Petrology of Four Drillholes in the Faribault Brook Formation near the Road 2 Showing, Western Cape Breton Highlands, Nova Scotia

B. Vibert[1], S. M. Barr[1], and C. E. White

Introduction

The Faribault Brook Formation is a mainly metavolcanic rock unit of probable Cambrian age that forms the lower part of the Jumping Brook Metamorphic Suite in the western Cape Breton Highlands (Fig. 1). Due to rugged topography, limited access, and poor exposure, geological relations among the formations of the Jumping Brook Metamorphic Suite and associated rock units have been difficult to observe, and hence different interpretations have been published over the decades (e.g. Currie, 1987; Jamieson et al., 1987, 1989, 1990; Barr et al., 1992; Lynch and Tremblay, 1992; Lynch, 1996; Lin et al., 2007; Tucker, 2011). The area is of particular importance because it includes at least 15 economic mineral occurrences and has been a focus of exploration since the 1890s (Sangster et al., 1990; MacKinnon, 2008; Tucker, 2011; White et al., 2015).

Recent mapping, petrological studies, and U-Pb dating have resolved some of the geological uncertainties in the area (White et al., 2015, 2016, 2017; Slaman et al., 2017; Shute, 2017). In the current view (Fig. 1), the Jumping Brook Metamorphic Suite consists of the mainly metavolcanic Faribault Brook Formation overlain by the mainly metasedimentary Dauphinee Brook Formation. A Cambrian age is inferred, based on new U-Pb dating of ca. 490 to 475 Ma plutonic units that intruded the formation, the documentation of faulted contacts with late Neoproterozoic plutons, and the presence of late Neoproterozoic and early Cambrian detrital zircon in tuffaceous and epiclastic rocks in the suite.

The petrography and chemistry of the Jumping Brook Metamorphic Suite have been investigated previously on a more regional scale based on surface outcrops (e.g. Connors, 1986; Tucker, 2011; Poirier, 2016; Shute, 2017). The goal of the present project was to investigate vertical and lateral variations in the Faribault Brook Formation in more detail by studying four holes drilled in 2008 by Globex Mining Enterprises Limited (MacKinnon, 2008). The holes are 50 m apart and were drilled to a depth of 50 m along a north-south line near the Road 2 showing (Fig. 1). We present here an overview of the results that formed the basis of the B.Sc. honours thesis project of the first author.

Methods

Core from drillholes GM-03-08 (UTM 660180E, 5162891N), GM-04-08 (UTM 660185E, 5162940N), GM-05-08 (UTM 660133E, 5162864N), and GM-07-08 (UTM 660170E, 5162994N) were visually logged and magnetic susceptibility was measured at intervals of approximately 50 cm. Visual logging of the core was hampered by fine grain-size and lack of distinctive macroscopic features, except in the basalt and rhyolite sills, and only the basalt sills have distinctive magnetic signatures. About 50 samples were examined in thin section, which resulted in the recognition of six metamorphic units in addition to the unmetamorphosed basalt and rhyolite sills. Twenty-one samples were selected for whole-rock analyses by X-ray fluorescence and inductively coupled plasma mass spectrometry (ICP-MS) at Bureau Veritas Commodities Canada Ltd., Vancouver, B.C. In addition, about 215

[1]Department of Earth and Environmental Science, Acadia University, Wolfville, NS B4P 2R6

Vibert, B., Barr, S.M., and White, C.E., 2018: *in* Geoscience and Mines Branch, Report of Activities 2017-2018; Nova Scotia Department of Energy and Mines, Report ME 2018-001, p. 81-88.

