Geology of the Washabuck Peninsula, Central Cape Breton Island, Nova Scotia

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Introduction

The Washabuck Peninsula is part of the Bras d'Or terrane (Barr and Raeside, 1989; Raeside and Barr 1990) of central Cape Breton Island (Fig. 1). Like other parts of the Bras d'Or terrane, the peninsula includes exposures of varied metamorphic and plutonic rocks surrounded by younger Carboniferous sedimentary units. The Carboniferous rocks on the peninsula are well known for their gypsum quarries and lead-zinc showings, and the presence of an abandoned gold mine and several other mineral occurrences in the older rocks (DeMont, 1991, 1992) suggest that they also have economic potential. The purpose of this project was to develop a better understanding of the distribution and field relations of rock units in the Washabuck Peninsula, with a focus on the petrological features of the pre-Carboniferous units and their comparison to equivalent units in other parts of central Cape Breton Island.

Geological Setting

Although historically most metamorphic rocks in Cape Breton Island were assigned to the George River Series or Group (e.g. Milligan, 1970; Keppie 1979), mapping and petrological studies during the past 25 years have resulted in the recognition of a number of different and in some cases unrelated metamorphic rock units which were given separate names (e.g. Raeside and Barr, 1990). Collectively, the separate metamorphic units in the Bras d'Or terrane are assigned now to either the George River Metamorphic Suite or the Bras d'Or Gneiss (Keppie, 2000). The George River Metamorphic Suite includes mainly low- to medium-grade clastic, carbonate, and volcanic rocks, whereas the Bras d'Or Gneiss consists of mainly high-grade (low-pressure, high-temperature) metamorphic rocks. Both units are intruded by ca. 565 Ma to 555 Ma plutons and less abundant Cambrian and younger plutons. These units are unconformably overlain by clastic sedimentary rocks of the Horton Group, which are in turn disconformably overlain by marine evaporite, carbonate, and clastic rocks of the Windsor Group (Keppie 2000).

Most previous work done on the Washabuck Peninsula concentrated on Carboniferous rocks. Hein *et al.* (1988) described the pre-Carboniferous rocks as "Devonian granitic and dioritic intrusive rocks, with minor gabbroic and dioritic dykes". Goudge (1934) reported a large deposit of Precambrian metamorphosed dolostone and limestone but subsequent published maps grouped the marble with a pre-Carboniferous granite unit (e.g. Lynch and Lafrance, 1996; Keppie, 2000). DeMont (1991, 1992) reported gold, silver, galena, pyrite, chalcopyrite, and sphalerite occurrences near Burnt Point (Fig. 2), hosted by quartzite, hornblende, feldspathic greywacke, and/or rhyolite tuff. He also reported occurrences of gold, silver, galena, chalcopyrite, specularite, bornite and malachite, hosted by similar rocks near Maskells Harbour. Jensen (1993, 1995a, b) reported pre-Carboniferous rocks over a wide area with gold, silver, sphalerite, galena, chalcopyrite, and pyrite

Geology of the Washabuck Area

Introduction

Geological mapping on the Washabuck Peninsula at a scale of 1:10 000 during June 2003, resulted in division of the rocks into five units: Maskells Harbour formation, Washabuck pluton, Grass Cove pluton, Horton Group (Creignish, Strathlorne and Ainslie formations), and Windsor Group (Fig. 2). Petrological studies of the pre-Horton Group rocks

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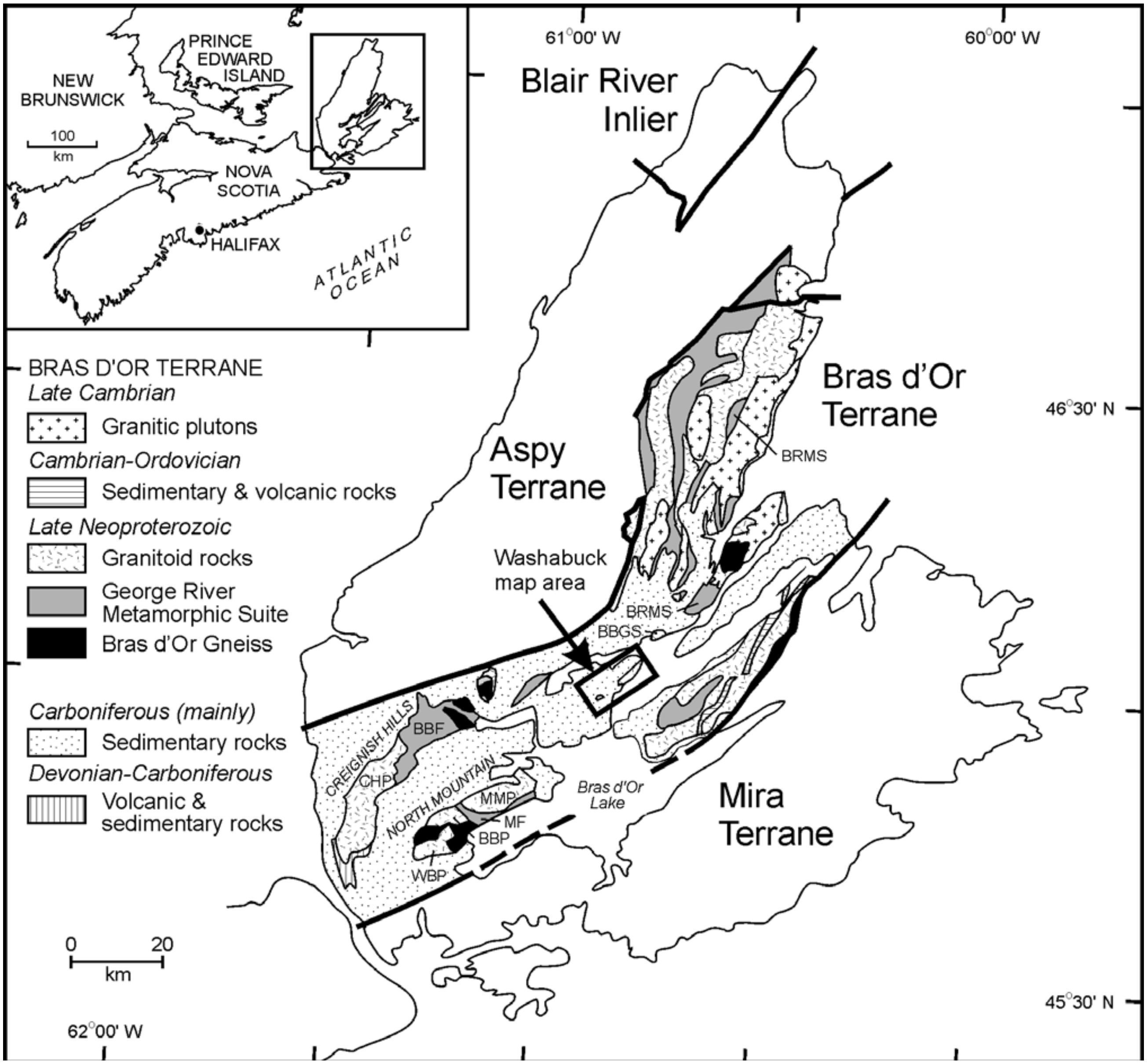


