 5057285); granodiorite; m.g. allot. gran.; intensely saussuritized plagioclase; about 25% mafic minerals, mostly altered to chlorite and epidote; minor relict amphibole and biotite; interstitial quartz and perthitic orthoclase

527 - (344301, 5057216); granodiorite gradational to monzogranite; m.g. hyp. gran.; moderately saussuritized plagioclase; abundant epidote; original mafic minerals unidentifiable; interstitial quartz and perthitic orthoclase

553 - (347844, 5060844); granodiorite; m.g.-c.g hyp. gran.; moderately saussuritized plagioclase; abundant epidote; about 15% mafic minerals mostly altered to chlorite and epidote; minor relict amphibole and biotite; interstitial quartz and perthitic orthoclase; abundant large titanite

596 - (349495, 5061559); granodiorite; similar to 21

618 - (351381, 5061491); granodiorite; similar to 521

4528 - (334468, 5047833); granodiorite to tonalite; m.g.-c.g hyp. gran.; moderately saussuritized plagioclase; abundant epidote; about 15% mafic minerals mostly altered to chlorite and epidote; minor relict biotite; interstitial quartz; minor orthoclase; moderate shearing

4529 - (334633, 5049499); granodiorite; m.g. allot. gran.; intensely altered and sheared; abundant epidote

8833 - (357173, 5062564); granodiorite; m.g. hyp. gran.; plagioclase and altered mafic minerals in a groundmass of quartz and minor K-feldspar; similar to 553 but finer grained and less titanite; moderately intense alteration (saussurite, sericite, epidote, chlorite)

8834A- (356850, 5063592); granodiorite; similar to 8833 but less altered

Goose Creek Leucotonalite (Z_{GC})

110 - (337377, 5056019); leucotonalite; m.g. allot. gran.; mainly plagioclase and quartz; minor interstitial granophyre; patches of chlorite and epidote may represent original mafic mineral

117A - (337287, 5054207); leucotonalite; similar to 110 but more altered plagioclase (to epidote)

503 - (337432, 5054124); leucotonalite; similar to 117A

653 - (341567, 5059170); leucotonalite; c.g. allot. gran.; dominantly plagioclase and quartz with some granular epidote

RM196- leucotonalite; abundant plagioclase, quartz, and epidote; similar to 117A, but more cataclased

Kent Hills Pluton (Z_{KH})

8078 - (360509, 5078875); granodiorite; m.g.-c.g. protomylonite, with augen of quartz, feldspar, and biotite (partly chloritized) in a polycrystalline, foliated matrix of quartz, sericite, chlorite, and saussurite

8105 - (354512, 5072920); granodiorite; f.g.- m.g. protomylonite; well foliated mixture of amphibole, quartz, plagioclase, epidote, sericite, and chlorite; little relict igneous texture

8121 - (355543, 5076246); granite; m.g. protomylonite with small augen of plagioclase and orthoclase in a foliated, polycrystalline, quartz-rich matrix, with sparse bands rich in chlorite, biotite, and epidote

8129B- (347455, 5066495); granodiorite; c.g. allot. gran.; relict amphibole and biotite; intense saussuritization of plagioclase; abundant chlorite and epidote; protolith of more deformed samples like 8078 and 8105

8130 - (348791, 5065425); granodiorite; similar to 8129B but m.g

8889 - (356630, 5078589); granite; f.g. - m.g. recrystallized mylonitic texture; fragments of mainly feldspar in a groundmass of fine sutured quartz aggregates; minor relict quartz ribbons

8893 - (357481, 5077373); granite; similar to 8889

8900 - (351857, 5075857); granite; similar to 8889

8914 - (350500, 5074788); granodiorite; protomylonitic, with amphibole and saussuritized plagioclase augen in a foliated quartz-rich groundmass

8958 - (361033, 5080455); granite; mylonitic; sparse plagioclase porphyroblasts in a f.g. foliated groundmass of quartz, feldspar, and epidote

8960 - (361953, 5080579); granite; similar to 8889

RM160- (348473, 5064921); granodiorite; m.g. allot. gran. but cataclased; plagioclase with interstitial quartz and minor K-feldspar; moderately intense alteration (saussurite, epidote, chlorite, carbonate)

RM327- granodiorite; protomylonitic and intensely altered (saussurite, sericite, chlorite, epidote, carbonate)

Point Wolfe River Pluton

Blueberry Hill granite (Z_{PWgt})

629 - (343090, 5069975); granite; sheared; similar to 1088c

1032A - (342373, 5069014); sheared granite; m.g., quartz, perthitic microcline, and saussuritized plagioclase. Original mafic minerals (biotite?) altered to clusters of biotite, epidote, and chlorite; quartz shows undulatory extinction and granulated grain boundaries

1088C - (333882, 5073684); granite; c.g., quartz, perthitic orthoclase, and moderately saussuritized plagioclase; minor relict biotite, mainly altered to epidote and chlorite; quartz shows undulatory extinction and granulated grain boundaries

8086A- (347958, 5076971); granite; c.g. allot. gran.; moderately intense saussuritization of plagioclase; original biotite(?) replaced by chlorite; minor cataclasis and polygonization of quartz; similar to 1088c

8086B- (347958, 5076971); granite; m.g. allot. gran.; intense saussuritization of plagioclase; abundant chlorite and epidote; moderate cataclasis

8137 - (347140, 5073999); granite; c.g. allot. gran.; quartz, perthitic orthoclase, and moderately saussuritized plagioclase; minor relict biotite, mainly altered to epidote and chlorite; quartz shows undulatory extinction and granulated grain boundaries; some interstitial patches of m.g. quartz and feldspar

Old Shepody Road granite (Z_{PWgg})

1082 - (337070, 5068390); granite; c.g. hyp. gran.; moderately saussuritized plagioclase; interstitial microcline and quartz; scattered rounded quartz phenocrysts; biotite partly replaced by chlorite; accessory opaques, titanite, allanite, and apatite

1803 - (329870, 5055480); granodiorite/granite; m.g. hyp. gran.; slightly saussuritized plagioclase; interstitial quartz and minor perthitic orthoclase; scattered rounded quartz phenocrysts; partly chloritized biotite; minor amphibole

1883 - (329738, 5059032); granodiorite/granite; similar to 1803

4012A- (321450, 5049979); granite; m.g.- c.g. allot. gran.; slightly saussuritized plagioclase; perthitic orthoclase; scattered rounded quartz phenocrysts; chloritized biotite

4017 - (322707, 5051770); granite; similar to 4012A but sheared and altered; abundant seritic alteration; polycrystalline quartz veinlets and patches

4188 - (327923, 5060920); granite; c.g. hyp. gran.; moderately saussuritized plagioclase; interstitial microcline and quartz; scattered rounded quartz phenocrysts; biotite mainly replaced by chlorite; abundant epidote; accessory opaques, titanite, apatite

4192 - (328335, 5058941); granite; similar to 4188 except somewhat deformed, with granulated quartz at grain boundaries

4200 - (325711, 5058660); granite; m.g.-c.g. allot. gran.; moderately saussuritized plagioclase; interstitial microcline and coarse granophyric intergrowths of quartz and feldspar; abundant rounded quartz phenocrysts; biotite completely replaced by chlorite and epidote

4527 - (327483, 5051055); granite; protomylonite; originally c.g. and similar to 4188

4538 - (321224, 5048287); granite; similar to 4192

4551 - (328500, 5056637); granite; similar to 4188, but contains a small microdioritic enclave

4558 - (325993, 5056371); granite; similar to 4012A

4563 - (322895, 5051194); granite; similar to 4012A

5136 - (329789, 5052238); granite; m.g. scattered plagioclase phenocrysts surrounded by granophyric intergrowth of quartz and perthitic orthoclase; plagioclase and orthoclase show moderate saussuritization

8132 - (346696, 5074777); granite; similar to 4012A

Pollet River granodiorite (Z_{PWgd})

504 - (332336, 5058638); tonalite; similar to 1065A but with less K-feldspar and more epidote

632 - (337155, 5071150); granodiorite; similar to 1065A but more sheared, with polycrystalline sheared quartz aggregates and sericitic shear bands

1065A- (336744, 5068624); granodiorite; m.g. hyp. gran.; framework of plagioclase laths (slightly saussuritized) with interstitial quartz and minor microcline; original mafic mineral (biotite?) replaced by chlorite; abundant accessory titanite and opaque minerals; abundant secondary epidote, chlorite, and sericite

1068A- (336263, 5070603); granodiorite; m.g. to c.g. allot. gran.; dominantly quartz, plagioclase, and microcline; original mafic mineral (biotite?) replaced by chlorite and coarse epidote. Euhedral secondary epidote is especially abundant

1119 - (337094, 5071043); granodiorite gradational to granite; m.g. to c.g. allot. gran.; dominantly quartz, plagioclase, and orthoclase (in part converted to microcline); original biotite and amphibole mostly replaced by chlorite and coarse epidote. Interstitial quartz replaced by polycrystalline sutured aggregates

1607 - (332226, 5059794); granodiorite; c.g. hyp. gran.; framework of plagioclase laths (moderately saussuritized) with interstitial quartz and orthoclase; relatively unaltered hornblende and biotite; abundant accessory titanite and opaque minerals; abundant secondary epidote, chlorite, and sericite

1671 - (334784, 5065087); granodiorite; similar to 1607 but slightly finer grained and more biotite and less amphibole

1672 - (334690, 5065753); granodiorite; similar to 1671

1677A- (333655, 5064068); granodiorite; similar to 1607

1689 - (331604, 50641990; tonalite; f.g. to m.g. hyp. gran.; abundant interstitial quartz; abundant amphibole and minor biotite; intensely saussuritized plagioclase; abundant epidote and chlorite

1704A- (332070, 5064880); granodiorite; similar to 1607

1882 - (331802, 5059046); granodiorite; similar to 1119, but with better preservation of the hornblende

8134 - (348281, 5079173); granodiorite/tonalite; m.g. protomylonite; dominantly plagioclase and amphibole with interstitial quartz; minor biotite; strongly foliated; intensely saussuritized plagioclase; abundant epidote and chlorite

Quartz Diorite (Z_{PWqd})

630 - (342960, 5069940); quartz monzodiorite; m.g. hyp. gran.; sheared and altered

1004A- (338230, 5068548); sheared quartz diorite; m.g. hyp. gran.; saussuritized plagioclase, partly chloritized amphibole and minor biotite, and interstitial quartz; abundant secondary epidote and sericite; quartz shows undulatory extinction and granulated boundaries

1005A- (338908, 5067902); quartz diorite; similar to 1004a, except unsheared and coarser grained, with more abundant quartz and minor microcline (grading to tonalite/granodiorite) and less alteration

1063 - (311002, 5078544); quartz diorite; similar to 1004a except unsheared

1070 - (335733, 5070050); quartz diorite to monzodiorite; similar to 1004A but contains more interstitial K-feldspar

1087 - (333037, 5073484); quartz diorite to tonalite; similar to 1004A but with more interstitial quartz and K-feldspar; mafic minerals are less altered than in 1004A

1667 - (336472, 5064159); quartz diorite; similar to 1087

1884 - (331014, 5060769); quartz diorite; extremely altered, sheared, and cataclased; original mafic minerals completely altered to chlorite; abundant carbonate and epidote

1886 - (331005, 5062299); quartz diorite; similar to 1087

8133 - (346862, 5076189); quartz diorite; c.g. hyp. gran.; relatively unaltered plagioclase, amphibole, and biotite with interstitial quartz; accessory titanite, apatite, and magnetite

Quartz Monzodiorite (Z_{PWqm})

1008 - (339578, 5067274); quartz monzodiorite; m.g. hyp. gran.; framework of plagioclase laths, biotite, and amphibole, with abundant interstitial microcline and less abundant quartz; amphibole is relatively fresh but biotite is completely chloritized; abundant titanite and scattered opaque minerals

Rat Tail Brook and similar plutons (Z_{RT})

8082 - (355629, 5069333); tonalite; protomylonitic; augen of plagioclase and quartz in a foliated matrix of biotite, chlorite, epidote, and granulated quartz

8862 - (356832, 5071991); granodiorite/tonalite; protomylonitic; augen of plagioclase in f.g. foliated groundmass of mainly ribbon quartz and biotite

8864A- (356359, 5071813); granodiorite/tonalite; mylonitic; similar to 8862 but more deformed

B.3. Coldbrook Group

Unit Cgd

6170 - (274960, 5030982); basaltic andesite; f.g. intergranular; plagioclase laths with interstitial epidote, chlorite, and carbonate, and abundant opaque minerals

6172 - (275568, 5030287); dacitic flow; m.g. intergranular; network of plagioclase laths with interstitial quartz and K-feldspar; sparse plagioclase microphenocrysts; abundant secondary carbonate and chlorite

CW627A - (730079, 5017855); dacitic/rhyolitic tuff; scattered plagioclase phenocrysts in a cryptocrystalline to spherulitic felsic groundmass

GSC134- dacitic tuff(?); trachytoid feldspar microlites in f.g. mosaic sericitic matrix; many crystal fragments (Currie and Eby, 1990)

NB12 - mafic flow; plagioclase microlites and rare lithic fragments in epidotized quartz-feldspar matrix (Currie and Eby, 1990)

NB13 - andesitic flow; plagioclase microlites and rare lithic fragments in carbonated quartz-feldspar matrix (Currie and Eby, 1990)

NB14 - andesitic flow similar to NB13 (Currie and Eby, 1990)

NB15 - dacitic flow; plagioclase microlites in epidotized quartz-feldspar matrix (Currie and Eby, 1990)

NB16 - andesitic ash tuff(?); very f.g. quartz-feldspar mosaic (Currie and Eby, 1990)

NB17 - andesitic flow(?) similar to NB13 (Currie and Eby, 1990)

NB18 - dacite(?); f.g. granoblastic quartz-feldspar with muscovite, biotite, opaques minerals, and titanite (Currie and Eby, 1990)

NB19 - dacite(?) similar to NB18 but with carbonate (Currie and Eby, 1990)

NB20 - dacite(?) similar to NB18 (Currie and Eby, 1990)

NB21 - volcaniclastic siltstone with abundant feldspar fragments (Currie and Eby, 1990)

NB22 - dacite(?) similar to NB18 (Currie and Eby, 1990)

Unit Clt

4068 - (314222, 5053302); basalt; f.g. flow-aligned plagioclase laths with interstitial chlorite; abundant large chlorite-and/or epidote-filled amygdules

4073 - (313380, 5055026); rhyolite; f.g., flow banded, spherulitic; minor amounts of sericite and iron oxide

5518 - (302541, 5041255); felsic lithic tuff; scattered rounded rhyolitic clasts of two main types (flow-banded and cryptocrystalline) and scattered mainly plagioclase crystals in a f.g. felsic cryptocrystalline groundmass

6070 - (289373, 5035242); dacitic, crystal lithic lapilli tuff; lapilli vary in texture and composition; most common are cryptocrystalline dacite, f.g. intergranular andesite, and f.g. dacite and rhyolite; some clasts contain relict biotite; secondary chlorite and carbonate are abundant

6071 - (290321, 5035604); dacitic, crystal lithic lapilli tuff; similar to 6070 except clasts are less varied and mainly of andesitic to dacitic composition

6193 - (270998, 5026529); dark grey andesitic to dacitic lithic lapilli tuff; similar to 6205

6529 - (290641, 5028249); black, dacitic, lithic lapilli tuff; mainly dark-coloured cryptocrystalline lapilli in a f.g. granular feldspar groundmass; scattered plagioclase crystals; abundant epidote and chlorite

GSC96 - felsic tuff; quartz, feldspar, and lithic clasts in a f.g. sericitized matrix (Currie & Eby, 1990)