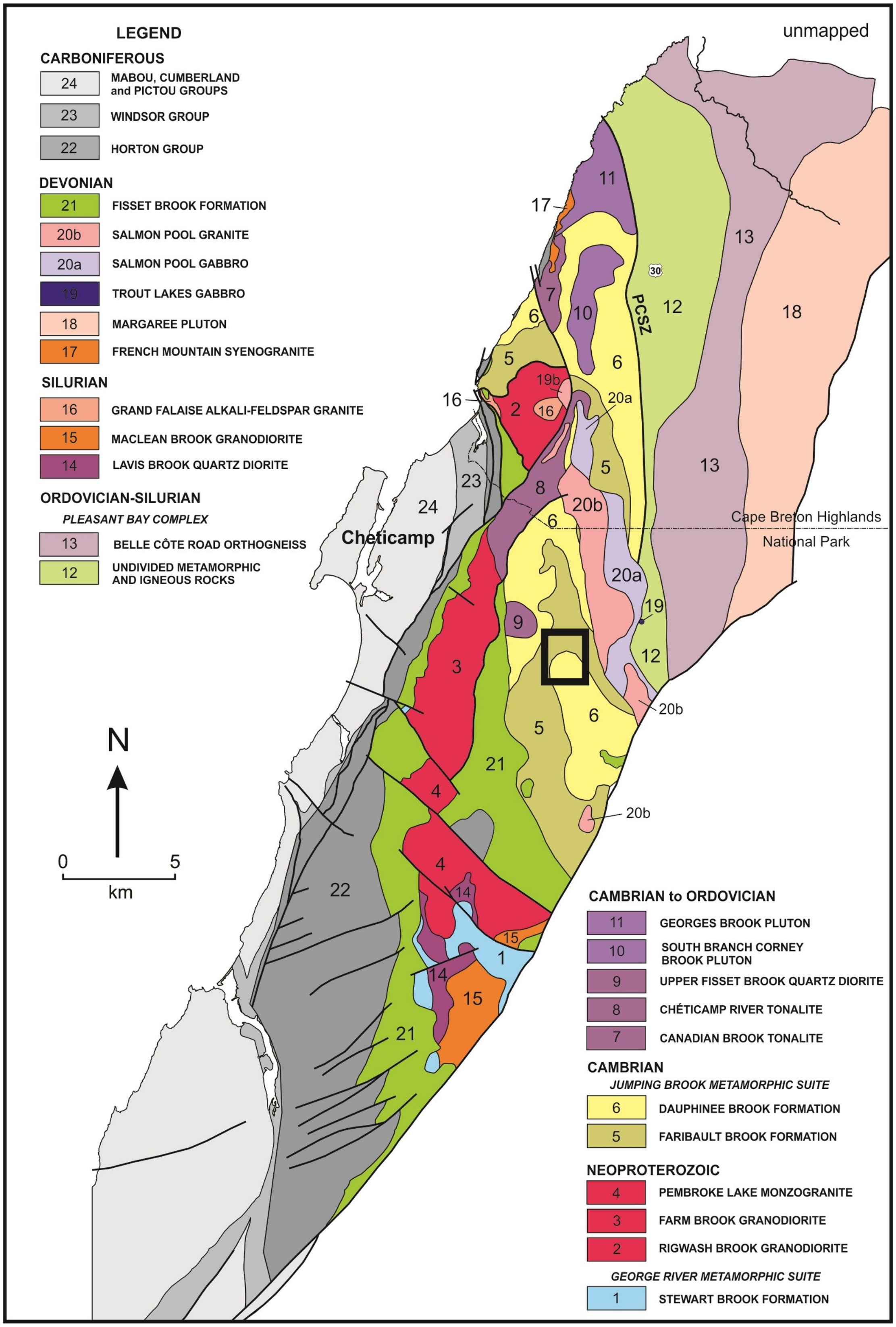

Figure 1. Geological map of the Chéticamp area from White et al. (2017) showing the distribution of the Faribault Brook Formation and the location of the Road 2 showing (black box) where the four holes were drilled.

analyses were made directly on the core or on cut slabs from the core using an Innov-X Canada X-5000 portable X-ray fluorescence spectrometer (pXRF) to obtain major- and trace-element concentrations to aid in identification and correlation of rock units between drillholes. Much of the detail in the resulting logs (Fig. 2) is based on whole-rock and pXRF chemical data, as documented by Vibert (2018).

Metamorphic Units

Metabasalt is the dominant rock type and occurs in all four drillholes (Fig. 2). In hand sample, the metabasalt is grey and aphanitic and does not exhibit prominent structural or textural features other than weak subhorizontal foliation. The most abundant mineral is actinolitic amphibole, which forms 60% or more of the rock. It forms elongate crystals, in some places in radiating clusters. Epidote, chlorite, untwinned plagioclase, and minor quartz occur interstitially to the more abundant actinolite. Variable amounts of calcite and opaque minerals are also present.