Figure 1. Location of the Washabuck Peninsula map area in the Bras d'Or terrane of central Cape Breton Island. Abbreviations: BBP, Big Brook Pluton; BBGS, Beinn Breagh Granitoid Suite; BRMS, Barachois River Metamorphic Suite; BBF, Blues Brook Formation; CHP, Creignish Hills Pluton; MF, Malagawatch Formation; MMP, Marble Mountain Pluton; WBP, West Bay Pluton.

formed the B.Sc. honours thesis of the senior author (Wasylik, 2004), results of which are the basis of this report.

Maskells Harbour Formation

Rocks assigned to the Maskells Harbour formation (MHf) occur in two areas of the Washabuck Peninsula, a larger area extending northeast from Maskells Harbour and a smaller area west of the community of Gillis Point (Fig. 2). In the northeastern area, the rocks are well exposed in cliff sections along the coast between Maskells Harbour and Burnt Point, and in smaller outcrops inland along streams and logging roads; the coastal section along the northern shore of Maskells Harbour is considered the type section for the formation. In this section, the formation consists of

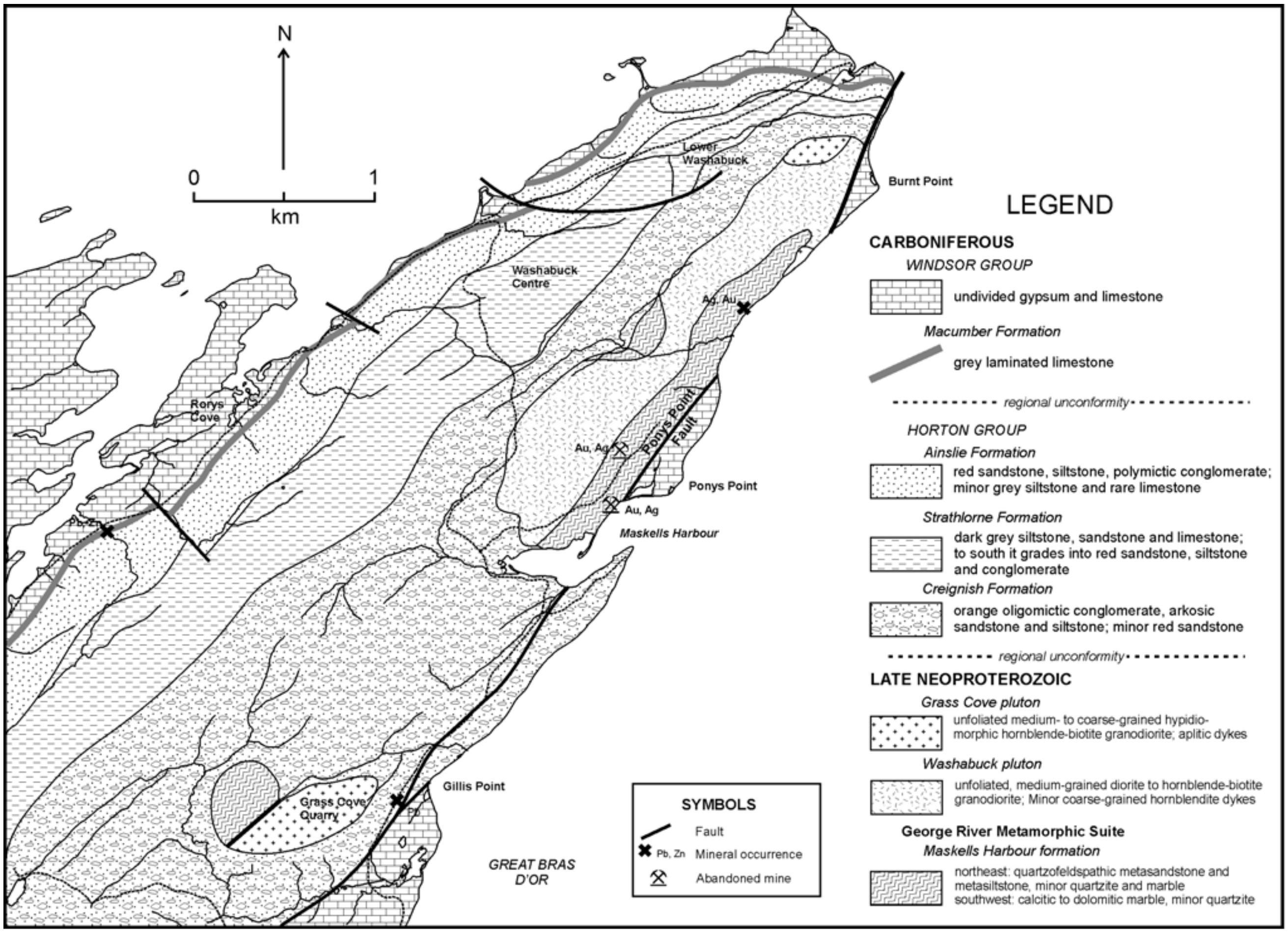


Figure 2. Geological map of the Washabuck Peninsula, simplified from Wasylik (2004).

grey interbedded quartzo-feldspathic metasandstone and metasiltstone with minor thin beds of fine-grained quartzite and fine-grained, dark grey marble. In the southern area near Gillis Point, the formation consists mainly of calcitic to dolomitic marble with minor white quartzite and quartzo-feldspathic metasandstone.