Unit Cft

4097 - (313778, 5049551); dacite/rhyolite; black due to fine dusting of opaques (magnetite?); flow-banded, with laminae varying in texture from spherulitic to patchy to microcrystalline to cryptocrystalline; scattered phenocrysts of plagioclase

4105 - (310286, 5047017); dacitic/rhyolitic, lithic lapilli tuff; clasts mainly of the same microcrystalline to cryptocrystalline quartz-feldspar aggregates; sparse plagioclase phenocrysts; dusting of black opaques

4262 - (313509, 5047529); basaltic(?) lithic lapilli tuff; clasts are mainly cryptocrystalline and altered to greenish clay minerals; sparse altered plagioclase phenocrysts and laths; some clasts highly amygdaloidal; abundant chlorite and epidote

5513 - (772133, 5045738); grey, lithic crystal tuff; dacitic to rhyolitic, flow banded; abundant granular epidote; most clasts are dacitic but some may be andesitic

5524 - (301089, 5037788); Black, lithic crystal tuff; very typical; scattered crystals are mainly of plagioclase; lithic clasts are f.g. and dacitic(?); groundmass is cryptocrystalline and looks devitrified, with small spherulite-like patches

6018 - (300672, 5039306); black, crystal lithic tuff; varied cryptocrystalline dacitic clasts in a welded cryptocrystalline felsic matrix; scattered m.g. crystals are mainly plagioclase

6197 - (272310, 5024375); black, dacitic lithic tuff; lithic clasts are mainly cryptocrystalline; groundmass is also cryptocrystalline with sparse plagioclase crystals; abundant chlorite and carbonate

6205 - (266340, 5021475); black dacitic lithic tuff; similar to 6197; mainly cryptocrystalline but better developed spherulitic devitrifcation textures; welded, flow fabric in groundmass; scattered plagioclase and sparse clinopyroxene phenocrysts

9511 - (317317, 5057092); dacite flow?; scattered crystals of plagioclase in a cryptocrystalline to spherulitic felsic groundmass; well banded

9519 - (326379, 5066559); dacitic lithic lapilli tuff; similar to 6197

Unit Cftb

1700 - (328590, 5067444); basalt; very f.g. plagioclase laths mixed with abundant epidote and scattered fine opaque grains

1794 - (327691, 5067232); basalt; f.g. pilotaxitic plagioclase laths, with interstitial chlorite and scattered opaque grains; abundant amygdules filled by mainly epidote and quartz

4036 - (316404, 5056403); basalt; f.g. flow-aligned plagioclase laths; abundant chlorite; sparse plagioclase phenocrysts and scattered small amygdules, mainly filled with quartz aggregates

4037A - (316466, 5056459); basalt; f.g.-m.g. intergranular with relict clinopyroxene; abundant saussurite, chlorite, and epidote; scattered opaques

4060A - (315878, 5052980); basalt; f.g. flow-aligned plagioclase laths with intergranular epidote, chlorite, and some relict clinopyroxene; scattered opaques

Unit Cmt

4609 - (315959, 5042059); basalt; relict variolitic texture with skeletal plagioclase; amygdules mainly filled with chlorite and sericite; microphenocrysts of plagioclase and altered mafic mineral (pyroxene?)

4642 - (315705, 5039890); basalt; relict intergranular texture; plagioclase, epidote, and chlorite; undeformed

Unit Cit

6095 - (276917, 5019404); basalt; f.g. intergranular; sparse amygdules filled with epidote and chlorite

6104 - (281058, 5021737); rhyolitic, crystal lithic lapilli tuff; dark, massive, flow-banded matrix with sparse crystals of saussuritized plagioclase

NB1 - dacitic tuff; lithic and crystal fragments in a f.g. sheared matrix; some carbonate and epidote (Currie and Eby, 1990)

NB3 - dacitic tuff; lithic and crystal fragments in a f.g. sheared matrix; some carbonate and epidote (Currie and Eby, 1990)

NB4 - dacitic flow(?); very f.g. homogeneous matrix with rare small lithic fragments (Currie and Eby, 1990)

NB5 - dacitic flow similar to NB4 (Currie and Eby, 1990)

Unit Cba

6112 - (280006, 5019267); amygdaloidal basalt; f.g. intergranular with abundant chlorite, carbonate, and opaque minerals

6118 - (276031,5016123); plagioclase porphyry; saussuritized plagioclase phenocrysts in a f.g. intergranular groundmass; abundant epidote and chlorite

6154 - (277070, 5017080); basaltic to andesitic flow; f.g. aligned plagioclase laths with abundant interstitial chlorite and carbonate; clots of carbonate and chlorite may represent amygdules

6519 - (277972, 5017725); altered basalt or gabbro; very abundant chlorite and epidote; saussuritized plagioclase

GSC71 - mafic flow; feldspar phenocrysts in granoblastic epidote-chlorite matrix (Currie and Eby, 1990)

NB08 - andesitic flow; abundant plagioclase in an opaque- and chlorite-rich matrix (Currie and Eby, 1990)

NB09 - mafic flow(?); plagioclase phenoclasts and lithic fragments in a f.g. epidotized matrix (Currie and Eby, 1990)

NB10 - mafic flow(?); plagioclase phenoclasts and lithic fragments in a f.g. epidotized matrix (Currie and Eby, 1990)

NB11 - mafic flow(?); plagioclase phenoclasts and lithic fragments in a f.g. epidotized matrix (Currie and Eby, 1990)

Unit Cr

1. NE of Point Wolfe River

1134A - (332362, 50559070); rhyolite; recrystallized; granoblastic quartz-feldspar layers and muscovite-rich layers

RM289 - rhyolitic lapilli tuff; protomylonite; recrystallized granoblastic quartz ribbons in a f.g. foliated sericite/muscovite-rich quartz/feldspar groundmass

2. SW of Point Wolfe River

4592 - (313725, 5036575); rhyolite; f.g. allot. gran.; sparse phenocrysts of plagioclase and quartz

5093 - (315567, 5033534); felsic, lithic crystal lapilli tuff; plagioclase and K-feldspar crystals and rhyolitic clasts in a f.g. sericite-rich foliated groundmass; abundant granular epidote.

5125 - (311234, 5032586); rhyolitic, crystal lithic tuff; plagioclase and quartz crystals, and rhyolitic porphyry clasts; mylonitic; abundant smeared opaques (graphite?)

3. Hanford Brook–Silver Hills area

6540 - (296565, 5038554); spherulitic rhyolite

7080 - (297004, 5040930); welded tuff; sanidine, quartz, and plagioclase crystals

7095 - (296745, 5036400); felsic, lithic lapilli tuff with spherulitic rhyolite fragments

4. Vernon Mountain–St. Martins area

6027 - (281955, 5022932); rhyolite; mainly cryptocrystalline with incipient spherulitic patches; scattered quartz and feldspar phenocrysts, some embayed

6082 - (299644, 50319?7); felsic tuff with spherulitic rhyolite clasts in a cryptocrystalline rhyolitic groundmass

6214 - spherulitic rhyolite; coarse spherulites in cryptocrystalline groundmass; scattered hematite, epidote, and cryptocrystalline secondary minerals

GSC73 - felsic flow; trachytoid feldspar phenocrysts in a f.g. quartzofeldspathic matrix (Currie and Eby, 1990)

5. Blackall Lake, Saint John

7034 - (265849, 5022052); rhyolite; cryptocrystalline with patchy incipient spherulites; scattered plagioclase phenocrysts; abundant sericite and hematite

Unit Cb

1. basalt unit NE from Point Wolfe River

1029B- (343479, 5067445); basalt; f.g. intersertal texture; aligned plagioclase laths intergrown with secondary chlorite and epidote. Amygdaloidal, with m.g. granular epidote filling most amygdules

1054 - (345692, 5068122); basalt; similar to 1029B, except with scattered microphenocrysts of plagioclase

1133 - (331915, 5056283); basalt; f.g. intergranular; plagioclase laths with abundant chlorite and epidote

1153 - (331238, 5055144); basalt/andesite; mainly aligned plagioclase laths, with abundant coarse crystalline epidote in patches throughout

1156 - (331348, 5054730); mafic tuff; f.g. mixture of altered plagioclase, chlorite, and epidote

1164 - (331024, 5054008); basalt; m.g. intergranular; saussuritized plagioclase laths with interstitial chlorite, epidote, and opaques

1310 - (341833, 5065604); basalt; f.g. intersertal to intergranular, with abundant amygdules filled by epidote, chlorite, albite, and quartz

1318 - (338584, 5062121); andesitic tuff; f.g. mainly plagioclase laths with chlorite-rich layers; abundant carbonate alteration

1355 - (339877, 5064237); basaltic tuff/autobreccia; f.g. intermixed plagioclase, epidote, and chlorite

5131 - (333187, 5058471); basalt; f.g. intergranular basalt; abundant interstitial epidote and chlorite; scattered amygdules contain mainly epidote; strongly foliated/sheared

8123 - (347217, 5070101); basaltic tuff; f.g.- m.g. mixture of mainly plagioclase, epidote, chlorite, and quartz

8126 - (346668, 5069854); rhyolitic crystal lapilli tuff; welded felsic groundmass with spherulitic patches; abundant crystals of plagioclase and embayed quartz; (rhyolite layer in basalt unit)

RM241 - mafic tuff; very f.g.; mixture of mainly plagioclase and epidote

2. basalt unit SW of Point Wolfe River

4504 - (325583, 5048201); basaltic tuff(?); very fine-grained; foliated epidote, chlorite, albite, and unrecognizable cryptocrystalline material (similar to RM241)

4569 - (318563, 5041166); basalt; poorly aligned plagioclase laths and intergranular chlorite; amygdules with epidote, carbonate, and chlorite; scattered opaques; microphenocrysts of plagioclase

4576 - (311355, 5014625); basalt; similar to 4569 but with coarser epidote

4594 - (313305, 5035542); basaltic tuff; fine-grained, patchy texture; maybe altered lithic fragments, now mainly chlorite, epidote and opaques

5006 - (325296, 5046456); basalt; f.g. intergranular; strongly foliated; abundant interstitial carbonate and chlorite; abundant granular opaques

5534 - (309764, 5034831); basalt; similar to 4642; scattered amygdules filled with quartz and/or chlorite; abundant chlorite and opaques in groundmass

EB24, 31, 34, 35, 36, 37 - basalt (from Dostal and McCutcheon, 1990)

3. basalt unit in Shanklin area

6002B- (296200, 5029524); basalt; m.g. ophitic patches mixed with hematite-rich patches; distinctive texture similar to 6036 but coarser grained

6034 - (291345, 5026258); basalt; f.g. ophitic patches but mainly intergranular with interstitial chlorite. Distinctive texture similar to 6036 and 6002B but with less hematite

6041 - (297886, 5029033); basalt; texture similar to 6034, except more epidote; scattered rounded amygdules contain chlorite, carbonate, and epidote

6043 - (297736, 5030855); basalt; f.g. intergranular clinopyroxene and plagioclase; abundant rounded chlorite-filled amygdules and sparse plagioclase phenocrysts

6044 - (297691, 5031353); basalt; f.g. intergranular and seriate porphyritic, with plagioclase phenocrysts

6083 - (298894, 5030909); basalt; f.g. intergranular and hiatal porphyritic, with plagioclase phenocrysts; abundant chlorite and epidote

6151 - (298824, 5028542); basalt; m.g. intergranular; framework of plagioclase laths with interstitial chlorite; chlorite also fills amygdules; abundant cryptocrystalline clays and opaque phases

CB07, 10, 12, 13, 15, 16 - basalt (from Dostal and McCutcheon, 1990)

Unit Cbrs

1. northern (Hanford Brook) area:

6050 - (297196, 5036690); basalt flow; intergranular, aligned plagioclase, chlorite-rich, granular interstitial epidote and opaques; scattered chlorite-filled amygdules

6053 - (297524, 5037414); basalt flow; similar to 6050

2. southwestern area:

6025 - (280767, 5023327); basalt; fine grained, intergranular, abundant epidote, chlorite, and carbonate

6036 - (289903, 5027361); basalt; f.g. ophitic patches mixed with hematite-rich patches; distinctive texture; abundant clinopyroxene

6216 - (286980, 5027060); basalt; m.g. intergranular; relict clinopyroxene; abundant chlorite, epidote, and hematite; irregular amygdules contain coarse barite

6528 - (288660,5026855); dacite; f.g. pilotaxitic plagioclase laths with scattered plagioclase phenocrysts and rare embayed quartz; abundant chlorite and epidote

7064A- (288300, 5027340); basalt; m.g. intergranular; relict clinopyroxene; abundant chlorite and epidote

7081 - (277388, 5023146); basalt; f.g. intergranular but very altered; abundant epidote and chlorite, and plagioclase is saussuritized

CB28, 29 - basalt (from Dostal and McCutcheon, 1990)

B.4. Circa *550 Ma Plutons*

Mechanic Settlement Pluton (Z_{MS})

4150A - (326706, 5065923); gabbro; plag, cpx, and minor green amphibole; f.g-m.g. hyp. gran.

4150B - (326706, 5065923); plag-bearing lherzolite; similar to MS025, with minor phlogopite

4160 - (323243, 5063328); diorite; plag, cpx, and opx; f.g. intergranular

4161 - (320783, 5062858); gabbro; similar to 4150A, with more green amphibole

4164 - (321542, 5062326); diorite; porphyritic with phenocrysts of plagioclase; similar to MS127 with less plag and more quartz

4167B - (323315, 5061422); quartz diorite; m.g. hyp. inequigranular; interstitial quartz around moderately saussuritized plag, cpx, and coarse biotite; abundant opaques, minor titanite

4168 - (322587, 5061075); quartz diorite; similar to MS130 but much more altered

4181 - (324852, 5063852); quartz diorite; similar to MS130 but finer grained; may be a chilled margin; abundant opaques and apatite

4209 - (324309, 5064193); olivine gabbronorite; olivine, opx, brown amphibole, green amphibole, plag; m.g. hyp. gran

4211 - (324125, 5065487); gabbro; similar to 4150A

9518 - gabbro; similar to 4150A; cpx rimmed by brown and green amphibole

9526 - (323930, 5063102); quartz diorite; similar to MS130, gradational to plagioclase-porphyritic lithology

9528 - (324227, 5063028); plagioclase-bearing lherzolite; similar to MS025

MS004 - olivine gabbronorite; m.g. hyp. inequigran.; plag., olivine, opx, cpx

MS009 - gabbronorite; m.g. hyp. gran. plagioclase, opx, cpx; minor phlogopite and amphibole

MS019 - olivine pyroxenite; mainly clinopyroxene and olivine; m.g. hyp. inequigranular

MS024 - gabbronorite; cpx, opx, plag, and minor brown amphibole; m.g. allot. inequigranular

MS025 - plag-bearing lherzolite; olivine and opx, with minor cpx and plag; m.g.-c.g. allot. inequigranular

MS027 - olivine gabbro; mainly cpx and plag with minor opx, olivine, and brown amphibole; m.g. hyp. inequigranular

MS030 - troctolite; mainly plag and olivine, with less abundant cpx; m.g. hyp. inequigranular

MS044A - olivine gabbronorite; olivine, plag, cpx, opx; f.g. - m.g. hyp. inequigranular

MS048 - plag-bearing lherzolite; similar to MS025, but with more olivine (mainly altered to serpentine)

MS065 - gabbro; plag and cpx; m.g. hyp. gran.; extensively altered

MS068 - gabbronorite; similar to MS065 but with more opx

MS072 - plagioclase-bearing lherzolite; similar to MS025

MS080 - plagioclase-bearing lherzolite; similar to MS025 but with a higher proportion of opx, phlogopite, and brown amphibole

MS119 - diorite; f.g. intergranular plag., cpx, opx, amphibole

MS127 - diorite; mainly f.g. plag. and amphibole.; porphyritic with phenocrysts of plagioclase

MS130 - quartz diorite; m.g. hyp. gran.; plag, amphibole, interstitial quartz, relict cpx

MS133 - quartz diorite; similar to MS130

MS145 - plagioclase porphyritic diorite similar to MS127

MS149 - quartz diorite; similar to MS130

Devine Corner Gabbro (Z_{DC})

DC01 - (302525, 5045730); gabbro; m.g. intergranular; unaltered clinopyroxene; plagioclase is moderately saussuritized; abundant interstitial chlorite and epidote; scattered opaque phase (ilmenite?)