The protolith is interpreted to be basalt based on fine grain-size and homogeneous composition. This interpretation is consistent with other studies of the Faribault Brook Formation that are based on surface outcrops where relict volcanic features, such as pillows, are visible (e.g. Connors, 1986; Tucker, 2011; Shute, 2017).

Porphyroblastic metabasalt was identified based on the presence of actinolite porphyroblasts seen in thin section and in core, and also in part on the basis of its distinctive chemical characteristics compared to the metabasalt, although the chemical characteristics are not present in all places. The actinolite porphyroblasts occur in a subhorizontally foliated groundmass of actinolite, chlorite, plagioclase, quartz, and epidote that in places looks like the metabasalt and elsewhere appears more like the metatuff described below.

Metatuff is difficult to distinguish from metabasalt except in thin section and hence is likely under-represented in the core logs. It tends to display coarser grain-size, more heterogeneity, and faint dark and light grey banding parallel to a subhorizontal foliation. In places, fragments are visible and vary in size from 2 mm to 5 cm. The metatuff is similar in mineralogy to the metabasalt but contains more plagioclase and quartz relative to actinolite, and most samples contain biotite, which is not present in the metabasalt. The protolith of these samples is interpreted to have been basaltic tuff.

Metagabbro occurs only near the bottom of drillhole GM-07-08 within a section of core dominated by basaltic sills (Fig. 2). The mineralogy is similar to that of the metabasalt, with actinolite being the dominant and largest grains. Interstitial areas are occupied by plagioclase, chlorite, epidote, quartz, calcite, and opaque minerals. Overall the grain-size is coarser than in the metabasalt and foliation is not well developed. Hence, these rocks are interpreted to represent gabbroic dykes or sills.

Calc-silicate rocks occur as scattered layers in all four drillholes, mainly in the metabasalt sections. They are difficult to distinguish in the core, in part because of the abundance of interstitial secondary carbonate minerals and veins throughout the core, and are likely gradational and interlayered with metatuff and metabasalt. In some places they contain large garnet porphyroblasts, which are evident in hand sample and range from <1 mm to 2 mm in diameter. Zoisite porphyroblasts occur in some layers, as do bands of sulphide minerals. The pXRF data indicated that the calc-silicate rocks display wide chemical variation and the protolith composition is uncertain.

Metawacke occurs in the lower parts of all four drillholes below 30 to 35 m. They tend to have lower magnetic susceptibility than the metabasaltic and metatuffaceous rocks, but the data overlap and cannot be used to reliably distinguish the metasedimentary and meta-igneous units in the core logging. In the core, bedding is apparent as colour banding from light to dark grey. Relict graded bedding in places provides an indication that the section youngs toward the tops of the holes. The metawacke is dominated by quartz but also includes variable amounts of plagioclase, biotite, chlorite, and muscovite. Minor secondary carbonate minerals are present in interstices and veins. The metawacke samples vary from weakly foliated to strongly foliated. Foliation varies in