Typical samples of metasandstone and metasiltstone of the MHf contain quartz, plagioclase, microcline, biotite, muscovite, chlorite, and epidote. Foliation is defined by biotite and muscovite, with biotite more abundant (10-25%) than muscovite (less than 5%). Samples from near the contacts with the Washabuck pluton contain porphyroblasts of cordierite, heavily altered to pinite and sericite. Minor marble interbedded with the clastic rocks is fine grained and granoblastic with a weak foliation defined by minor muscovite and chlorite. Metamorphic grade in the Maskells Harbour formation is generally in the biotite zone, except near the contacts of the Washabuck pluton where contact metamorphism has produced cordierite. These contact metamorphosed units were previously considered to be correlative with gneissic units exposed at Kellys Mountain farther to the northeast (Lynch and Lafrance 1996).

Marble in the area of the formation west of Gillis Point is dominantly white, fine- to medium-grained and homogeneous, with layering evident in some places. The layered rocks consist of medium-grained calcite layers and fine-grained calcite and quartz layers. Diopside and minor tremolite occur in the quartz-rich layers, an assemblage consistent with hornblende-hornfels facies metamorphism (Blatt and Tracy, 1996). This assemblage is interpreted to be the result of contact metamorphism by the Grass Cove pluton. Zoisite has partially replaced diopside and small amounts of epidote replace tremolite, evidence of retrograde metamorphism. The quartzite varies from massive and white to thinly layered and grey. The layered rocks are more quartzo-feldspathic and contain biotite.

Bedding in the Maskells Harbour formation dips mainly to the northwest but the distribution of poles to bedding suggests weakly developed sub-horizontal, northeast-trending folds (Fig. 3a). Foliation is sub-parallel to bedding, which results in a steep, northeast-trending intersection lineation (Fig. 3b). A northwest-trending, moderately dipping lineation (Fig. 3c), defined by quartz rods, is evident on foliation planes in some of the coarser grained metasedimentary beds.

In the coastal section northeast of Maskells Harbour, the rocks shows evidence of ductile deformation (mylonitic stretching lineations and related folds) overprinted by later faults, most notably the Ponys Point fault which separates the Maskells Harbour formation from rocks of the Windsor Group to the east. Veins of quartz and calcite are numerous, and some of the larger quartz veins were mined in the past for gold and silver. The Maskells Harbour formation hosts many of these mineral occurrences (Fig. 2) described by DeMont (1991, 1992).

Washabuck Pluton

The Washabuck pluton intruded the Maskells Harbour formation in the northeastern part of the Washabuck Peninsula (Fig. 2). The northeast-trending pluton has an exposed length of approximately 2.5 km and an average width of approximately 300 m (Fig. 2). It consists of unfoliated, medium-grained diorite, quartz diorite, tonalite, quartz monzodiorite, and hornblende-biotite granodiorite (Fig. 4). Variations among these different lithologies appear to be gradational. Also present are coarse-grained hornblende-rich rocks ('hornblendite') containing hornblende crystals up to 2 cm in length, interpreted to represent pegmatoid lenses and segregations related to the pluton. A granitic pod, with smaller pods and dykes of aplite within it, intruded the diorite in the coastal section, and a small granitic body, not observed during the present study, was reported by Jensen (1993) inland at the northern margin of the pluton. These granitic units are likely to be related to the Grass Cove pluton, described below.

Major minerals in the Washabuck pluton are plagioclase and amphibole, with variable amounts of biotite, quartz, and microcline. All samples are fine- to medium-grained, hypidiomorphic granular to inequigranular in texture with accessory opaque minerals, titanite, apatite, and zircon. Secondary minerals include sericite, saussurite, chlorite, epidote and clinozoisite. Microprobe analyses indicate that the amphibole composition is magnesio-hornblende (Wasylik, 2004). Plagioclase composition ranges from An 36-49, and biotite has a lower Al_2O_3 content than the metamorphic biotite in the Maskells Harbour formation.

Grass Cove Pluton

The Grass Cove pluton outcrops over an area of less than 1 km^2, but is well exposed in a large quarry west of Gillis Point and northwest of Grass Cove (Fig. 2). It consists mainly of pink, massive, homogeneous medium- to coarse-grained hornblende-biotite granodiorite with areas of fine-grained, grading to coarse-grained, monzogranite to syenogranite and associated muscovite-bearing aplite dykes. The granodiorite and granite units do not appear gradational, but due to limited outcrop it was not possible to map the distribution of the two rock types. Both the granodiorite and granite are dominantly unfoliated, but a weak foliation is developed in the western part of the intrusion, near and parallel to the inferred faulted contact with the Maskells Harbour formation to the west. Like the Washabuck pluton, the Grass Cove pluton contains metasedimentary xenoliths with lithologies consistent with derivation from the Maskells Harbour formation. Also present in the Grass Cove pluton are dioritic xenoliths likely derived from the Washabuck pluton.