5502 - (770979, 5048349); gabbro; m.g. intergranular; relict clinopyroxene; plagioclase is intensely saussuritized; abundant chlorite and carbonate; skeletal opaque phase (ilmenite?)

Caledonia Mountain Pluton (Z_{CM})

8073A - (363782, 5080319); gabbronorite; c.g. cumulate-like texture, with a framework of plagioclase (60% of rock) and interstitial opx, cpx, amphibole, and opaque grains; intense alteration to amphibole, chlorite, saussurite, and epidote

8074A - (364332, 5080694); diorite; c.g. cumulate-like texture, with a framework of plagioclase (60% of rock) and interstitial amphibole and opaque grains; relict opx in cores of large amphibole; minor alteration (chlorite, saussurite, epidote)

8075 - (364731, 5080790); gabbronorite; m.g. cumulate-like texture, with a framework of plagioclase (50% of rock), cpx, and opx, with interstitial brown amphibole, apatite, and opaque grains; minor alteration as above

8961 - (362119, 5080304); gabbro; c.g.; very altered (saussuritized plagioclase, actinolite, chlorite)

Baxters Mountain Pluton (Z_{BM})

6544 - (281716, 5027473); granite; m.g. hyp. gran.; slightly saussuritized plagioclase surrounded by anhedral quartz and perthitic orthoclase; minor biotite and amphibole

6545 - (281581, 5027261); granitic porphyry; scattered phenocrysts of quartz, K-feldspar, and plag in a f.g. allot. gran. groundmass with minor muscovite and biotite

8026 - (286206, 5029136); granophyric granite; m.g.-c.g. hypi. gran.; plagioclase and quartz with interstitial K-feldspar and granophyre; original biotite(?) replaced by chlorite and epidote

6201 - (279878, 5025888); diorite/gabbro breccia; m.g. ophitic diorite or gabbro, brecciated and sheared into rounded clasts; very altered with abundant actinolite, chlorite; and sericite; minor relict pyroxene

6542 - (282600, 5026155); gabbro; m.g. subophitic, inequigranular; abundant apatite, ilmenite; slightly altered (chlorite, epidote); (dyke in unit HCrd)

Bonnell Brook Pluton

dioritic unit (Z_{BBd})

4251 - (314637, 5041826); quartz diorite; f.g.-m.g. hyp. gran.; intensely saussuritized plagioclase, green-brown amphibole, and interstitial quartz; scattered biotite, opaques, and titanite; secondary chlorite (after biotite) and epidote

4252 - (314707, 5041084); quartz diorite; similar to 5251 but coarser grained

4578 - (310667, 5015253); granodiorite; m.g. hyp. gran.; plagioclase and less abundant orthoclase surrounded by interstitial quartz; about 10% chloritized biotite; moderate saussuritization of plagioclase; abundant epidote; (dyke in dioritic unit)

4590B- (315286, 5038752); diorite; c.g., hyp. gran; same minerals as 4251 and 4251, but c.g. and less quartz

granitic unit (Z_{BBg})

4094 - (310510, 5050738); granite; m.g. allot. gran.; microperthitic orthoclase, plagioclase, quartz, and minor biotite; accessory titanite and opaques; deformation lamellae in feldspars and quartz; moderately intense saussuritization of plagioclase and chloritization of biotite

4102 - (310592, 5048251); granite; m.g. allot. inequigranular; patchy in terms of grain size; granular in places but elsewhere coarsely granophyric; xenolith of plagioclase laths; biotite partly replaced by chlorite and epidote

4114 - (307568, 5049468); granite; m.g. allot. gran.; microperthitic orthoclase, plagioclase, quartz, and minor biotite, partly replaced by chlorite and epidote; accessory titanite and opaques;

4115 - (306830, 5048449); granite; similar to 4114 but coarse-grained

4125 - (306687, 5046551); granite; similar to 4115

4136 - (311728, 5045250); granite; similar to 4102

4140 - (308371, 5045564); granite; similar to 4115

4144 - (310657, 5041943); granite; similar to 4114; accessory pyrite

4247 - (312860, 5042113); granite; similar to 4114

4249 - (313822, 5042288); granite; f.g.-m.g. granophyric; with scattered plagioclase phenocrysts; abundant secondary epidote

4259- (313029, 5046115); granite; m.g.-c.g allot. inequigranular; patchy in terms of grain size; granular in places but elsewhere coarsely granophyric; abundant microperthitic orthoclase

4272 - (309860, 5038067); granite; similar to 4115

4296 - (307139, 5041350); granite; similar to 4115

4305 - (314345, 5044269); granite; similar to 4114

4599 - (318562, 5045850); granite; m.g. allot. gran.; microperthitic orthoclase, plagioclase, quartz, and minor biotite; deformation lamellae in quartz; moderately intense saussuritization of plagioclase and chloritization of biotite

4600A - (314919, 5042191); granite; similar to 4114

4626 - (316043, 5049091); granite; similar to 4115

5528 - (304048, 5034014); granite; similar to 4114

5540 - (306248, 5039002); granite; m.g.-c.g allot. inequigranular; granular in places but elsewhere coarsely granophyric; abundant microperthitic orthoclase, commonly forming rims around subhedral plagioclase crystals

5541 - (306847, 5038170); granite; m.g. hyp. inequigranular, with phenocrysts of plagioclase, orthoclase, and quartz in a granophyric groundmass; minor chloritized biotite, titanite, and opaques

6061 - (299887, 5033543); granite; m.g. allot. gran.; mainly perthitic orthoclase and quartz, with coarsely granophyric patches; minor plagioclase and biotite

6079 - (300674, 5033887); granite; similar to 6061

6090 - (305871, 5038650); granite; similar to 5540

6091 - (307889, 5037950); granite; similar to 5541

6094 - (309371, 5036463); granite; similar to 5541

Dykes related to Bonnell Brook Granite

4537 - (320737, 5049024); granite; m.g. granophyric, with scattered phenocrysts of plagioclase; (dyke in Old Shepody Road granite; unit Z_{PWgg})

4579 - (315638, 5041201); granite; similar to 4114; (dyke in unit Cmt)

4581 - (317153, 5041889); granite; m.g. hyp. gran.; plagioclase and microperthitic orthoclase, with interstitial quartz and minor biotite, partly replaced by chlorite and epidote; accessory titanite and opaques; (dyke in unit Cmt)

Bonnell Brook fine-grained granite (Z_{BBfg})

4110 - (306428, 5048725); granite; f.g.-m.g. allot. gran.; almost granophyric; biotite altered to chlorite

4297 - (307088, 5041484); granite; f.g. granophyric, with scattered phenocrysts of plagioclase

5509 - (770790, 5045293); granite; f.g. slightly granophyric to allot. gran., with sparse plag. phenocrysts and abundant quartz microphenocrysts

5599 - (771219, 5046865); granite; f.g. granophyric, similar to 4297

Bonnell Brook rhyolitic porphyry (Z_{BBr})

4055 - (316305, 5052827); rhyolitic porphyry; plagioclase phenocrysts in a mainly spherulitic groundmass; abundant secondary epidote and chlorite patches

4058 - (316265, 5053492); rhyolitic porphyry; subhedral plagioclase phenocrysts in a groundmass of spherulites and fine-grained granular quartz and feldspar; abundant secondary epidote, carbonate, chlorite, and hematite

Upham Mountain Pluton (Z_{UM})

6072 - (290498, 5035604); syenogranite; m.g. radiating masses (spherulites) of microgranophyric K-feldspar, as well as interstitial granophyre and quartz; scattered plagioclase laths; granular opaque phases, and sparse altered mafic grains (biotite?)

6073 - (290938, 50370390; syenogranite; m.g.plagioclase laths form a framework surrounded by interstitial granular quartz and K-feldspar, scattered opaque grains, and chloritized mafic grains (originally biotite?)

6207 - (291302, 5037816); syenogranite; scattered m.g. to c.g. blocky plagioclase crystals surrounded by feathery spherulites and interstitial granophyre and quartz grains; scattered chloritized mafic minerals (originally biotite) and opaque grains

6208 - (291469, 5038421); syenogranite; c.g. plagioclase grains surrounded by coarse granophyre; scattered mafic grains are altered to carbonate, chlorite, and in places titanite

B.5 Grassy Lake formation (Unit O_G)

5526 - (302447, 5035533); grey dacite; f.g. inequigranular to seriate porphyritic; could be a tuff but more likely a flow; phenocrysts of plagioclase, sanidine, and quartz; minor carbonate alteration

5542 - (302507, 5034491); grey dacite; f.g. to cryptocrystalline, with alternating flow-banded and spherulitic layering; scattered phenocrysts, mainly of plagioclase; minor chlorite and epidote alteration

B.6 Fairfield formation (Unit D_{Fr})

6218 - (288252, 5023452); rhyolite; cryptocrystalline to patchy f.g. quartz and K-feldspar; scattered plagioclase and sanidine phenocrysts; secondary carbonate, epidote, sericite

APPENDIX C

Chemical data

Analytical methods

Sample powders were prepared at Acadia University using a hardened-steel jaw crusher, and Rocklabs pulverizer with tungsten carbide puck and container. The powders were analyzed by X-ray fluorescence at the Nova Scotia Regional Geochemical Centre, St. Mary's University, Halifax, Nova Scotia, except as noted below. Major elements were analyzed using fused disks, and trace elements using pressed-powder pellets. Precision is generally about 5% for major elements and 3-10% for trace elements, based on replicate analyses of internal standards (S. Stanford, pers. comm., 1990). However, MgO values less than 1% in high-silica samples may not be reliable.

Chemical data are listed in tables C.1 through C.4. Sample locations are shown on Figures 3, 9, 15, and 16. Petrographic descriptions of analyzed samples are compiled in Appendix B. Because many rocks of intermediate composition are tuffaceous and hence less suitable for chemical characterization, the analyses tend to be from mafic and felsic rocks, and hence are not generally proportional to the relative abundance of lithological types. Pyroclastic rocks, especially those with abundant lithic fragments, generally were not selected for analysis.

Notes about the data tables

1. Major-element oxides, LOI, and Total are in weight %. Trace elements are in ppm.
2. $Fe_2O_3^t$ is total iron content expressed as Fe_2O_3.
3. LOI refers to loss on ignition (% weight loss after about 1 hour at 1000°C).
4. Symbol < indicates values less than the detection limit of the analytical method.
5. Dashes indicate that the element was not included in the analysis.

Table C.1. Broad River Group.

SAMPLE	SiO_2	TiO_2	Al_2O_3	$Fe_2O_3^t$	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	LOI	TOTAL	Ba	Rb	Sr	Y	Zr	Nb	Pb	Ga	Zn	Cu	Ni	V	Cr
UNIT Bls																									
8155	77.90	0.13	11.13	2.11	0.05	1.02	0.04	2.35	3.00	0.01	1.40	99.14	607	70	21	63	270	12	<10	14	58	5	5	5	10
8179	77.57	0.27	12.09	1.92	0.02	0.93	0.15	3.78	2.10	0.03	0.90	99.76	354	65	35	39	196	9	<10	12	42	5	5	21	5
8861	47.96	1.80	14.09	14.39	0.22	6.38	10.76	1.18	0.55	0.14	3.00	100.47	67	32	177	39	98	<5	<10	18	114	63	53	392	89
8873	74.90	0.31	13.04	3.33	0.07	1.38	0.88	3.20	1.61	0.07	2.00	100.79	199	46	64	17	103	<5	<10	13	57	5	5	15	5
8943	64.25	0.54	14.23	5.54	0.09	4.12	1.95	3.99	1.01	0.10	4.20	100.02	252	45	70	25	146	7	<10	16	62	14	40	146	136
8948	74.23	0.28	11.91	4.32	0.05	3.93	0.09	0.63	1.95	0.05	2.90	100.34	247	65	35	59	243	<10	<10	18	120	5	5	5	5
RM297	75.93	0.28	10.21	4.30	0.10	1.41	1.45	2.30	1.08	0.06	1.80	98.92	235	41	93	56	195	<5	<10	9	98	7	5	19	5
RM298	50.19	0.43	13.68	8.83	0.16	9.03	11.94	1.86	0.27	0.04	1.80	98.23	101	7	188	7	34	<5	<10	11	65	67	108	261	211
RM301	49.53	0.52	14.20	8.54	0.21	8.68	12.03	1.68	0.53	0.10	2.10	98.12	218	15	226	11	37	<5	<10	13	67	59	106	247	310
UNIT Btp																									
44	56.84	1.51	15.06	10.28	0.23	4.34	3.75	5.32	0.24	0.40	2.31	100.28	127	2	141	36	107	<5	7	22	99	12	18	160	86
8112	52.57	1.26	13.34	10.25	0.21	5.20	6.83	3.96	0.01	0.11	7.70	101.44	17	5	111	27	74	<5	<10	14	77	28	15	369	56
RM33	50.71	1.07	15.89	9.67	0.16	5.63	7.28	4.45	0.07	0.35	4.30	99.58	97	5	407	35	156	<10	<10	15	88	65	63	221	139
RM62	71.86	0.27	13.07	4.48	0.08	0.83	3.30	2.27	1.15	0.06	1.80	99.17	149	33	91	14	51	<5	<10	13	50	31	5	31	6
RM73	49.39	0.79	18.53	11.33	0.20	4.73	8.69	2.20	0.30	0.13	3.60	99.89	124	8	738	16	81	<5	<10	15	83	29	14	277	51
RM78	64.01	0.28	12.43	6.94	0.15	4.49	6.82	2.00	0.70	0.06	1.70	99.58	216	27	96	15	78	<5	<10	11	53	44	35	164	248
RM84	53.25	0.74	16.95	12.98	0.31	4.75	5.48	3.64	0.41	0.11	1.90	100.52	87	12	171	24	68	<5	11	17	128	78	9	336	17
RM85	70.96	0.61	13.03	3.91	0.12	1.84	3.07	3.54	0.66	0.14	1.90	99.78	82	33	417	32	195	14	27	13	60	13	17	71	57
RM106	63.50	0.38	13.42	7.54	0.10	3.88	3.74	3.36	0.45	0.10	2.40	98.87	113	15	128	20	82	<5	<10	11	69	15	32	172	190
RM108	65.79	0.35	12.87	6.79	0.12	2.77	3.41	5.33	0.16	0.05	1.00	98.64	21	5	46	19	71	<5	<10	13	60	56	9	145	38
RM114	49.88	0.56	17.00	8.48	0.17	8.34	4.72	3.84	1.28	0.07	4.10	98.44	389	29	161	11	50	<5	<10	15	130	38	76	230	267
RM121	49.71	0.67	15.04	11.43	0.16	5.86	7.10	3.13	0.03	0.05	5.80	98.98	5	5	241	10	41	<5	<10	15	76	92	25	356	99
RM124	74.09	0.27	12.93	2.93	0.03	0.61	0.13	4.61	1.67	0.06	1.20	98.53	218	59	58	30	143	6	<10	13	32	5	6	12	7
RM131	74.49	0.21	11.04	3.54	0.09	1.44	0.61	5.26	0.14	0.03	1.90	98.75	33	5	76	84	261	8	<10	15	42	5	5	12	10
RM133	52.58	0.64	15.64	11.97	0.23	6.06	4.16	3.33	0.10	0.04	4.60	99.35	40	5	196	11	37	<5	<10	15	103	79	19	369	83
RM152	47.99	0.60	17.68	11.11	0.19	6.20	9.02	1.20	0.05	0.10	5.40	99.54	38	5	277	14	48	<5	<10	12	93	75	54	287	90
RM162	69.59	0.61	12.39	4.45	0.13	1.96	2.40	2.91	2.00	0.13	2.20	98.77	482	70	333	29	168	12	14	15	62	5	25	92	73
RM174	64.49	0.81	14.90	7.00	0.12	2.15	0.93	2.79	2.62	0.16	2.80	98.77	677	96	55	34	246	16	<10	20	102	15	30	103	84
RM176	64.42	0.81	14.83	7.37	0.08	1.93	0.84	1.93	3.16	0.11	2.90	98.38	539	121	36	38	245	18	<10	20	98	14	26	96	69
RM179	56.38	0.59	12.33	5.31	0.10	4.17	7.88	0.93	1.92	0.09	9.40	99.10	294	65	122	25	143	7	<10	14	60	36	28	127	203
RM206A	50.27	1.73	13.93	13.02	0.20	6.55	7.86	3.08	0.41	0.20	3.40	100.65	134	8	199	44	136	<5	<10	17	104	44	43	344	118
RM219	46.37	1.08	15.34	10.72	0.19	8.86	8.27	2.61	0.05	0.18	4.70	98.37	45	5	315	25	81	<5	<10	14	93	78	176	243	515
UNIT Bdt																									
35	75.30	0.30	13.16	1.75	0.05	0.00	1.41	5.19	1.51	0.05	0.76	99.48	290	37	249	14	185	11	8	15	31	8	–	8	29
80	77.50	0.23	11.52	1.52	0.04	0.10	0.14	4.59	3.14	0.03	0.47	99.28	683	58	56	39	164	12	13	14	46	–	14	–	30
566	70.79	0.39	14.52	1.72	0.07	0.34	2.71	4.10	3.52	0.07	0.99	99.22	1186	51	348	15	182	9	29	16	44	28	3	41	32
573	68.50	0.83	15.92	2.06	0.10	0.49	1.60	3.71	2.16	0.10	2.52	97.99	583	61	298	50	248	<10	11	20	92	4	19	49	15
600	74.02	0.34	14.16	1.95	0.05	0.80	0.81	4.89	2.66	0.05	0.76	100.49	828	61	130	17	180	8	16	16	42	–	7	4	31
8803	56.32	0.90	17.94	8.70	0.15	3.85	3.53	4.74	1.09	0.26	3.30	100.78	312	41	491	30	122	<5	<10	19	97	20	14	207	30
8808	63.93	0.60	16.45	5.66	0.11	2.45	2.25	4.48	2.09	0.18	1.90	100.10	676	54	424	20	151	<5	<10	17	76	28	9	114	14
8838	55.63	0.76	18.27	8.55	0.15	3.73	5.37	4.10	1.48	0.21	2.50	100.75	410	51	534	25	107	<5	<10	19	119	63	14	185	14
UNIT Bdtb (basalt layers/lenses in Unit Bdt)																									
85	51.84	2.07	16.05	13.08	0.22	4.81	2.53	5.95	0.13	0.40	2.91	99.99	85	1	194	40	145	8	11	24	165	30	10	449	10
155C	47.50	1.59	16.89	12.67	0.20	6.86	4.14	5.31	0.54	0.34	3.88	99.92	268	10	136	27	104	6	7	18	141	7	37	290	88
182	47.91	1.71	16.64	10.91	0.19	6.92	7.31	3.17	1.76	0.33	3.03	99.88	516	41	341	30	147	9	9	20	131	7	79	245	280
188	47.61	1.31	17.15	10.18	0.19	7.65	7.09	3.17	1.54	0.38	3.42	99.69	787	32	336	26	129	8	12	21	191	15	59	275	219
191	48.09	1.79	16.89	13.51	0.21	5.80	4.14	5.45	0.68	0.35	3.12	100.03	368	13	291	33	127	7	<10	22	195	11	18	433	37