The granitic units contain perthitic microcline, whereas the granodiorite contains less abundant orthoclase. One analysis of plagioclase in the monzogranite gave an oligoclase (An24) composition, whereas plagioclase in the granodiorite is more calcic andesine (An36). Biotite is lower in aluminum than that in the Washabuck pluton or Maskells Harbour formation (Wasylik, 2004). Minor hornblende is present in the granodiorite. Accessory minerals are magnetite, titanite and apatite in both the granite and

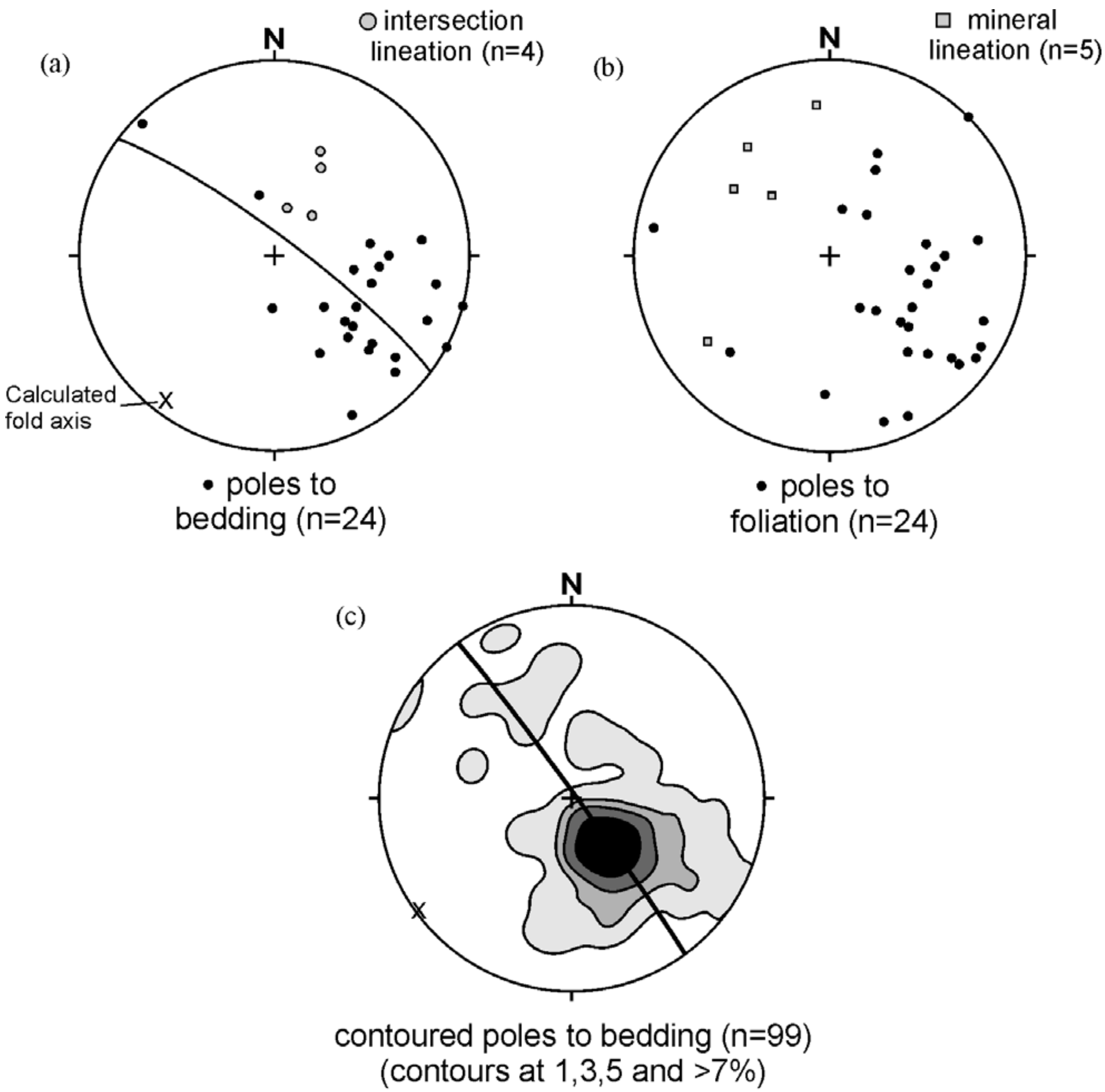


Figure 3. Structural data from the Washabuck Peninsula plotted on equal area stereonets. (a) Poles to bedding (black circles, n=24) and intersection lineations (grey circles, n=4) in the Maskells Harbour formation. (b) Poles to foliation (black circles, n= 24) and mineral lineations (grey squares, n=5) in the Maskells Harbour formation. (c) Equal area stereonets showing contoured poles to bedding (n=99) in Carboniferous rocks in the area shown in Figure 2. X is the calculated fold axis. Contours are at 1, 3, 5, and >7%.

granodiorite, and the granodiorite also contains subhedral allanite.

Pods of aplite, pegmatite and medium- to coarse-grained granite in both the Maskells Harbour formation and the Washabuck pluton are likely to be related to the granitic unit of the Grass Cove pluton.

Minor Mafic Intrusive Units

Mafic dykes and sills occur in both the metamorphic and plutonic units and are of two types: fine-grained greenish-grey diorite and dark grey porphyritic diorite. Both types range in

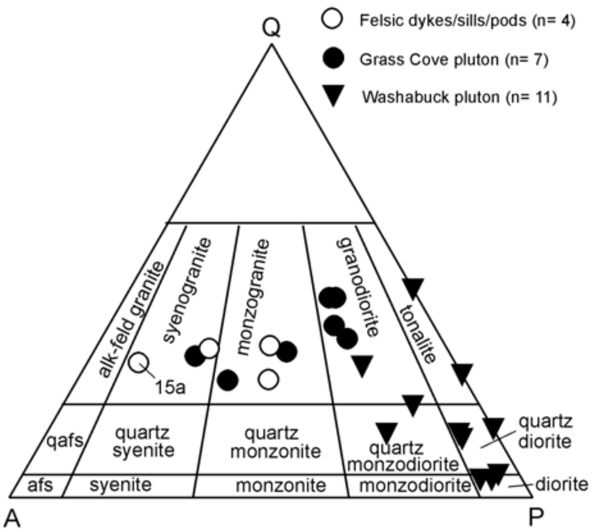


Figure 4. Modal compositions of samples from the Washabuck and Grass Cove plutons and associated felsic dykes plotted on a Q (quartz)- A (alkali feldspar) - P (plagioclase) ternary diagram with fields after Streckeisen (1976).

thickness from approximately 15 cm to 3 m, and in some places the porphyritic dykes were observed to cut the fine-grained dykes. The porphyritic dykes contain very fine-grained quartz, plagioclase, hornblende and epidote in the groundmass, with phenocrysts of plagioclase and some larger clusters of hornblende. Plagioclase is heavily altered to sericite. The fine-grained dykes consist mainly of plagioclase, hornblende, clinopyroxene and biotite.

Horton Group

Sedimentary rocks assigned to the Carboniferous Horton Group overlie the metamorphic and plutonic units (Fig. 2). Although contacts are not exposed, the shallow dips of bedding suggest that the contacts are unconformities. The Horton Group is divided into the Creignish, Strathlorne, and Ainslie formations based on lithological comparisons to the Horton Group elsewhere in the region (e.g. Lynch and Lafrance, 1996). In the Washabuck Peninsula, the Creignish Formation consists of orange oligomictic conglomerate, arkosic sandstone and siltstone with minor red sandstone and siltstone. Clasts in the conglomerate are dominantly granitic with minor quartzite and resemble units in the underlying Washabuck and Grass Cove plutons, and Maskells Harbour formation. The overlying Strathlorne Formation is characterized by dark grey siltstone, sandstone, and thin impure limestone. Although red sandstone and siltstone are typically absent in the Strathlorne Formation, they increase in abundance towards the top of the unit, which is conformably overlain by red sandstone, siltstone and polymictic conglomerate and minor grey siltstone of the Ainslie Formation. Grey, locally algal to oolitic limestone beds occurs throughout the Ainslie Formation.

Bedding orientations in the Carboniferous units indicate a southwest-plunging anticline cored by the Maskells Harbour formation, Washabuck pluton and Grass Cove pluton (Fig. 3c). Minor local faulting occurs in the Carboniferous units along the northwest coast of the peninsula.

Windsor Group

The Windsor Group in the Washabuck Peninsula is divided into the basal Macumber Formation, which consists of grey laminated limestone, and an upper undivided gypsum and limestone unit with minor siltstone (e.g. Hein *et al.*, 1988). Along the northwestern margin of the peninsula, an outcrop shows a disconformable contact between the Ainslie Formation of the Horton Group and the Macumber Formation of the Windsor Group. In the southeastern part of the peninsula, the Windsor Group is in faulted contact, along the Ponys Point fault, with pre-Carboniferous rocks.

Geochemistry

Major and trace element analyses were obtained for representative samples from the Washabuck and Grass Cove plutons, as well as from granitic and mafic dykes and sills in these units. The data and analytical methods were presented by Wasylik (2004), and only a summary of the results is presented here.

Eleven samples analyzed from the Washabuck pluton range in SiO_2 content from 50.15% to 62.31% (Fig. 5). Dioritic samples have the lowest SiO_2 contents, and a granodiorite sample has the highest SiO_2 content. TiO_2, $Fe_2O_3^t$, MgO, CaO and P_2O_5 all show strong negative correlation with SiO_2, whereas Na_2O and K_2O show a scattered positive correlation (Fig. 5). Al_2O_3 contents vary