Table C.1. (cont.)

SAMPLE	SiO_2	TiO_2	Al_2O_3	$Fe_2O_3^t$	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	LOI	TOTAL	Ba	Rb	Sr	Y	Zr	Nb	Pb	Ga	Zn	Cu	Ni	V	Cr
577A	50.66	1.45	17.09	9.67	0.19	4.34	8.08	4.44	0.14	0.52	3.48	100.06	133		510	28	149	8	<5	24	126	239	14	275	51
578B	47.15	1.45	18.95	10.43	0.20	7.25	4.14	4.97	0.47	0.55	4.16	99.72	177	6	232	32	165	10	<10	22	156	38	27	258	105
1016	44.83	1.52	17.22	12.23	0.22	9.63	5.92	3.68	0.70	0.40	4.30	100.65	252	10	382	24	120	8	–	25	129	19	44	330	172
603	57.58	1.24	17.02	10.40	0.09	1.63	2.97	6.32	0.91	0.24	1.39	99.79	314	28	369	27	126	7	9	17	69	15	4	270	18
1377	52.70	1.73	14.96	12.62	0.19	3.88	5.38	5.66	0.50	0.36	2.40	100.38	307	4	270	33	130	6	<5	26	131	71	12	383	16
1378	49.38	1.15	16.04	10.17	0.18	7.96	8.09	3.64	0.62	0.30	3.00	100.53	218	7	369	24	109	7	–	21	97	34	46	261	255
1712	51.65	1.56	16.39	11.92	0.22	4.42	5.90	4.95	0.36	0.41	2.40	100.18	256	1	373	39	173	7	<10	21	171	32	20	274	47
1835	54.00	1.08	17.69	9.42	0.16	3.80	4.32	6.05	0.55	0.25	2.70	100.02	303	7	411	23	118	<5	2	22	90	52	5	291	18
UNIT Bts																									
8845	56.63	0.92	15.30	6.49	0.14	2.60	7.94	1.91	2.43	0.24	4.90	99.50	561	83	388	25	158	13	<10	20	84	40	35	143	59
UNIT Bmf																									
6	57.38	1.18	15.09	9.24	0.15	3.07	4.53	4.57	0.19	0.38	4.12	99.90	39	3	196	33	204	13	<5	20	114	85	12	244	10
1142A	52.88	0.83	16.87	8.32	0.16	5.04	5.34	4.55	1.27	0.18	5.50	100.94	318	39	197	22	119	7	<5	22	77	30	20	252	41
1343B	49.84	0.81	18.48	9.61	0.16	5.37	9.26	2.92	0.36	0.19	3.70	100.70	461	6	578	16	83	<5	7	23	98	42	10	323	94
1344A	56.19	1.44	15.63	9.62	0.20	3.50	6.68	3.61	0.36	0.53	2.50	100.26	111	4	312	39	158	9	<5	25	112	4	13	111	6
1754B	51.77	1.55	15.44	9.95	0.28	6.07	9.21	4.09	0.46	0.11	0.70	99.63	129	10	209	29	87	4	13	20	118	7	55	342	296
4510	45.05	3.10	13.18	16.85	0.33	5.51	8.44	2.06	0.95	0.94	2.00	98.41	440	15	252	41	175	7	–	23	197	55	58	405	17
5008	59.43	0.83	17.18	6.87	0.16	3.05	2.43	6.02	1.30	0.15	2.00	99.42	362	23	158	26	137	<5	<10	18	110	5	12	138	25
5098	48.99	0.61	15.02	10.10	0.18	8.22	6.27	3.83	0.01	0.05	7.80	101.08	31	5	36	11	23	<5	<10	13	162	10	132	243	524
5099	54.28	0.69	13.12	7.32	0.15	7.86	6.81	4.05	0.04	0.06	5.80	100.18	54	5	103	12	23	<5	<10	15	97	68	125	278	525
8896	54.12	0.97	17.23	9.44	0.15	3.11	8.32	2.54	0.85	0.31	2.20	99.24	229	29	594	24	129	7	16	20	127	26	10	232	25
8899	50.03	1.26	18.75	12.47	0.18	3.98	4.69	5.30	0.67	0.46	2.80	100.59	203	24	215	38	160	11	<10	20	127	190	14	316	8
8913	71.52	0.48	14.96	3.34	0.09	0.81	1.89	2.96	2.91	0.08	1.40	100.44	589	136	224	34	211	16	19	16	77	5	6	48	18
8929	53.37	1.00	17.65	10.11	0.16	3.58	6.76	3.91	1.00	0.30	2.40	100.24	248	41	452	26	125	8	15	16	101	13	18	239	31
8959	54.57	1.02	16.00	9.88	0.18	3.83	7.55	2.74	0.73	0.35	3.00	99.85	266	20	412	27	109	<5	29	17	117	46	5	229	5
EB25	49.77	0.83	15.07	11.78	0.35	6.84	8.32	2.21	0.03	0.06	5.30	100.56	13	1	176	21	48	3	–	14	101	1	87	293	303
UNIT Bmf (Quiddy River section)																									
EB2	53.38	0.62	14.81	8.17	0.28	7.21	8.43	4.86	0.05	0.05	2.10	99.96	73	1	188	16	38	3	6	13	156	2	49	259	566
EB6	51.11	1.73	14.54	14.10	0.20	5.55	4.55	4.46	0.07	0.12	3.60	100.03	106	1	185	32	89	4	11	17	124	26	15	538	60
EB9	50.30	1.06	15.63	9.87	0.16	7.40	8.29	3.30	0.47	0.25	3.40	100.13	165	3	198	28	123	<10	<10	13	97	52	72	256	236
EB11	47.71	0.62	12.82	10.74	0.17	12.85	8.39	2.11	0.33	0.04	3.90	99.68	72	3	65	12	27	1	7	12	72	42	149	258	702
EB12	50.27	0.76	14.51	10.43	0.18	9.89	5.79	4.04	0.04	0.06	4.40	100.37	22	1	85	15	33	2	19	14	103	39	101	302	516
EB15	53.16	0.70	15.09	7.64	0.14	7.95	7.80	4.78	0.03	0.06	2.30	99.65	21	1	85	17	35	2	3	11	75	229	61	252	729
EB18	48.83	0.83	15.10	10.16	0.22	8.43	8.67	3.35	0.03	0.06	4.10	99.78	28	1	210	19	41	2	<10	15	101	21	66	322	505
EB19	55.68	1.27	13.96	13.23	0.14	5.54	2.49	3.17	0.01	0.08	5.40	100.97	10	1	49	24	51	3	9	17	107	11	20	533	19
UNIT Bmt																									
1177B	62.93	1.30	14.03	8.67	0.16	4.00	0.95	3.67	1.49	0.46	2.80	100.46	199	43	23	60	228	<10	<10	28	450	–	26	42	8
8150	51.83	1.07	18.89	10.29	0.16	3.62	5.08	3.62	1.41	0.29	4.60	100.86	495	35	506	20	54	<5	<10	19	114	64	64	252	27
8175	52.53	0.98	17.57	9.35	0.14	5.41	6.69	3.52	1.66	0.25	2.90	101.00	543	33	799	17	94	<5	<10	18	100	127	127	253	70
8904	47.02	1.33	16.62	11.62	0.18	6.93	5.94	3.91	0.31	0.34	5.70	99.90	192	5	528	26	101	<5	<10	18	107	99	89	327	213
8933	61.11	1.10	15.59	7.88	0.17	2.82	5.10	3.46	0.72	0.23	2.40	100.58	119	18	396	30	128	<5	11	19	103	34	12	175	24
UNIT Bat																									
1691	53.52	1.67	14.66	11.79	0.17	4.42	7.69	3.05	1.02	0.27	1.60	99.86	275	40	169	33	152	<10	<10	22	109	27	17	326	21
1751	55.17	1.84	15.04	10.50	0.16	4.48	3.99	3.92	1.04	0.32	2.90	99.36	281	36	249	34	160	7	22	23	108	8	14	277	13
UNIT Bdr																									
1122A	67.17	0.81	14.54	4.50	0.08	2.27	2.01	5.69	1.16	0.22	1.70	100.15	296	39	152	31	232	<10	25	23	63	11	13	95	10
UNIT Bit																									
6158	58.19	1.06	15.41	11.08	0.14	2.45	3.90	3.25	1.69	0.30	2.70	100.17	465	78	309	33	145	6	<10	16	79	12	5	182	12

Table C.2. *Circa* 620 Ma plutons.