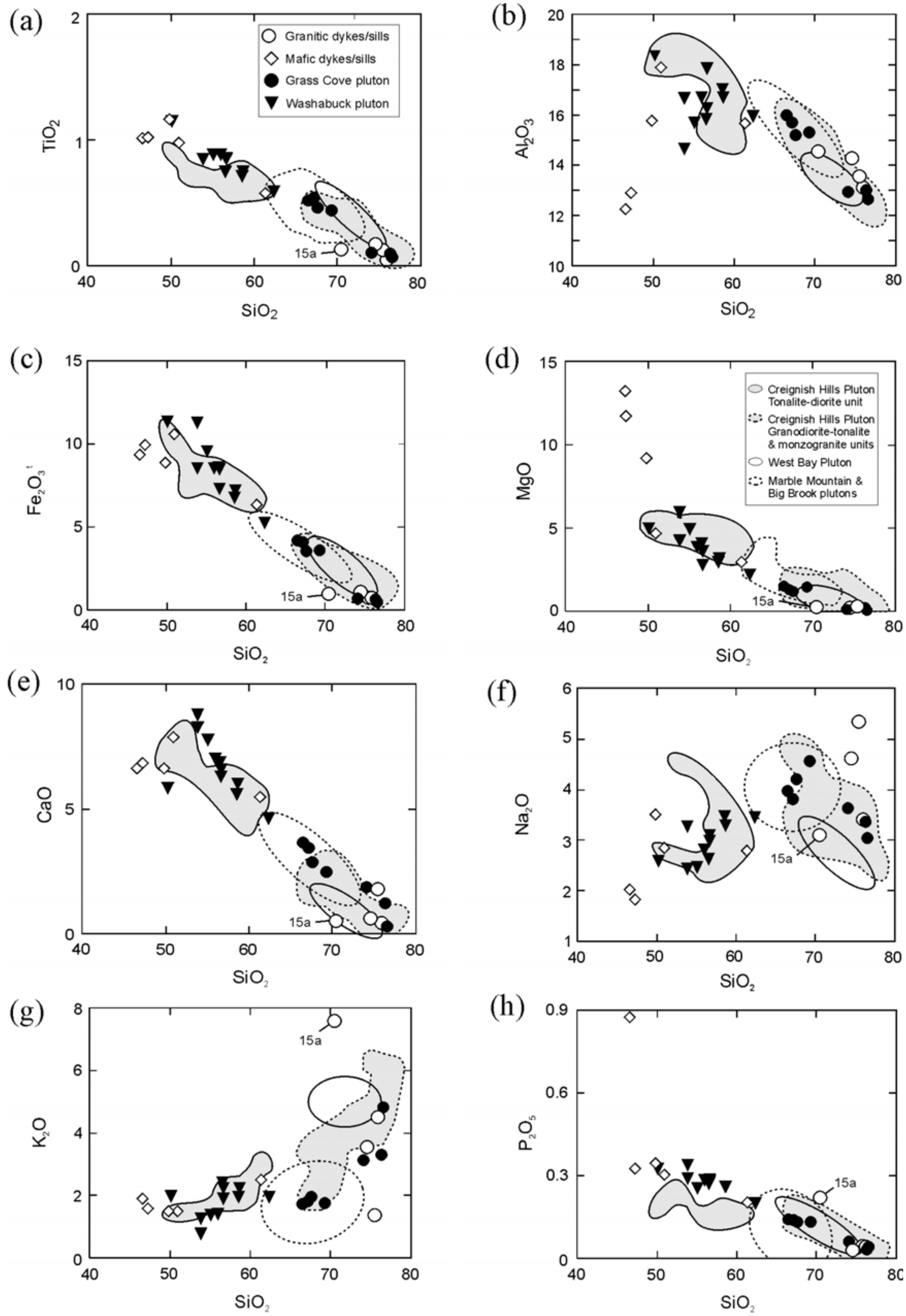


Figure 5. Plots of selected major element oxides against SiO_2 to illustrate chemical variation in the Washabuck and Grass Cove plutons and associated mafic and felsic dykes. Fields for plutons in the Creignish Hills and North Mountain areas (Fig. 1) are shown for comparison.

from 14.65% to 18.39 % and show little correlation with SiO_2 (Fig. 5b).

The seven samples analyzed from the Grass Cove pluton range in SiO_2 content from 66.43% to 76.51% (Fig. 5). The four granodiorite samples have the lowest SiO_2 contents (66-70%), whereas the monzogranite and syenogranite samples have the highest SiO_2 content, (ca. 75%). In the felsic samples as a whole, Al_2O_3, TiO_2, $Fe_2O_3^t$, MgO, CaO, Na_2O, and P_2O_5 all show strong negative correlation with SiO_2, and K_2O shows strong positive correlation (Fig. 5). The most felsic granodiorite sample in the Washabuck pluton is chemically similar to the lowest SiO_2 granodiorite sample from the Grass Cove pluton, suggesting that the two plutons could be co-magmatic and related by crystal fractionation processes, although the gaps in SiO_2 contents suggests that not all components of the plutonic suite are exposed. Three granitic dykes are generally similar in composition to the monzogranite/syenogranite samples from the Grass Cove Pluton, supporting the interpretation based on petrographic features that they are related to that unit. However, a fourth dyke of syenogranite composition (15a on Fig. 4) has lower SiO_2 , similar to that in the granodiorite samples, but with much lower TiO_2, $Fe_2O_3^t$, MgO, CaO and Na_2O, and much higher K_2O and P_2O_5 (Fig. 5), and is unlikely to be directly related to the other granitic units.

Three of the mafic dyke/sill samples are basaltic (ca. 50% or less SiO_2) but two samples, both from porphyritic dykes in the Maskells Harbour formation, have higher SiO_2 and are chemically very similar to the sample suite from the Washabuck pluton, to which they are likely related. The other dykes occur in both the Maskells Harbour formation and the plutonic units, show chemical differences from the dioritic Washabuck pluton samples, and are probably younger than and unrelated to the pluton.

Trace elements generally display more variation than the major element oxides. Typical examples are illustrated in Figure 6. Wide variation in Ba and Rb in the granitic samples suggest the influence of K-feldspar fractionation in the later stages of magma evolution. Metal levels are generally low, but some of the Washabuck pluton samples show elevated levels of Pb, Zn, and/or Cu (Fig. 6f, g, h).

On the AFM diagram (Fig. 7), the samples overall display a calc-alkaline trend for both plutons, with a prominent gap between the granodiorite and monzogranite/syenogranite samples in the Grass Cove pluton. On this diagram, the Washabuck pluton and granodiorite unit of the Grass Cove pluton appear related whereas the granitic dykes and sills appear to be related to the granitic parts of the Grass Cove pluton.

Samples with more than 60% SiO_2 plot in the volcanic-arc granite field on the Rb/Y+Nb discrimination diagram (Fig. 8a). Samples with less than 55% SiO_2 from the Washabuck pluton and mafic dykes and sills plot in the calc-alkalic basalt field of the Ti-Zr-Y discrimination diagram (Fig. 8b).

Taken all together, the chemical characteristics indicate calc-alkalic chemical affinity for samples from the Washabuck Peninsula area, and are consistent with origin in a volcanic-arc setting. Given the range in compositions, the Washabuck and Grass Cove plutons can be considered to be an I-type granitoid suite, which typically form in a continental margin subduction zone such as the modern-day Andes (e.g. Pitcher, 1983). However, given the small areas of exposure of these units, it is likely that the full range of compositions in the original plutons is not represented by the sample set.

Regional Correlations

The Maskells Harbour formation is similar to units elsewhere in the Bras d'Or terrane that make up the George River Metamorphic Suite, especially the Blues Brook and Malagawatch formations (Campbell 1990). Like the Maskells Harbour formation, these units consist of metapelite, calcitic and dolomitic carbonate-bearing rocks, and quartzite, as well as minor metavolcanic rocks not found in the Maskells Harbour formation. Based on location along trend from the Barachois River Metamorphic Suite (Fig. 1), Raeside and Barr (1990) suggested that metamorphic rocks here assigned to the Maskells Harbour formation, as well as those across Bras d'Or Lake at Beinn Breagh, are low-grade portions of that suite. The Barachois River Metamorphic Suite, however, lacks marble and calc-silicate rocks, so that correlation may not be correct.

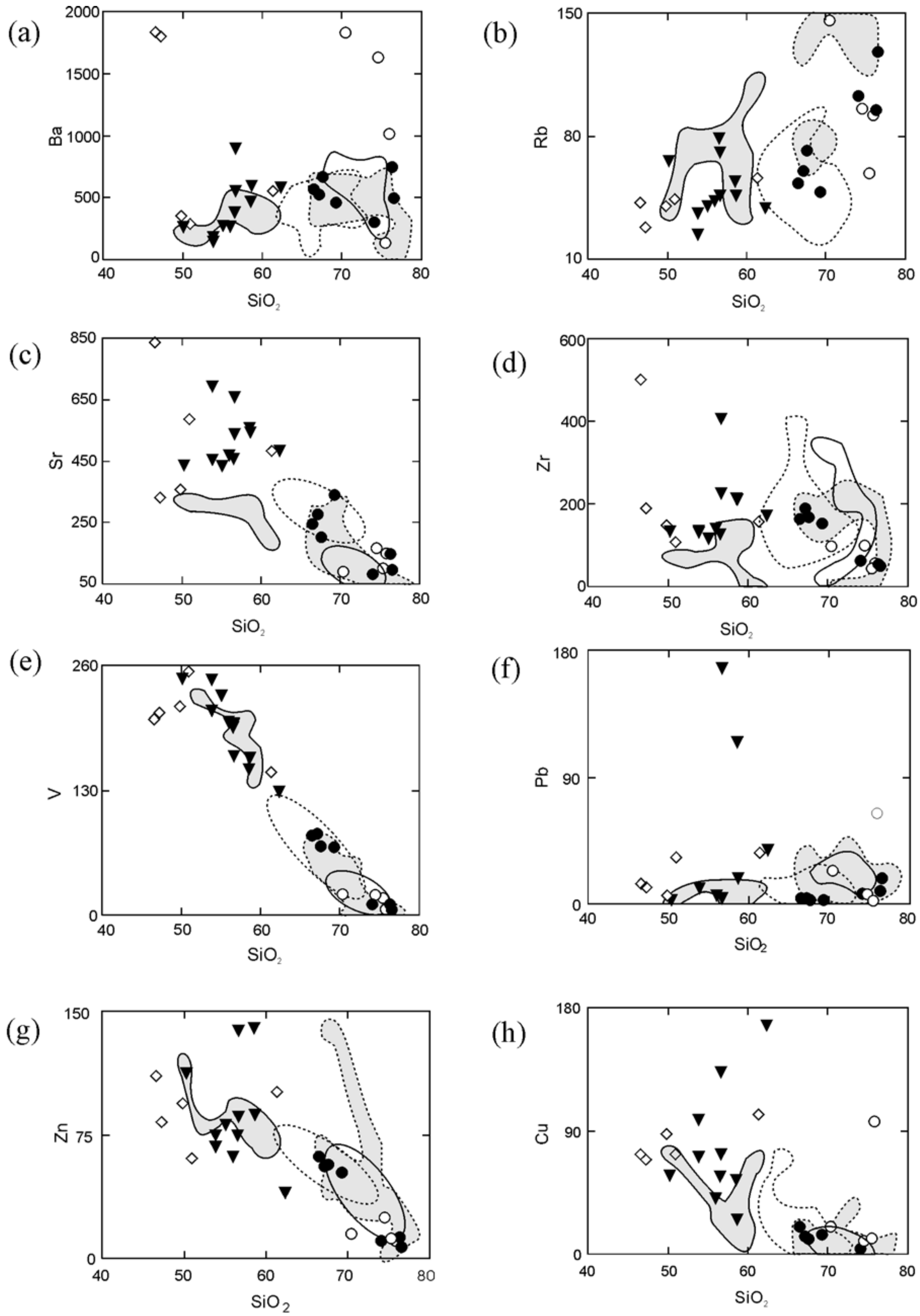


Figure 6. Plots of selected trace elements against SiO_2 to illustrate chemical variation in the Washabuck and Grass Cove plutons and associated mafic and felsic dykes. Fields for plutons in the Creignish Hills and North Mountain areas (Fig. 1) are shown for comparison.

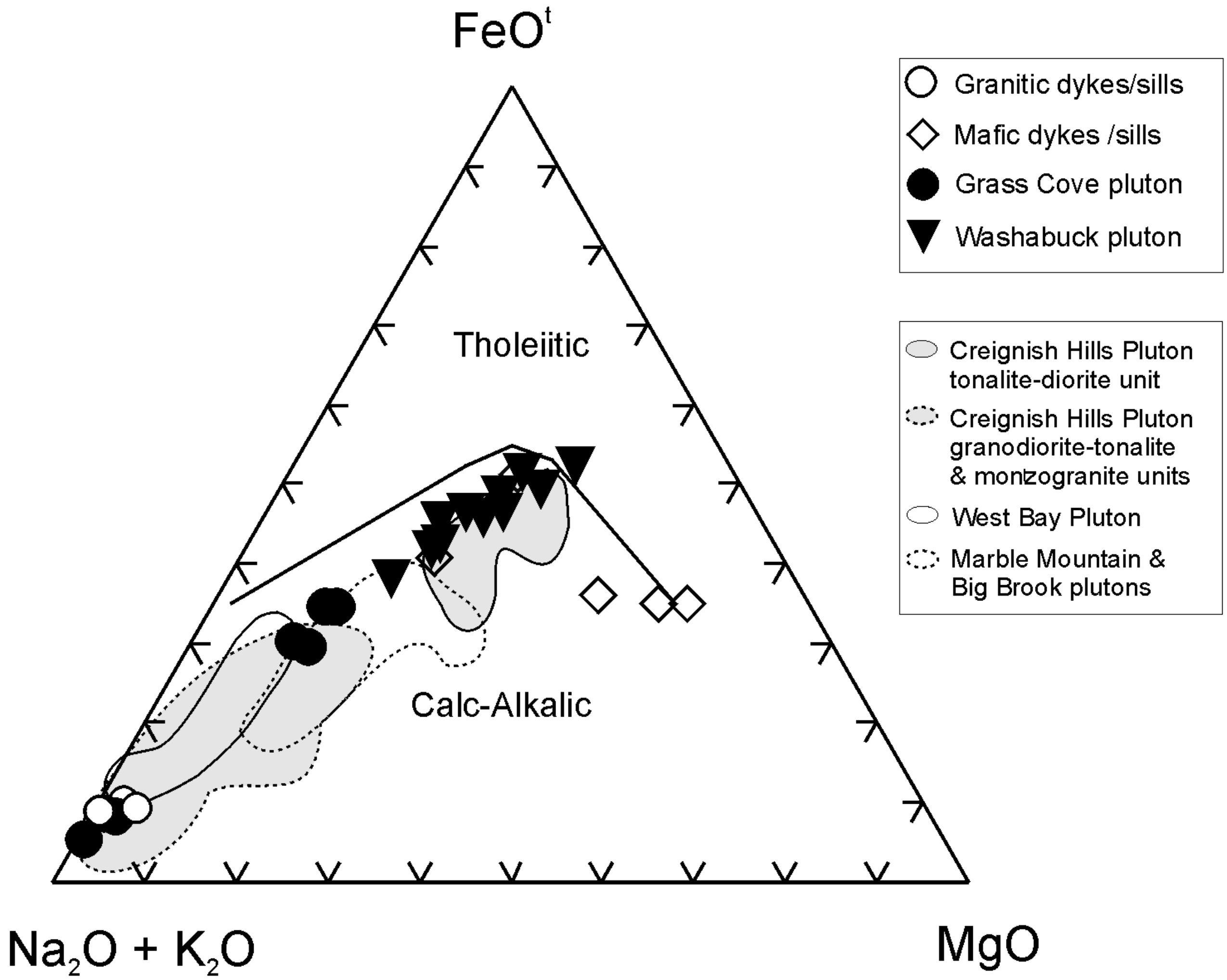
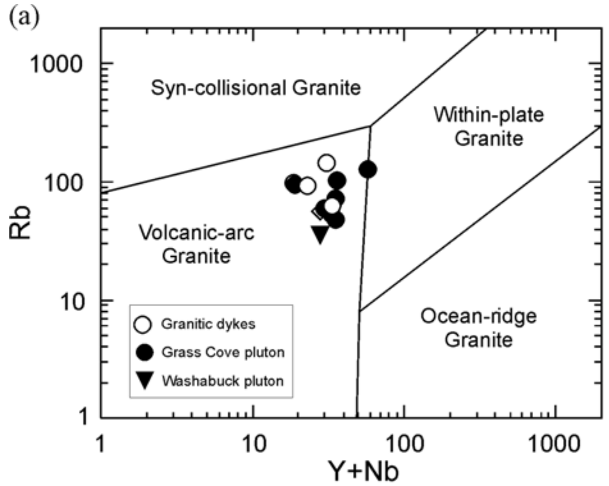