SAMPLE	SiO_2	TiO_2	Al_2O_3	$Fe_2O_3^t$	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	LOI	TOTAL	Ba	Rb	Sr	Y	Zr	Nb	Pb	Ga	Zn	Cu	Ni	V	Cr
Alma Pluton (Z_A)																									
24	45.07	1.10	19.15	12.07	0.21	5.23	11.22	2.39	0.26	0.49	2.70	99.89	73	3	741	13	34	3	11	21	99	41	3	266	24
29	56.65	0.59	19.88	6.40	0.14	2.66	6.33	4.20	0.79	0.26	2.50	100.40	244	11	656	21	81	<5	6	24	88	25	3	95	18
34	54.84	0.71	18.29	8.09	0.16	3.72	6.67	3.68	1.44	0.33	2.30	100.23	379	26	567	17	74	5	2	21	86	34	5	170	20
37	47.74	0.90	22.56	8.39	0.17	3.89	8.80	3.20	1.26	0.37	3.20	100.48	422	27	656	16	45	4	4	24	117	21	3	137	11
60	46.81	1.03	20.34	10.69	0.14	4.68	10.12	3.10	0.41	0.54	1.20	99.06	109	4	803	23	41	4	1	24	94	131	9	264	14
87	56.80	0.83	17.78	7.23	0.16	3.47	5.66	3.80	0.88	0.22	2.80	99.63	391	13	500	20	65	5	4	21	138	69	7	184	18
88	53.44	0.79	18.49	9.29	0.20	3.74	5.85	3.46	1.03	0.51	2.80	99.60	438	18	604	19	69	5	1	18	120	90	2	164	28
176	57.87	0.52	20.05	5.55	0.11	2.15	5.20	4.40	1.69	0.21	2.10	99.85	450	32	499	21	95	5	9	20	90	24	6	85	16
186	62.57	0.47	17.63	5.08	0.11	3.10	1.65	5.44	1.37	0.20	2.00	99.62	339	31	149	18	107	5	6	19	99	11	4	79	16
531	54.98	0.71	18.63	8.06	0.17	3.82	6.29	3.84	1.09	0.23	2.30	100.12	255	26	604	19	61	6	5	22	91	25	1	160	14
572	66.97	0.39	15.59	4.64	0.08	1.95	3.46	3.99	1.26	0.13	2.00	100.46	386	26	349	15	114	5	2	20	63	6	4	72	27
Caledonia Brook Granodiorite (Z_{CB})																									
8071	60.74	0.67	16.72	6.95	0.12	2.92	5.12	3.49	2.03	0.18	1.70	100.64	620	47	557	22	103	5	<10	14	63	27	6	146	10
8072	60.13	1.22	16.68	6.91	0.17	2.09	4.27	4.20	1.70	0.54	2.00	99.91	550	49	464	50	245	11	10	20	85	5	5	73	5
8882	63.54	0.60	15.71	5.74	0.10	2.28	4.54	3.37	2.46	0.16	1.00	99.50	698	62	468	26	148	6	10	17	56	18	9	129	11
8884	64.71	0.90	15.92	5.48	0.12	1.74	3.76	3.72	2.95	0.34	0.70	100.34	618	108	444	38	203	9	10	18	64	14	5	84	6
Caledonia Road Granitic Suite (Z_{CR})																									
8068	72.43	0.36	13.86	2.19	0.06	0.49	0.23	4.74	4.01	0.07	0.60	99.04	506	105	46	29	274	32	10	18	72	5	5	16	5
8070	49.94	0.92	16.73	9.53	0.19	7.46	8.64	2.94	0.95	0.20	2.40	99.90	304	22	520	24	94	5	10	17	123	31	70	205	324
8141C	73.60	0.31	13.78	1.74	0.03	0.22	0.16	4.58	4.27	0.05	0.60	99.34	481	105	50	28	258	30	10	18	26	25	5	13	5
8145	73.50	0.33	13.95	1.60	0.05	0.20	0.52	4.91	4.14	0.05	0.60	99.85	497	83	64	34	271	31	10	17	40	10	10	14	14
8171	72.22	0.33	14.23	3.00	0.06	0.60	1.93	4.27	2.56	0.08	1.10	100.38	825	52	275	17	189	5	10	14	44	8	8	28	8
8850	44.29	0.95	19.06	11.23	0.14	6.50	11.31	1.94	0.13	0.11	3.40	99.06	25	5	600	14	52	5	10	17	93	133	34	371	66
8860	61.61	0.64	16.14	6.00	0.11	2.37	4.75	3.36	2.25	0.17	1.80	99.20	652	48	506	24	148	5	10	17	62	14	9	132	12
8870	55.48	1.20	16.12	9.82	0.20	3.18	5.83	4.55	1.17	0.34	2.30	100.19	444	16	451	34	111	5	10	21	107	97	10	231	7
8871	70.26	0.28	15.24	2.60	0.06	0.96	2.09	4.06	3.04	0.09	1.00	99.68	614	69	319	16	95	6	10	14	29	5	5	44	8
8880	73.03	0.30	14.42	2.13	0.05	0.54	1.69	4.09	2.97	0.07	0.70	99.99	767	55	229	19	167	7	10	14	28	5	5	22	7
8886	53.65	1.29	16.18	11.06	0.21	3.50	6.72	4.10	1.31	0.63	1.70	100.35	446	29	550	41	115	5	10	20	108	69	5	236	5
8888	73.85	0.27	14.09	2.06	0.04	0.59	1.19	3.92	3.35	0.07	0.80	100.23	779	60	165	15	151	6	12	13	25	5	5	20	5
8909	62.85	0.60	16.14	5.89	0.08	2.47	4.51	3.40	2.19	0.18	1.50	99.81	684	53	523	22	116	5	10	18	42	24	7	127	12
8937	72.23	0.33	14.15	1.77	0.07	0.41	0.51	4.34	4.00	0.06	0.70	98.57	534	114	90	39	226	29	10	18	39	5	5	18	5
8940	50.56	0.78	18.77	9.01	0.21	5.22	8.67	3.55	0.65	0.15	2.20	99.77	253	11	545	14	52	5	10	17	105	58	42	239	164
8941	71.25	0.29	15.16	2.31	0.07	1.00	2.99	4.26	0.99	0.09	1.10	99.51	294	31	474	14	106	5	10	14	46	5	5	38	11
8942	60.71	0.68	16.79	6.70	0.12	2.79	5.60	3.38	1.58	0.20	1.40	99.95	627	41	621	23	123	5	10	20	77	30	14	154	16
8950	56.88	0.73	17.81	8.02	0.14	3.65	6.22	3.32	1.21	0.23	1.80	100.01	325	28	564	22	80	5	10	17	70	14	18	166	43
8952A	66.57	0.51	17.14	3.35	0.05	1.01	2.43	4.97	2.23	0.21	1.00	99.47	891	35	509	19	255	12	10	18	54	5	5	44	5
8956	69.97	0.34	14.60	3.11	0.06	0.78	2.28	4.70	1.66	0.09	0.80	98.39	957	34	305	19	197	5	10	15	46	5	5	40	11
Emerson Creek Pluton (Z_{EC})																									
6107	68.19	0.42	13.63	3.31	0.05	2.35	1.47	5.06	2.33	0.09	2.40	99.30	471	78	114	8	128	5	10	12	30	10	9	52	27
8017	69.31	0.42	15.75	3.45	0.04	1.86	0.79	4.71	2.78	0.10	2.20	101.41	394	101	102	6	115	5	10	14	33	5	6	76	12
Millican Lake Pluton (Z_{ML})																									
82074	69.00	0.47	15.80	2.51	0.06	0.65	1.35	6.05	1.66	0.10	2.25	99.90	225	73	97	15	143	7	4	15	27	–	–	59	–
Fortyfive River Granodiorite (Z_{FF})																									
9	64.71	0.50	14.94	4.54	0.08	2.29	4.00	4.23	2.06	0.14	2.70	100.19	610	34	300	21	131	8	6	15	52	20	11	89	23
014A	63.88	0.62	16.11	4.94	0.08	2.30	2.98	4.29	1.91	0.20	2.90	100.21	548	60	450	22	143	9	11	19	66	73	8	110	26
50C	62.89	0.64	15.84	5.95	0.12	2.80	4.35	2.91	2.77	0.16	1.90	100.33	842	73	427	25	123	8	5	18	101	14	11	126	10
51	61.48	0.64	16.37	6.03	0.13	2.82	4.81	3.29	2.71	0.16	1.60	100.04	806	65	443	24	138	8	6	18	74	13	7	135	17
52	61.61	0.60	15.41	5.70	0.10	2.49	3.70	3.04	3.28	0.15	2.30	98.38	923	77	346	26	139	8	5	16	55	95	10	120	21
90	65.37	0.54	16.26	4.49	0.08	1.88	1.55	4.31	3.33	0.18	1.70	99.69	1063	98	272	23	146	10	12	18	68	27	7	76	28
133	61.28	0.67	17.03	5.74	0.11	3.22	2.79	4.47	2.54	0.20	2.10	100.15	1073	46	261	23	144	9	5	18	89	16	8	117	21

Table C.2. (cont.)

SAMPLE	SiO_2	TiO_2	Al_2O_3	$Fe_2O_3^t$	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	LOI	TOTAL	Ba	Rb	Sr	Y	Zr	Nb	Pb	Ga	Zn	Cu	Ni	V	Cr
518	63.49	0.48	15.66	4.26	0.08	1.91	3.86	3.72	2.59	0.17	2.30	98.52	735	58	444	19	140	10	8	19	41	11	8	73	20
521	65.60	0.52	15.42	4.71	0.10	2.02	3.51	3.64	2.98	0.14	1.50	100.14	755	76	406	24	136	9	8	17	53	20	10	101	26
527	63.47	0.72	15.99	5.40	0.11	2.59	3.40	3.12	2.91	0.16	2.10	99.97	776	71	433	24	146	9	6	17	66	26	10	104	22
553	68.29	0.45	15.10	3.57	0.07	1.59	2.52	3.65	3.46	0.15	1.40	100.25	692	101	294	22	141	10	12	18	55	9	10	58	23
596	63.00	0.66	16.57	5.42	0.13	2.47	3.40	4.01	2.67	0.19	1.70	100.22	913	64	446	21	145	9	9	19	63	24	8	116	21
618	68.93	0.39	15.15	3.59	0.06	1.71	1.73	3.86	3.35	0.11	1.30	100.18	770	79	322	20	128	9	9	20	41	6	9	66	24
4528	65.65	0.53	16.10	4.32	0.08	2.20	2.32	4.39	2.90	0.17	1.30	99.96	834	72	220	24	143	9	–	13	47	9	3	74	7
4529	71.41	0.41	13.57	3.45	0.06	1.45	2.55	3.96	1.61	0.08	0.90	99.45	418	38	144	23	130	6	–	14	32	1	3	18	7
8833	63.65	0.59	16.28	5.30	0.10	2.25	3.25	3.71	2.97	0.15	2.20	100.45	761	80	316	19	109	5	17	17	158	20	10	125	14
8834A	62.41	0.61	16.43	5.83	0.10	2.42	4.46	3.54	2.46	0.16	1.60	100.02	637	66	430	23	123	5	10	17	58	35	7	122	11
Goose Creek Leucotonalite (Z_{GC})																									
110	74.76	0.34	12.16	4.51	0.05	0.69	1.15	5.10	0.64	0.07	0.70	100.17	143	15	106	21	94	4	8	19	33	2	4	–	33
117A	71.32	0.40	14.26	3.65	0.08	1.18	4.01	3.69	0.51	0.08	1.00	100.18	202	9	190	21	125	9	10	18	42	7	1	33	31
503	70.47	0.40	14.20	3.62	0.08	1.09	3.95	3.75	0.63	0.08	1.00	99.27	264	12	169	24	124	8	6	15	45	2	4	32	25
653	74.64	0.31	12.50	4.26	0.06	0.75	1.39	5.35	0.11	0.06	0.40	99.83	45	5	76	48	144	6	7	17	27	–	1	–	42
RM196	75.94	0.31	11.90	1.97	0.04	0.49	1.27	5.02	0.53	0.05	1.00	98.52	91	14	120	49	259	6	10	10	7	12	5	17	12
Kent Hills Pluton (Z_{KH})																									
8078	63.77	0.64	16.01	5.43	0.11	1.89	4.35	3.31	2.93	0.22	1.60	100.26	794	94	352	27	140	7	14	16	41	22	5	105	11
8105	57.71	0.69	16.22	8.36	0.14	3.96	7.22	2.62	1.58	0.16	2.20	100.86	474	49	319	19	99	5	10	18	61	24	17	204	39
8121	76.10	0.15	12.68	0.97	0.03	0.15	0.70	3.29	4.39	0.03	0.60	99.09	439	170	68	17	97	11	10	12	12	5	5	7	6
8129B	65.28	0.63	15.71	4.88	0.10	1.68	3.37	3.52	3.25	0.22	1.70	100.34	855	89	307	28	139	6	10	15	57	18	5	97	7
8130	62.84	0.72	16.05	6.16	0.13	2.09	3.29	3.65	3.23	0.24	2.10	100.50	918	102	325	40	141	5	10	17	58	42	7	128	5
8889	76.89	0.20	12.70	1.64	0.02	0.19	0.53	3.75	4.02	0.02	0.50	100.46	812	109	56	50	239	18	18	15	23	5	5	7	5
8893	76.05	0.16	12.95	1.02	0.03	0.18	0.55	3.53	4.30	0.04	0.60	99.41	502	190	67	21	104	12	22	13	27	5	5	5	5
8900	74.46	0.24	12.72	2.58	0.07	0.09	0.90	4.04	3.45	0.03	1.10	99.68	799	94	71	88	349	20	13	17	56	5	5	5	11
8914	62.39	0.70	15.16	6.84	0.11	2.80	4.73	2.92	2.95	0.15	1.40	100.15	606	113	234	24	154	8	96	15	62	214	17	152	49
8958	77.07	0.10	12.31	1.58	0.04	0.07	0.90	3.41	3.36	0.01	0.70	99.55	828	98	134	69	170	17	12	17	21	5	5	5	5
8960	75.70	0.17	12.81	1.53	0.03	0.11	0.69	3.92	3.78	0.02	0.40	99.16	657	100	42	81	213	19	12	17	30	8	5	5	5
RM160	61.93	0.71	16.05	5.78	0.14	2.20	3.06	5.14	2.19	0.25	2.60	100.05	665	61	282	27	142	7	11	16	94	15	6	125	9
RM327	63.87	0.47	14.51	6.48	0.11	2.36	4.10	2.43	1.40	0.08	2.30	98.11	413	48	208	24	88	5	10	14	54	22	10	145	33
Point Wolfe River Pluton																									
Blueberry Hill granite (Z_{PWgt})																									
629	72.17	0.26	14.70	2.00	0.05	0.96	1.93	3.64	3.51	0.07	0.70	99.99	1056	112	212	15	146	8	29	14	36	6	6	20	24
1032A	72.49	0.23	14.43	1.88	0.05	0.84	1.86	4.22	3.75	0.06	0.50	100.31	704	125	181	20	133	10	12	17	35	13	12	18	20
1088C	71.23	0.29	14.76	2.21	0.06	1.11	1.98	3.95	3.42	0.07	1.00	100.08	1071	111	222	16	167	9	14	17	33	–	15	25	21
8086A	70.72	0.32	15.25	2.17	0.05	0.70	2.09	3.75	3.49	0.07	1.00	99.61	1167	109	244	13	176	5	10	14	26	5	5	24	8
8086B	74.06	0.21	13.54	1.72	0.04	0.45	1.61	3.00	3.94	0.05	0.90	99.52	682	124	179	21	110	6	11	11	22	5	5	20	5
8137	73.49	0.21	14.04	1.60	0.04	0.19	1.14	3.50	5.35	0.04	0.60	100.20	800	163	190	11	122	8	25	13	28	5	5	15	9
Old Shepody Road granite/granodiorite (Z_{PWgg})																									
1082	69.86	0.44	15.12	2.86	0.11	1.35	1.53	5.01	2.65	0.13	0.80	99.86	752	72	280	20	146	11	10	17	49	–	6	36	17
1803	69.39	0.36	15.26	2.88	0.09	1.40	2.42	4.49	2.42	0.11	1.00	99.82	668	65	278	23	130	11	13	20	42	2	8	46	18
1883	70.27	0.37	14.94	2.87	0.08	1.39	2.41	4.41	2.72	0.10	1.00	100.56	712	70	300	14	109	6	11	16	47	5	10	50	15
4012A	74.75	0.25	12.70	1.77	0.06	1.19	0.90	4.02	3.95	0.06	0.90	100.55	664	125	125	20	117	11	–	14	25	1	3	23	8
4017	72.24	0.28	14.35	2.07	0.07	1.37	1.38	3.72	3.16	0.08	0.80	99.52	602	88	215	21	134	11	1	11	28	2	7	29	7
4188	71.47	0.30	14.65	2.15	0.07	1.27	1.83	4.12	3.07	0.09	0.70	99.72	694	87	229	18	142	10	–	15	39	3	6	29	7
4192	69.06	0.36	15.12	3.03	0.07	1.47	2.68	3.71	2.69	0.09	1.70	99.98	679	82	300	16	127	7	–	12	44	–	6	21	14
4200	72.06	0.26	14.24	1.83	0.06	1.16	1.66	4.16	3.26	0.07	0.70	99.46	669	100	215	22	136	9	11	13	31	3	2	25	9
4527	74.01	0.29	13.38	1.86	0.08	1.42	0.45	4.22	3.68	0.07	0.60	100.06	743	82	95	24	152	17	–	13	56	88	5	26	1
4538	70.30	0.32	14.15	2.31	0.08	1.43	1.61	4.25	2.87	0.08	1.20	98.60	658	87	226	15	137	7	6	12	47	6	2	38	5
4551	70.23	0.36	14.71	2.71	0.09	1.60	1.73	4.13	2.65	0.10	0.90	99.21	656	60	253	23	130	11	–	13	42	2	3	43	9
4558	71.62	0.33	14.31	2.41	0.08	1.40	2.06	4.23	2.99	0.09	0.90	100.42	662	98	243	16	136	9	13	13	35	2	8	35	6

Table C.2. (cont.)

SAMPLE	SiO_2	TiO_2	Al_2O_3	$Fe_2O_3^t$	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	LOI	TOTAL	Ba	Rb	Sr	Y	Zr	Nb	Pb	Ga	Zn	Cu	Ni	V	Cr
4563	70.56	0.35	14.82	2.57	0.05	1.59	1.66	4.07	3.19	0.10	1.00	99.96	647	99	263	16	143	8	1	14	34	4	5	44	8
5136	74.85	0.21	13.33	1.10	0.05	0.93	0.56	3.92	4.08	0.06	0.60	99.69	756	106	94	27	113	12	10	15	24	5	5	6	7
8132	73.37	0.23	14.59	1.63	0.04	0.41	1.45	3.66	4.01	0.04	0.60	100.03	723	98	184	20	133	8	18	13	18	5	5	13	9
Pollet River granodiorite (Z_{PWgd})																									
504	64.34	0.54	15.67	4.97	0.11	2.52	3.35	3.82	2.06	0.14	2.20	99.72	634	57	292	21	117	9	11	18	74	11	9	112	35
632	67.62	0.43	15.43	3.35	0.07	1.80	2.63	3.97	3.39	0.11	1.40	100.20	709	102	295	13	142	7	20	16	37	11	10	70	27
1065A	68.81	0.51	15.40	3.13	0.10	1.53	2.40	4.37	2.46	0.17	0.90	99.78	730	57	347	19	152	8	12	18	59	–	10	38	19
1068A	61.56	0.49	18.08	4.15	0.09	1.49	4.64	5.06	3.53	0.12	1.20	100.41	805	82	555	15	160	8	5	22	42	13	7	105	18
1119	67.42	0.43	15.76	3.34	0.07	1.72	2.32	4.14	3.93	0.11	1.20	100.44	801	152	317	15	149	8	9	18	51	26	15	74	16
1607	63.02	0.56	15.97	5.31	0.12	3.03	4.57	3.85	2.25	0.14	1.20	100.02	675	57	404	21	124	10	8	21	74	21	–	132	44
1671	68.13	0.54	15.50	3.36	0.11	1.52	2.72	4.70	2.34	0.17	1.20	100.29	710	49	381	22	148	10	10	20	59	6	9	40	16
1672	66.29	0.59	16.26	3.83	0.12	1.62	2.98	5.06	2.08	0.20	1.10	100.13	596	48	412	21	150	10	10	22	65	13	8	47	16
1677A	63.70	0.63	16.20	4.92	0.11	2.34	4.31	4.15	2.10	0.18	1.10	99.74	625	54	427	22	127	8	1	19	65	29	15	101	23
1689	62.58	0.70	15.95	5.54	0.10	3.22	3.82	4.17	2.65	0.16	1.60	100.49	781	71	316	29	180	9	11	17	70	27	19	128	44
1704A	67.77	0.47	15.22	3.57	0.08	1.86	2.35	4.49	3.29	0.11	0.90	100.11	762	99	289	17	143	8	12	21	48	3	15	76	22
1882	63.94	0.53	15.52	4.95	0.09	2.75	3.63	3.72	2.24	0.14	2.80	100.31	655	75	367	19	131	9	12	20	65	15	17	123	39
8134	61.96	0.69	16.94	6.30	0.10	2.72	4.86	3.56	1.89	0.16	1.40	100.58	639	69	382	24	104	5	16	16	73	86	14	140	20
quartz diorite (Z_{PWqd})																									
630	62.36	0.67	16.72	5.86	0.10	3.27	2.48	3.66	2.69	0.16	2.50	100.47	696	104	187	32	111	8	12	17	89	25	20	123	57
1004A	61.23	0.62	16.72	5.74	0.10	3.11	5.25	3.95	1.86	0.14	1.20	99.92	538	64	377	21	120	8	11	23	70	37	13	143	44
1005A	60.33	0.71	16.00	7.23	0.18	3.03	5.82	3.57	1.66	0.13	0.80	99.46	418	47	227	29	192	9	9	19	93	20	12	181	21
1063	61.68	0.67	16.55	6.02	0.11	3.47	3.34	4.37	2.24	0.14	1.70	100.29	577	94	324	19	98	7	7	21	79	23	22	145	29
1070	56.92	0.80	16.63	7.29	0.12	4.17	6.54	3.46	2.17	0.19	1.80	100.09	530	58	435	21	118	6	6	22	77	67	25	207	61
1087	60.85	0.63	17.25	5.44	0.11	3.03	5.19	3.90	1.96	0.15	1.40	99.91	565	57	385	23	186	8	10	20	75	28	20	137	53
1667	59.44	0.71	15.57	8.14	0.14	3.74	7.07	2.70	1.24	0.12	1.20	100.07	338	37	170	25	108	6	6	18	75	30	14	238	42
1884	52.45	0.99	19.17	7.72	0.11	4.39	6.93	3.30	1.44	0.33	3.00	99.83	492	43	540	16	81	7	1	22	69	39	20	219	36
1886	57.40	0.89	17.53	6.78	0.12	3.23	6.28	3.90	1.57	0.26	1.60	99.56	564	39	562	22	95	7	1	21	75	45	5	163	20
8133	57.01	0.75	18.41	7.14	0.15	3.47	5.90	3.69	1.52	0.18	1.80	100.02	593	50	515	23	89	5	11	19	84	25	27	152	61
quartz monzodiorite (Z_{PWqm})																									
1008A	60.42	0.74	16.49	6.34	0.12	3.44	5.35	3.37	2.05	0.18	1.65	100.15	559	63	332	27	142	8	11	20	73	29	21	161	62
Rat Tail Brook and similar plutons (Z_{RT})																									
8082	67.43	0.55	14.92	4.64	0.08	1.73	3.70	3.28	1.94	0.10	1.50	99.87	360	76	171	35	158	9	10	18	52	11	13	89	30
8862	65.88	0.53	15.22	5.12	0.09	2.50	4.41	3.16	1.43	0.10	1.70	100.14	373	46	154	33	159	8	10	17	49	17	24	108	84
8864A	68.64	0.50	14.77	4.43	0.08	1.84	3.82	3.33	1.75	0.09	0.90	100.15	462	56	150	27	163	7	10	15	43	8	11	80	45

Table C.3. Coldbrook Group and Grassy Lake and Fairfield formations.

SAMPLE	SiO_2	TiO_2	Al_2O_3	$Fe_2O_3^t$	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	LOI	TOTAL	Ba	Rb	Sr	Y	Zr	Nb	Th	Pb	Ga	Zn	Cu	Ni	V	Cr
UNIT Cgd																										
6170	53.41	1.14	16.63	8.09	0.14	3.73	7.37	3.19	0.86	0.22	4.6	99.38	252	28	279	25	166	5	14	10	19	95	112	33	260	30
6172	66.13	0.83	13.29	5.24	0.13	1.54	2.77	3.48	2.29	0.20	4.3	100.20	301	90	83	53	302	15	21	16	17	92	10	5	21	5
CW627A	73.49	0.30	13.79	2.38	0.05	0.44	0.56	3.93	2.78	0.04	1.5	99.26	483	94	92	51	304	15	11	14	15	61	5	5	5	5
GSC134	67.55	0.90	14.85	6.33	0.10	0.70	0.78	3.20	2.70	0.31	2.7	100.12	447	87	47	29	280	18	9	–	–	97	6	14	20	7
NB12	51.62	1.10	17.08	12.18	0.28	3.34	9.44	2.46	0.74	–	–	98.24	384	12	390	31	148	8	3	11	19	82	22	35	167	67
NB13	59.32	1.16	15.56	8.07	0.13	1.59	4.47	4.03	2.14	–	–	96.47	808	66	241	48	274	13	7	11	19	78	50	12	120	50
NB14	59.88	1.21	14.97	8.06	0.10	0.79	4.20	3.25	2.61	–	–	95.07	591	93	211	41	221	12	5	12	17	47	50	12	154	39
NB15	63.25	1.27	14.85	6.72	0.17	1.53	4.92	4.17	1.64	–	–	98.52	496	33	197	53	302	15	7	11	18	98	38	9	101	53
NB16	59.09	1.01	13.63	4.91	0.14	1.76	4.71	4.08	1.26	–	–	90.59	214	43	165	52	294	14	7	10	16	82	32	9	93	47
NB17	55.53	1.20	16.55	6.78	0.14	2.86	4.09	5.07	1.22	–	–	93.44	210	36	280	37	202	11	6	11	19	88	40	23	162	59
NB18	65.38	0.54	12.97	3.62	0.14	0.97	3.23	2.89	2.20	–	–	91.94	343	80	73	61	299	16	84	13	16	86	13	6	35	27
NB19	71.54	0.22	11.97	2.31	0.11	0.47	2.71	2.19	2.67	–	–	94.19	283	96	90	67	345	18	11	15	16	78	18	7	9	34
NB20	61.39	0.95	14.14	6.60	0.13	1.30	3.65	3.68	2.33	–	–	94.17	453	77	115	54	259	15	8	10	18	91	23	8	67	31
NB21	74.07	0.25	12.30	2.82	0.07	0.05	1.22	4.30	2.43	–	–	97.51	413	73	44	49	350	19	11	11	16	66	23	8	10	47
NB22	74.97	0.36	12.52	2.39	0.09	0.14	1.17	3.64	2.88	–	–	98.16	580	88	52	60	360	17	10	34	15	72	22	9	13	46
UNIT Clt																										
4068	55.16	1.61	15.78	12.22	0.17	4.32	2.02	5.68	0.09	0.21	3.1	100.36	32	–	55	29	142	8	–	–	15	184	12	17	180	9
4073	74.70	0.15	12.48	2.09	0.09	1.76	0.44	4.09	3.21	0.02	0.4	99.43	597	102	44	67	346	18	16	24	17	87	1	7	–	7
5518	74.51	0.33	13.00	2.59	0.11	0.98	0.65	5.00	2.22	0.06	0.5	99.95	480	65	50	54	331	16	10	10	13	88	5	5	5	5
6070	57.55	1.40	14.11	8.84	0.17	3.20	4.20	4.58	0.75	0.33	5.2	100.33	325	28	137	36	183	7	18	10	16	118	20	8	223	18
6071	57.99	1.57	14.73	9.08	0.15	3.44	4.37	3.75	1.75	0.58	2.4	99.81	660	60	252	39	169	7	17	10	20	100	11	15	149	12
6193	58.31	1.35	14.97	8.65	0.16	3.09	3.28	6.17	1.42	0.33	1.9	99.63	497	33	255	39	209	8	19	10	16	107	17	5	180	16
6529	62.47	1.23	14.82	6.96	0.14	2.34	3.47	5.16	1.27	0.42	1.6	99.88	213	28	73	39	209	9	12	10	19	96	10	5	88	15
GSC96	79.50	0.12	11.75	1.29	0.04	0.25	0.73	3.30	1.84	0.03	1.0	99.85	260	110	420	62	210	27	34	–	–	30	17	7	4	9
UNIT Cft																										
4097	70.17	0.43	12.90	3.26	0.12	1.91	1.26	4.91	2.91	0.06	0.6	98.53	536	96	74	61	363	15	8	10	14	88	–	4	3	3
4105	73.09	0.25	13.05	2.25	0.07	0.75	0.54	5.69	1.95	0.03	0.7	98.37	528	49	59	54	320	16	8	–	14	45	6	3	1	10
4262	56.28	1.18	15.24	8.88	0.17	4.49	7.47	3.33	0.98	0.27	1.5	99.79	319	29	180	34	158	8	–	2	17	112	28	20	213	34
5513	70.36	0.48	13.82	3.63	0.14	1.05	1.56	4.58	2.14	0.07	1.2	99.03	491	68	70	54	317	14	10	10	16	103	5	6	5	5
5524	72.86	0.39	13.44	2.99	0.13	1.19	0.68	5.26	1.85	0.07	0.8	99.66	460	47	49	43	329	16	10	10	15	136	5	7	7	5
6018	64.22	1.06	14.12	6.21	0.15	2.39	3.28	5.06	2.32	0.33	1.2	100.34	588	73	168	51	264	10	16	16	19	98	23	8	81	13
6197	60.57	1.28	14.63	8.12	0.19	2.66	2.74	5.46	1.73	0.36	2.0	99.74	422	44	158	43	227	10	10	10	18	148	21	5	153	14
6205	60.40	1.35	14.63	8.70	0.19	3.04	2.90	5.37	1.27	0.39	1.6	99.84	389	33	132	41	220	12	19	10	17	108	27	5	176	10
9511	74.16	0.52	12.80	2.63	0.11	0.35	1.12	3.58	2.19	0.08	1.5	99.04	409	60	69	68	299	14	10	17	18	118	5	5	5	5
9519	70.30	0.65	14.95	3.43	0.07	1.04	0.73	4.94	2.90	0.14	0.8	99.95	491	77	107	60	389	15	15	24	18	70	5	5	19	6
UNIT Cftb (basalt layers/lenses in Unit Cft)																										
1700	49.45	1.39	16.21	10.14	0.15	7.99	7.67	2.93	0.81	0.36	3.7	100.80	246	8	371	31	161	10	–	–	20	103	51	75	230	264
1794	53.98	1.96	15.05	10.83	0.18	4.49	5.85	4.42	0.75	0.37	2.2	100.08	169	11	138	37	196	10	–	13	27	144	2	17	411	10
4036	53.25	1.08	16.10	9.75	0.17	5.80	6.48	4.99	0.35	0.17	2.6	100.74	129	–	206	25	111	7	–	–	15	102	112	17	287	9
4037A	50.82	0.90	14.30	9.23	0.15	10.01	6.37	2.82	1.08	0.15	4.0	99.83	441	42	232	23	118	5	–	–	17	102	38	217	201	433
4060A	55.78	1.24	15.22	9.86	0.19	4.13	6.77	2.91	1.39	0.17	1.9	99.56	289	55	203	28	131	7	2	73	19	252	76	8	263	6
UNIT Cmt																										
4609	51.63	0.87	14.27	7.45	0.16	7.81	12.02	3.20	0.33	0.10	1.0	98.84	91	9	242	18	115	5	–	17	16	182	21	278	134	548
4642	53.71	1.10	15.81	10.71	0.22	4.89	7.96	2.19	0.30	0.23	1.2	98.32	120	8	180	27	162	8	–	–	17	103	35	94	213	248
UNIT Cit																										
6095	62.08	1.27	15.28	7.08	0.15	2.19	3.54	4.18	2.01	0.47	1.5	99.75	559	56	163	46	233	9	11	10	18	118	17	5	63	9
6104	71.56	0.45	13.91	3.50	0.11	1.33	1.42	4.67	2.72	0.11	0.7	100.48	592	79	114	63	344	15	25	15	16	70	8	5	20	17
NB1	62.12	1.08	15.77	6.64	0.13	1.61	2.40	3.42	3.01	–	–	96.18	557	105	96	56	267	19	8	18	20	107	30	8	64	36
NB3	61.46	1.21	15.51	6.49	0.15	1.47	3.36	4.56	2.24	–	–	96.45	457	75	243	55	257	15	7	9	19	257	18	9	67	42

Table C.3. (cont.)