Figure 7. Samples from the Washabuck and Grass Cove plutons and associated mafic and felsic dykes plotted on an AFM diagram with tholeiitic-calc-alkalic dividing line from Irvine and Baragar (1973). Fields for plutons in the Creignish Hills and North Mountain areas (Fig. 1) are shown for comparison.

Late Neoproterozoic and Late Cambrian plutonic rocks are characteristic of the Bras d'Or Terrane (Raeside and Barr, 1990; Fig. 1). The Creignish Hills and related satellite plutons include tonalite-diorite, granodiorite-monzogranite, and monzogranite units (White *et al.*, 1990, 2003), and the Marble Mountain, Big Brook, and West Bay plutons of the North Mountain area also include similar rock types (Justino and Barr, 1994). These units show chemical trends very similar to those in the Washabuck and Grass Cove plutons, although the Washabuck Pluton tends to have higher CaO, P_2O_5, and Sr abundances (Figs. 5, 6). All of these plutons show similar calc-alkalic trends on the AFM diagram (Fig. 7), and likely formed in a continental margin subduction zone setting (Raeside and Barr, 1990; Grecco and Barr, 1999).

Most of the plutonic rocks in the Creignish Hills and North Mountain areas have yielded precise U-Pb ages of ca. 553 Ma (White *et al.*, 2003). Hence it is likely that the Washabuck and Grass Cove plutons are of similar late Neoproterozoic age. The protolith age of the George River Metamorphic Suite is less well constrained, but likely to be ca. 650 Ma (Keppie *et al.*, 1998; Barr *et al.*, 2003). The mainly unfoliated character of the plutonic rocks indicates that they were emplaced after regional metamorphism and deformation of their host rocks.

(a)



(b)

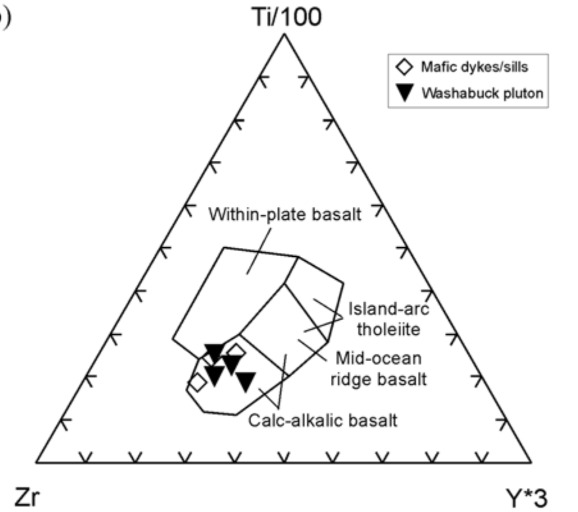


Figure 8. Tectonic setting discrimination diagrams for (a) granitoid and (b) mafic rocks after Pearce *et al.* (1986) and Pearce and Cann (1973), respectively. Samples from the study area with more than 60% SiO_2 are plotted on (a) and those with less than 55% SiO_2 are plotted on (b).

Conclusions

The Washabuck Peninsula is underlain by metasedimentary rocks of the Maskells Harbour formation, part of the George River Metamorphic Suite of the Bras d'Or terrane. The formation is intruded by dioritic to granodioritic rocks of the Washabuck Pluton, and granodioritic and monzogranitic to syenogranite rocks of the Grass Cove Pluton. Similarity to dated plutons in other areas of the Bras d'Or terrane suggests an age of ca. 553 Ma for both plutons. Their petrological features indicate that they are part of an I-type granitoid suite emplaced as a result of subduction at a continental margin. Carboniferous sedimentary rocks of the Horton and Windsor groups surround the exposed Precambrian units.

Acknowledgments

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