SAMPLE	SiO_2	TiO_2	Al_2O_3	$Fe_2O_3^t$	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	LOI	TOTAL	Ba	Rb	Sr	Y	Zr	Nb	Th	Pb	Ga	Zn	Cu	Ni	V	Cr
NB4	62.26	1.28	14.86	7.06	0.18	1.71	3.12	4.42	2.21	–	–	97.10	504	76	131	55	227	14	6	13	19	227	23	11	68	55
NB5	61.40	1.12	14.65	7.52	0.15	1.81	1.89	5.06	1.58	–	–	95.18	428	48	106	49	231	14	7	8	20	112	19	8	69	45
UNIT Cba																										
6112	50.61	1.88	14.28	16.04	0.22	6.08	3.93	2.92	0.13	0.36	4.1	100.55	66	9	156	30	138	5	21	10	17	188	24	83	510	116
6118	50.42	1.08	19.25	8.54	0.14	6.38	5.62	5.01	0.27	0.10	3.7	100.51	104	5	286	22	105	5	15	10	16	125	17	55	209	190
6154	56.24	0.96	13.63	7.21	0.17	4.86	5.46	4.05	0.56	0.22	6.3	99.66	142	16	154	25	193	7	16	10	14	111	16	5	125	15
6519	49.73	1.73	13.86	13.82	0.23	6.32	7.76	2.20	0.08	0.33	3.6	99.66	49	6	466	38	196	5	17	10	21	142	101	54	313	76
GSC71	52.50	1.25	18.20	7.87	0.14	6.90	4.98	5.15	0.10	0.11	3.9	101.10	71	1	110	32	130	6	4	–	–	170	7	69	160	165
NB8	55.72	1.31	19.52	5.83	0.11	4.67	1.65	4.51	2.92	–	–	96.24	333	99	69	30	133	7	4	8	23	89	17	53	175	122
NB9	50.82	1.12	18.04	9.03	0.17	8.94	2.85	1.69	2.64	–	–	95.30	421	98	93	27	124	6	4	8	18	153	1	62	145	149
NB10	51.43	1.16	17.10	9.11	0.15	7.18	3.52	2.28	2.44	–	–	94.37	433	85	104	27	127	6	4	12	18	133	3	52	133	141
NB11	48.28	0.98	20.94	9.67	0.24	3.63	7.52	1.99	4.11	–	–	97.36	702	107	678	26	162	9	10	17	25	69	6	27	20	47
UNIT Cr																										
1. NE of Point Wolfe River																										
1134A	78.84	0.10	11.99	1.37	0.03	0.61	0.14	3.63	3.05	0.02	0.7	100.48	733	79	30	37	156	15	11	7	16	50	–	20	3	14
RM289	75.95	0.14	11.98	1.90	0.04	0.11	0.25	4.14	3.84	0.02	0.4	98.77	761	127	47	91	239	21	15	25	16	74	5	5	7	6
2. SW of Point Wolfe River																										
4592	75.46	0.12	12.30	1.52	0.04	0.88	0.04	4.09	3.37	0.02	0.8	98.64	697	103	24	57	224	16	12	4	18	30	5	4	1	–
5093	77.33	0.15	12.57	1.49	0.05	1.17	2.42	1.57	2.39	0.02	1.5	100.66	432	118	158	59	206	16	10	10	12	68	5	5	5	6
5125	78.39	0.15	11.36	1.27	0.02	0.65	0.00	3.58	3.60	0.02	0.5	99.54	3548	78	91	37	199	15	10	10	9	14	5	5	5	5
3. Hanford Brook-Silver Hills area																										
6540	77.35	0.13	12.30	1.40	0.04	0.87	0.44	4.77	1.24	0.01	1.5	100.05	175	57	178	59	260	17	10	10	15	62	7	6	5	13
7080	74.80	0.26	13.25	2.73	0.04	0.21	0.27	4.59	2.21	0.04	1.0	99.40	386	77	133	53	361	17	10	13	16	69	5	5	11	5
7095	76.42	0.36	11.78	2.43	0.04	0.27	1.49	3.88	1.33	0.07	2.3	100.37	236	43	70	47	284	14	10	10	13	56	5	5	7	6
4. Vernon Mountain-St. Martins area																										
6027	76.64	0.14	12.23	1.94	0.03	0.69	0.04	4.72	3.13	0.01	0.6	100.17	514	98	21	62	328	16	24	14	16	25	6	5	5	20
6082	74.89	0.17	12.80	2.07	0.05	1.06	0.11	1.74	5.75	0.02	1.1	99.76	1100	184	85	77	221	18	10	10	19	107	9	5	5	17
6214	75.99	0.13	12.69	1.71	0.03	0.76	0.08	4.62	3.34	0.01	0.3	99.66	587	90	35	61	421	17	20	10	19	26	8	5	5	8
GSC73	77.15	0.15	12.40	1.60	0.02	0.20	0.29	5.35	2.10	0.00	0.6	99.81	420	66	31	75	390	27	12	–	–	13	1	15	2	7
5. Blackall Lake (Saint John)																										
7034	71.63	0.58	14.35	2.74	0.08	0.83	0.48	3.02	3.74	0.08	1.6	99.13	416	196	67	62	343	17	11	11	15	138	5	5	5	5
UNIT Cb																										
1. NE from Point Wolfe River																										
1029B	49.75	1.86	16.35	11.42	0.20	6.57	5.52	4.30	0.31	0.33	3.3	99.91	60	–	154	43	171	9	–	9	21	144	149	37	352	196
1054	50.80	1.16	16.33	9.95	0.21	5.82	8.04	4.28	0.79	0.18	2.4	99.96	407	14	190	29	110	5	–	2	19	93	79	42	290	178
1133	51.13	1.23	16.52	10.73	0.19	5.67	6.31	5.44	0.02	0.32	3.1	100.66	43	–	220	32	145	7	–	1	22	107	52	44	242	99
1153	55.26	1.12	14.11	12.21	0.20	3.49	8.23	3.30	0.35	0.16	1.4	99.83	96	5	212	35	109	5	1	14	18	100	17	17	285	5
1156	46.14	1.00	17.39	12.04	0.17	8.07	9.13	3.05	0.34	0.13	3.5	100.96	159	8	109	26	68	5	–	13	24	106	15	70	243	87
1164	44.48	1.12	18.86	13.25	0.19	8.11	6.98	3.31	0.56	0.14	4.0	101.00	166	20	150	27	74	5	–	6	22	125	42	79	301	82
1310	49.92	1.68	15.38	11.12	0.21	6.95	8.43	3.19	0.37	0.25	2.8	100.30	84	5	224	37	148	9	–	21	19	197	101	53	334	257
1318	55.13	1.98	14.96	8.90	0.15	4.60	5.87	5.12	0.12	0.24	4.7	101.77	60	–	234	37	125	10	–	10	18	93	9	36	212	129
1355	46.91	1.27	16.03	14.15	0.19	6.78	7.28	2.89	0.23	0.21	4.1	100.04	96	4	245	31	91	6	1	7	21	121	87	46	337	133
5131	51.01	1.08	16.33	10.47	0.21	5.84	5.70	4.93	0.24	0.18	3.0	98.99	161	7	155	30	88	7	10	10	20	144	72	95	229	161
8123	52.17	1.35	15.02	10.70	0.17	5.51	9.88	2.10	0.12	0.21	3.0	100.23	65	5	344	34	111	5	10	29	13	88	137	164	287	329
8126	79.15	0.12	11.33	1.12	0.03	0.06	0.76	3.84	2.67	0.01	0.6	99.69	892	42	111	85	257	18	10	10	7	13	36	5	5	12
RM241	47.44	0.65	17.55	11.53	0.19	6.08	9.17	2.23	0.28	0.10	3.8	99.02	194	7	257	16	52	5	10	10	15	94	38	34	307	53
2. SW of Point Wolfe River																										
4504	49.49	0.91	16.07	9.85	0.16	6.84	9.14	2.71	0.85	0.20	2.9	99.12	216	23	388	19	77	5	–	–	16	105	30	130	254	331
4569	52.10	1.65	14.89	13.44	0.18	4.54	4.40	4.68	0.21	0.27	2.9	99.26	128	3	99	29	133	5	4	–	18	124	65	51	321	25

Table C.3. (cont.)

SAMPLE	SiO_2	TiO_2	Al_2O_3	$Fe_2O_3^t$	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	LOI	TOTAL	Ba	Rb	Sr	Y	Zr	Nb	Th	Pb	Ga	Zn	Cu	Ni	V	Cr
4576	51.25	1.15	17.58	9.94	0.14	5.75	5.99	3.82	0.02	0.23	4.3	100.17	36	–	266	23	119	7	–	–	14	86	78	78	215	260
4594	49.26	1.45	16.07	10.93	0.18	7.99	6.04	3.26	0.05	0.24	4.3	99.77	45	–	351	37	141	6	–	–	17	110	130	94	278	265
5006	49.78	1.56	15.66	11.73	0.20	5.10	5.40	4.22	1.21	0.36	5.7	100.92	294	39	135	37	142	7	10	10	21	141	5	67	308	34
5534	55.73	2.14	14.19	11.89	0.14	3.10	2.98	4.63	1.47	0.49	2.1	98.86	381	20	68	47	225	12	10	10	12	138	166	20	295	5
EB24	49.85	0.89	16.53	9.78	0.16	6.97	9.38	2.67	1.03	0.17	2.9	100.33	259	26	355	19	76	5	1	15	17	98	34	73	245	280
EB31	48.11	1.12	18.45	11.06	0.17	5.04	8.61	2.24	1.26	0.23	3.4	99.69	460	31	562	21	94	6	4	10	14	115	42	21	274	52
EB34	48.23	0.92	16.67	10.21	0.17	7.58	8.63	2.82	1.33	0.16	3.3	100.02	386	38	317	20	76	6	1	5	14	92	46	79	257	339
EB35	49.88	1.10	16.14	10.25	0.15	6.50	7.06	4.49	0.75	0.31	2.6	99.23	312	15	391	23	115	8	3	4	16	108	–	62	265	178
EB36	49.44	1.08	16.47	10.30	0.16	6.64	7.50	3.74	1.47	0.30	2.8	99.90	380	44	315	23	112	7	3	7	17	103	48	60	275	181
EB37	49.81	1.27	16.40	10.63	0.19	6.14	7.34	4.99	0.17	0.26	2.5	99.70	83	1	332	24	128	7	1	9	18	109	58	57	264	162
3. Shanklin area																										
6002B	48.38	1.07	16.14	11.81	0.19	7.60	7.42	2.76	0.58	0.17	3.4	99.52	269	18	194	21	65	5	10	13	17	102	43	140	226	171
6034	46.91	1.52	14.66	14.18	0.24	8.19	5.51	4.00	0.48	0.25	3.5	99.44	265	12	188	29	96	5	12	19	19	170	84	117	367	194
6041	49.72	1.82	16.12	15.01	0.46	4.29	3.03	5.16	0.02	0.26	3.4	99.29	29	5	46	41	153	5	19	16	18	263	30	45	363	166
6043	52.80	1.54	13.90	12.55	0.22	4.82	5.41	5.29	0.11	0.28	2.3	99.22	75	11	58	33	133	5	19	10	18	114	51	37	336	133
6044	51.07	0.96	16.43	9.65	0.15	6.18	9.16	2.63	0.71	0.23	1.9	99.07	217	12	230	18	115	5	17	10	18	96	19	95	222	170
6083	49.73	1.43	15.34	12.99	0.20	6.54	5.45	4.33	0.85	0.24	2.8	99.90	514	27	102	31	140	5	10	10	19	125	59	96	303	156
6151	46.07	1.18	20.95	10.58	0.50	8.06	4.50	2.56	0.19	0.30	6.0	100.89	247	6	202	23	146	8	18	10	25	142	23	101	292	238
CB07	51.68	1.03	15.14	11.27	0.20	6.55	5.64	5.08	0.05	0.15	2.9	99.69	15	–	43	33	89	8	4	14	15	96	87	67	281	169
CB10	46.85	1.23	16.64	11.62	0.21	8.29	6.45	4.06	0.24	0.26	4.1	99.95	155	1	242	28	108	7	1	14	14	99	11	74	284	272
CB12	47.12	1.13	16.39	11.98	0.21	7.98	7.09	2.76	0.66	0.18	3.4	98.90	314	9	205	28	72	5	1	5	18	113	14	95	246	181
CB13	49.42	1.06	15.48	11.43	0.20	7.50	7.20	3.41	0.59	0.15	3.1	99.54	448	6	203	28	74	7	2	17	15	110	70	78	234	120
CB15	47.27	1.03	15.87	11.83	0.17	8.20	9.37	2.44	0.39	0.14	2.6	99.31	98	7	140	25	58	5	1	9	15	91	18	108	247	231
CB16	50.91	0.96	14.92	11.21	0.24	7.01	5.56	4.85	0.33	0.13	3.4	99.52	132	5	95	29	76	7	2	12	14	146	48	67	310	190
UNIT Cbrs																										
1. northern (Hanford brook) area																										
6050	53.36	1.46	15.35	10.36	0.19	5.55	4.79	4.06	1.47	0.22	3.3	100.11	1035	40	514	23	136	7	20	19	16	122	33	22	331	38
6053	54.25	1.48	15.02	10.59	0.15	4.08	6.49	2.81	1.96	0.23	2.2	99.26	394	67	332	27	142	7	17	14	21	110	40	16	354	24
2. southwestern (Vernon Mountain) area																										
6025	48.22	1.21	16.29	10.21	0.21	6.04	8.76	2.87	0.07	0.24	6.6	100.72	32	5	355	24	106	5	13	12	19	122	13	104	271	116
6036	45.90	1.02	16.10	12.26	0.19	7.65	10.80	2.80	0.43	0.14	2.4	99.69	145	14	153	26	54	5	16	18	22	112	31	149	257	196
6216	44.01	1.46	16.51	14.80	0.21	6.35	8.99	2.37	0.05	0.20	4.6	99.55	53	6	209	29	84	5	10	10	19	137	117	155	290	94
6528	67.94	1.02	13.21	6.23	0.15	1.94	1.56	5.84	1.23	0.30	0.9	100.32	367	29	91	50	285	8	17	10	15	108	14	5	27	13
7064A	52.16	1.21	16.09	12.26	0.20	6.41	4.02	4.22	0.62	0.20	3.0	100.39	237	12	270	30	125	6	10	10	14	124	45	63	274	29
7081	49.47	0.90	15.77	9.25	0.19	8.08	8.63	2.26	0.26	0.12	4.4	99.33	98	9	300	22	103	5	10	13	14	85	9	180	245	441
CB28	48.66	1.08	15.84	11.94	0.21	6.88	8.60	2.79	0.85	0.16	2.1	99.11	234	20	194	27	78	5	1	3	16	92	16	79	238	158
CB29	49.78	0.97	15.35	11.61	0.19	6.72	9.52	2.17	0.52	0.13	1.9	98.86	172	12	151	24	59	4	1	11	14	99	11	78	234	180
UNIT O_G (Grassy Lake formation)																										
5526	71.99	0.44	13.69	3.53	0.11	0.92	0.75	4.24	2.80	0.06	0.8	99.33	481	85	52	65	383	18	10	10	18	97	5	5	5	5
5542	74.55	0.24	13.08	2.37	0.09	0.75	0.43	4.04	3.23	0.04	0.6	99.42	575	96	47	61	320	17	10	10	16	63	5	5	5	10
UNIT D_F (Fairfield formation)																										
6218	73.79	0.32	13.40	1.76	0.07	1.10	0.45	5.25	3.27	0.06	0.9	100.37	467	63	66	28	230	9	19	10	13	27	8	5	5	8

Table C.4. *Circa* 560-550 Ma plutons.

SAMPLE	SiO_2	TiO_2	Al_2O_3	$Fe_2O_3^t$	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	LOI	TOTAL	Ba	Rb	Sr	Y	Zr	Nb	Th	Pb	Ga	Zn	Cu	Ni	V	Cr
Mechanic Settlement Pluton (Z_{MS})																										
4150A	49.11	0.52	16.77	6.61	0.12	8.41	13.49	1.62	0.43	0.08	1.8	98.96	140	9	178	14	70	4	–	–	13	61	40	97	143	207
4150B	41.41	0.36	4.99	14.11	0.21	27.78	3.22	0.77	0.19	0.05	6.1	99.19	47	6	55	8	35	4	–	–	7	89	33	858	108	1577
4160	53.42	1.25	16.40	9.40	0.15	4.76	8.52	3.09	0.91	0.19	0.4	98.49	232	24	239	30	126	10	–	–	21	88	41	27	263	30
4161	46.50	1.75	16.01	11.39	0.16	6.56	11.33	2.01	0.57	0.15	2.5	98.93	185	11	358	20	71	4	–	–	20	87	610	44	339	28
4164	58.41	1.17	16.07	8.51	0.23	3.07	4.76	3.93	1.57	0.22	1.2	99.14	391	58	273	44	157	11	–	6	19	117	8	15	144	10
4167B	48.60	2.13	14.71	15.42	0.20	4.29	7.98	2.14	0.86	0.20	1.8	98.33	304	25	293	26	141	7	–	–	19	115	67	8	642	6
4168	53.78	1.83	14.39	12.30	0.29	3.69	6.74	3.43	1.04	0.48	0.9	98.87	331	21	303	40	122	5	–	–	19	140	13	3	253	5
4181	46.72	1.59	16.80	14.68	0.18	4.85	10.11	2.43	0.57	0.12	1.1	99.15	165	19	276	24	74	5	10	10	20	84	57	5	472	11
4209	45.35	0.36	11.26	11.08	0.17	16.76	8.72	1.31	0.33	0.05	3.6	98.99	82	8	157	11	50	4	–	–	11	80	58	433	109	552
4211	48.61	0.88	18.03	7.35	0.14	7.10	11.42	1.77	0.65	0.45	1.8	98.20	190	19	367	24	61	5	10	10	17	57	11	64	145	251
9518	50.34	0.67	14.28	8.84	0.18	11.26	7.88	1.56	0.56	0.11	3.5	99.18	274	16	183	18	65	5	10	10	13	79	18	166	178	355
9526	62.26	1.19	14.44	8.00	0.23	1.27	4.00	4.38	1.90	0.33	1.1	99.10	550	42	236	62	201	15	10	20	20	184	7	8	5	5
9528	40.77	0.24	5.46	11.36	0.18	28.79	3.62	0.15	0.33	0.03	7.5	98.43	57	11	63	6	44	5	10	10	5	75	5	1054	88	2419
MS04	45.22	0.22	16.19	9.99	0.17	14.54	9.38	0.82	0.23	0.02	2.8	99.58	76	7	221	7	19	5	10	10	13	65	609	554	57	331
MS09	51.89	0.39	12.22	9.81	0.20	15.44	8.22	0.89	0.34	0.03	1.1	100.53	87	9	139	11	29	5	10	10	9	73	13	220	130	542
MS19	47.49	0.24	2.59	9.63	0.20	22.80	13.86	0.09	0.01	0.00	3.2	100.11	12	5	15	9	9	5	10	10	5	58	8	367	110	2377
MS24	46.05	0.40	16.24	9.64	0.16	13.10	8.90	0.86	0.65	0.06	4.3	100.36	269	19	195	13	46	5	10	15	12	102	268	276	114	304
MS25	39.97	0.37	3.81	13.56	0.21	32.92	2.02	0.09	0.23	0.06	7.0	100.24	45	7	39	8	28	5	10	10	7	79	12	1092	97	2577
MS27	49.83	0.45	8.05	10.99	0.21	19.82	9.04	0.60	0.29	0.03	0.9	100.21	86	11	85	14	34	5	10	10	7	72	33	296	142	1067
MS30	45.15	0.07	27.01	4.03	0.06	7.11	12.13	1.25	0.15	0.01	2.3	99.27	66	5	333	5	12	5	10	11	17	27	6	168	16	162
MS44A	42.86	0.10	12.18	15.29	0.23	21.24	6.08	0.43	0.03	0.00	2.9	101.34	37	5	148	5	5	5	10	10	10	99	264	380	31	57
MS48	39.02	0.14	7.41	12.85	0.22	28.29	4.35	0.11	0.08	0.02	8.3	100.79	31	5	112	5	9	5	10	10	7	68	30	883	50	1286
MS65	44.15	0.54	19.52	9.33	0.14	9.07	10.89	1.65	0.32	0.01	3.6	99.22	115	8	407	10	12	5	10	10	16	69	211	123	226	219
MS68	48.66	0.35	17.17	7.21	0.13	10.80	11.31	1.17	0.28	0.05	1.5	98.63	93	8	239	14	41	5	10	10	14	53	21	182	89	415
MS72	39.52	0.32	5.87	13.92	0.23	29.05	3.60	0.16	0.14	0.01	8.0	100.82	36	5	100	8	15	5	10	10	6	79	239	1043	115	1912
MS80	42.57	0.39	7.28	11.86	0.20	27.41	4.59	0.27	0.28	0.02	5.2	100.07	71	10	86	102	25	5	10	10	8	77	40	898	102	1669
MS119	54.06	1.19	16.63	10.21	0.16	4.56	8.13	2.80	0.77	0.19	0.7	99.40	235	19	249	33	118	5	10	10	18	82	18	26	239	27
MS127	65.01	1.14	15.02	5.99	0.11	1.52	3.71	3.97	1.63	0.32	1.1	99.52	380	51	210	53	204	12	10	10	19	63	5	10	44	9
MS130	52.53	0.36	19.91	6.53	0.10	4.27	8.43	3.17	0.54	0.08	2.3	98.22	235	14	318	16	58	5	10	10	20	69	920	545	50	109
MS133	57.33	0.87	18.94	4.71	0.16	4.15	4.83	3.93	1.36	0.27	2.0	98.55	815	37	359	18	106	7	10	10	14	49	48	93	75	75
MS145	58.06	0.81	16.95	7.58	0.16	3.64	6.10	3.51	1.02	0.20	1.3	99.33	316	24	284	26	94	6	10	10	18	99	47	28	157	46
MS149	54.44	1.05	16.14	9.79	0.21	5.23	7.42	2.75	0.81	0.17	1.2	99.21	238	25	236	33	90	7	10	10	16	117	76	46	187	64
Devine Corner gabbro (Z_{DC})																										
5502	47.84	0.88	16.33	7.50	0.14	8.31	9.60	2.46	1.90	0.30	4.7	99.96	385	66	401	19	97	5	10	10	17	69	5	91	181	284
DC01	48.00	0.85	14.33	9.93	0.16	10.49	8.95	2.44	0.65	0.26	3.6	99.66	314	13	419	24	106	5	10	10	12	86	74	125	147	248
Caledonia Mountain Pluton (Z_{CM})																										
35-8073	41.18	1.93	17.06	17.37	0.16	5.59	13.18	1.60	0.67	0.09	2.0	100.83	118	18	464	9	13	5	10	11	23	93	34	27	734	5
8074A	44.75	2.72	14.82	17.15	0.26	5.74	9.27	2.84	0.84	0.92	1.5	100.81	349	28	511	30	36	5	10	10	22	115	42	5	304	5
8075	40.52	3.00	13.33	20.58	0.24	6.72	11.95	2.01	0.27	0.76	1.5	100.88	86	7	465	20	22	5	10	10	21	123	31	5	588	5
8961	51.81	0.84	11.45	12.96	0.22	10.90	8.14	1.30	0.56	0.06	2.2	100.44	112	17	126	9	34	5	10	10	12	90	55	51	378	157
Baxters Mountain Pluton (Z_{BM})																										
6544	73.65	0.26	13.61	2.06	0.06	1.01	0.67	4.93	3.27	0.05	0.9	100.47	511	102	48	45	231	14	29	10	16	38	14	5	9	10
6545	75.57	0.18	11.99	1.77	0.02	0.86	0.14	3.24	4.79	0.03	0.7	99.29	618	202	22	93	233	19	10	10	20	37	7	5	5	11
8026	75.76	0.26	13.15	1.64	0.03	0.34	0.53	4.06	3.58	0.04	0.7	100.09	464	127	40	41	217	13	11	10	16	28	5	5	11	5
6201	49.94	0.88	15.04	9.72	0.20	8.97	7.87	2.54	0.62	0.32	2.2	98.30	575	62	282	22	138	7	11	10	15	117	15	117	181	304
6542	47.18	2.68	12.36	15.68	0.22	6.29	9.52	2.13	1.02	0.39	1.5	98.97	290	49	128	45	182	7	14	10	20	149	62	47	557	62
Bonnell Brook Pluton																										
dioritic unit (Z_{BBd})																										
4251	52.23	0.88	15.95	8.83	0.15	6.05	9.55	3.06	0.82	0.16	1.7	99.38	168	24	232	28	90	6	2	5	17	102	87	69	242	166
4252	53.18	0.83	16.45	8.34	0.14	6.09	8.54	2.88	1.05	0.18	1.6	99.28	208	35	251	27	80	8	–	–	15	98	76	98	210	41

Table C.4. (cont.)

SAMPLE	SiO_2	TiO_2	Al_2O_3	$Fe_2O_3^t$	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	LOI	TOTAL	Ba	Rb	Sr	Y	Zr	Nb	Th	Pb	Ga	Zn	Cu	Ni	V	Cr
4578	73.92	0.27	13.91	1.90	0.05	1.10	1.75	3.57	3.19	0.07	0.7	100.43	511	127	105	28	143	11	9	2	14	29	–	8	21	10
4590B	49.90	0.77	16.96	8.84	0.16	7.44	9.44	2.73	1.12	0.14	1.7	99.20	201	45	255	22	75	5	–	5	19	102	59	154	211	85
granitic unit (Z_{BBg})																										
4094	74.59	0.24	13.10	1.79	0.04	0.85	0.75	3.78	3.68	0.04	0.4	99.26	506	142	46	58	211	17	15		15	34	6	4	5	4
4102	74.30	0.24	13.38	1.95	0.04	0.90	0.66	4.24	3.60	0.04	0.7	100.05	504	133	51	53	207	17	11	10	12	43	3	7	8	12
4114	73.98	0.28	13.19	2.01	0.05	0.92	0.64	4.82	3.15	0.04	0.9	99.98	643	97	59	46	252	15	5	3	15	41	–	3	8	10
4115	75.93	0.23	13.18	1.71	0.05	0.96	0.44	4.23	3.57	0.03	0.4	100.73	570	111	46	44	201	14	12	8	13	43	1	4	4	9
4125	74.23	0.24	12.98	1.75	0.04	0.95	0.80	4.16	3.70	0.05	0.4	99.30	483	134	48	51	195	15	20	27	14	67	10	4	11	8
4136	75.99	0.15	12.55	1.29	0.04	0.85	0.33	4.08	3.91	0.14	0.1	99.43	498	143	22	39	156	17	10	10	16	25	5	5	5	5
4140	75.33	0.20	12.80	1.62	0.04	0.85	0.39	4.56	3.69	0.04	0.5	100.02	485	131	36	54	205	17	13	29	15	46	5	5	5	5
4144	75.99	0.17	12.58	1.35	0.04	0.84	0.44	4.57	3.44	0.03	0.3	99.75	565	82	53	40	177	13	17	10	13	27	5	5	5	5
4247	74.48	0.24	13.17	1.84	0.04	1.04	0.74	4.28	3.54	0.04	0.5	99.91	531	127	48	43	206	16	11	2	15	30	5	4	3	9
4249	73.92	0.31	13.50	2.09	0.05	0.93	1.07	4.16	3.41	0.06	0.7	100.20	430	124	74	34	192	10	14	5	12	55	16	3	8	4
4259	74.26	0.22	12.94	1.68	0.04	0.84	0.63	4.41	3.59	0.04	0.4	99.05	477	128	41	51	227	18	10	3	15	43	3	2	5	5
4272	74.38	0.25	13.04	1.80	0.05	0.91	0.78	4.57	3.55	0.04	0.6	99.97	477	116	45	42	203	13	12	12	15	41	5	5	8	6
4296	74.77	0.22	13.14	1.70	0.04	1.00	0.41	4.71	3.61	0.03	0.4	100.03	458	135	41	41	204	15	10	10	15	46	5	5	5	7
4305	74.73	0.25	13.08	1.33	0.03	0.86	0.91	3.96	3.84	0.04	0.5	99.53	484	143	60	30	162	10	18	5	12	24	3	2	11	3
4599	72.81	0.26	13.37	2.11	0.05	0.92	0.79	4.39	3.17	0.05	1.0	98.92	506	111	50	76	234	19	16	4	16	50	5	8	9	3
4600A	75.28	0.24	13.14	1.79	0.04	0.92	0.78	4.33	3.39	0.04	0.4	100.35	455	99	52	50	209	15	12	7	13	49	6	6	6	11
4626	73.93	0.19	12.87	1.71	0.07	0.82	0.69	4.34	3.51	0.04	0.7	98.87	509	116	48	57	211	14	14	8	14	39	2	10	4	11
5528	75.20	0.23	13.07	1.47	0.04	1.05	0.39	4.38	3.68	0.04	0.8	100.35	491	136	30	44	217	16	10	10	15	33	5	6	5	5
5540	75.23	0.21	13.03	1.62	0.06	0.95	0.47	3.89	3.60	0.03	0.7	99.79	486	136	38	63	209	14	10	10	15	56	5	5	5	5
5541	75.34	0.21	13.05	1.65	0.04	0.84	0.50	3.60	3.62	0.03	0.6	99.48	511	135	37	43	209	16	10	10	15	44	5	5	5	7
6061	76.47	0.10	12.32	1.31	0.04	0.71	0.20	4.31	3.84	0.01	0.5	99.81	502	144	12	60	150	18	14	13	14	36	7	5	5	14
6079	76.79	0.10	12.34	1.02	0.02	1.07	0.13	4.47	3.83	0.01	0.1	99.88	457	154	16	57	151	17	14	19	16	27	7	5	5	14
6090	75.46	0.21	13.46	1.68	0.04	0.82	0.42	4.39	3.60	0.02	0.7	100.80	511	135	33	52	214	16	18	16	14	37	9	5	5	13
6091	75.58	0.27	13.33	1.76	0.06	0.91	0.81	5.13	2.86	0.03	0.3	101.04	453	83	72	41	209	14	12	13	13	38	5	5	8	15
6094	74.68	0.26	13.45	1.80	0.05	1.10	0.89	4.22	3.48	0.03	0.4	100.36	497	137	43	47	218	13	18	12	15	42	8	6	8	18
Dykes related to Bonnell Brook granite																										
4537	74.34	0.20	13.40	1.24	0.07	1.02	0.37	4.01	3.95	0.05	0.7	99.35	585	135	114	21	129	10	19	12	11	30	6	6	10	7
4579	75.97	0.18	13.00	1.68	0.05	0.82	0.57	4.53	3.58	0.03	0.3	100.71	484	123	40	57	201	18	12	27	13	52	4	5	4	6
4581	72.52	0.31	14.03	2.84	0.11	1.08	1.19	4.93	2.75	0.06	0.5	100.32	476	99	80	47	307	15	7	21	16	69	5	5	6	13
Bonnell Brook fine-grained granite (Z_{BBfg})																										
4110	73.44	0.27	13.23	2.64	0.08	0.93	0.45	4.98	3.02	0.05	0.3	99.39	544	100	66	81	336	18	9		16	63	5	6	–	8
4297	73.28	0.24	13.25	2.52	0.09	0.83	0.73	5.22	3.16	0.04	0.2	99.56	599	81	62	60	342	17	10	10	18	73	5	8	5	5
5509	73.18	0.25	13.25	2.17	0.09	0.92	0.66	4.82	2.91	0.05	1.1	99.40	541	96	52	65	334	19	10	10	17	56	5	6	5	5
5599	73.48	0.26	13.30	2.55	0.11	1.04	0.40	4.76	2.95	0.04	0.8	99.69	531	94	47	64	345	16	10	10	19	77	5	5	5	5
Bonnell Brook rhyolitic porphyry (Z_{BBr})																										
4055	72.71	0.28	12.96	2.45	0.08	0.81	0.93	4.86	2.83	0.04	0.5	98.45	526	90	57	65	354	17	6		17	39	1	7	–	4
4058	73.56	0.28	12.97	2.69	0.10	0.87	0.68	4.73	2.82	0.04	0.6	99.34	525	92	46	70	349	18	17	12	17	84	–	2	–	5
Upham Mountain Pluton (Z_{UM})																										
6072	73.26	0.30	12.55	2.55	0.08	0.87	0.60	4.84	3.17	0.04	1.2	99.46	589	109	59	70	388	16	18	18	15	70	9	5	5	12
6073	71.13	0.45	13.20	3.53	0.10	1.02	0.90	5.24	2.98	0.07	1.0	99.62	541	99	114	65	378	16	36	13	20	97	6	5	5	16
6207	74.37	0.24	12.87	2.38	0.06	0.84	0.71	4.42	3.17	0.02	0.9	99.98	580	106	42	71	380	15	30	10	18	59	5	5	5	13
6208	72.93	0.32	12.56	2.34	0.08	0.88	0.86	5.22	2.81	0.04	1.5	99.54	443	86	41	67	357	15	24	10	17	61	8	5	5	10