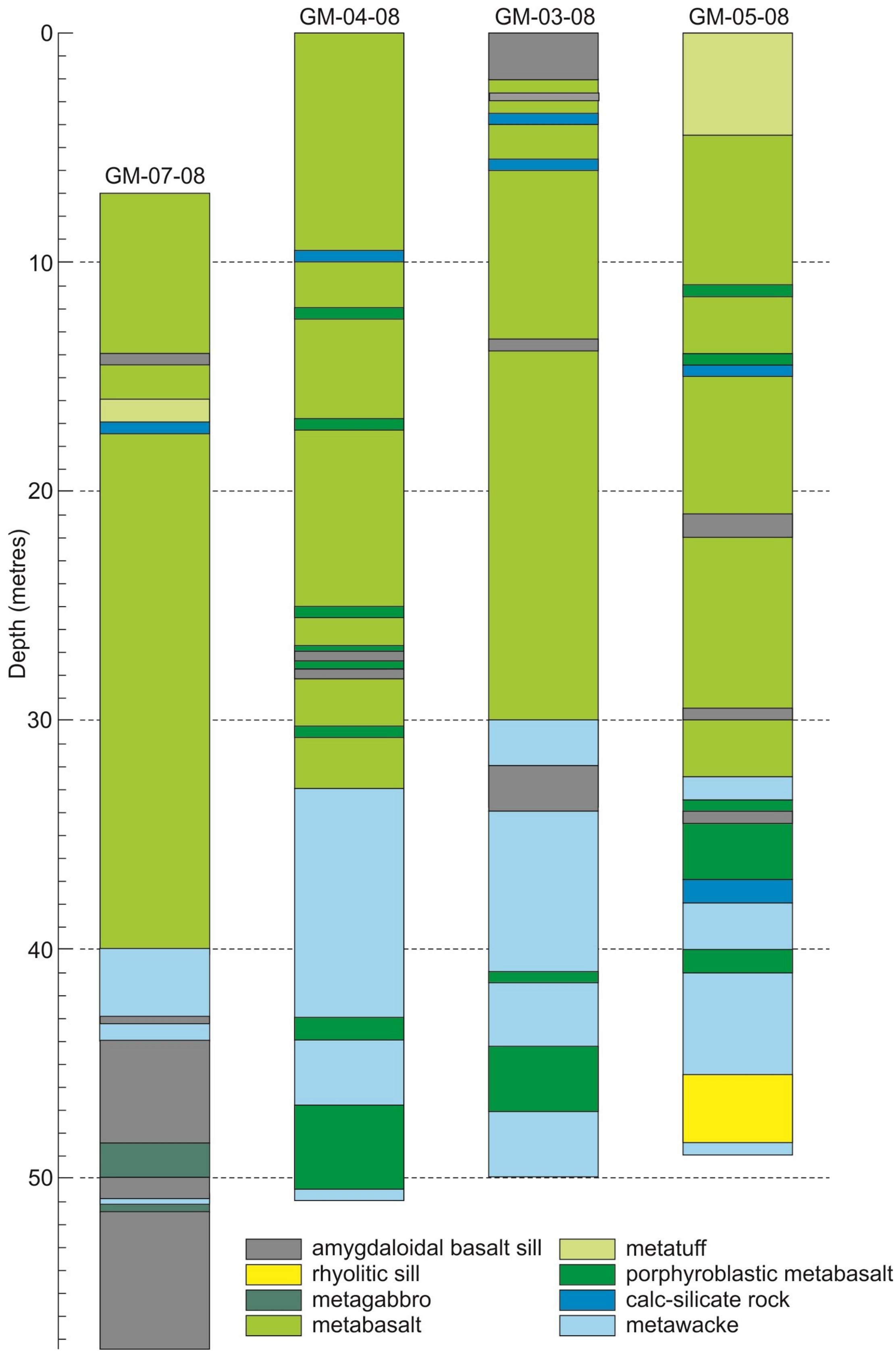

Figure 2. Core logs derived from this study after Vibert (2018). The 0 level is at an elevation of 411 m.

intensity but is everywhere subhorizontal and parallel to compositional and grain-size layering (bedding).

Basalt Sills

Basalt sills occur in all drillholes, ranging in thickness from a few centimetres to several metres near the bottom of hole GM-07-08 (Fig. 2). The basalt is dark grey to black and aphanitic, and has white phenocrysts and amygdales that range in diameter up to 1 cm or more. It has high magnetic susceptibility compared to all the other rocks in the core, up to 34 x10^{-3} SI units. Texture is typically hyalopilitic, and exhibits needle-like plagioclase laths in a cryptocrystalline groundmass that may have originally been volcanic glass. More slowly cooled samples have hyalo-ophitic to intersertal texture that is dominated by plagioclase laths and microcrystalline pyroxene. The coarsest samples in the thicker sills have intergranular texture consisting of clinopyroxene intergrown with plagioclase laths. Plagioclase phenocrysts occur throughout and are variably saussuritized. Amygdales are mainly rounded and typically contain chlorite or calcite. They vary in size and abundance from a fraction of a millimetre in diameter up to 1 cm. Although the sills have textures typical of extrusive lava flows, they are clearly sills, exhibiting chilled margins on both sides. They are unmetamorphosed and undeformed, and hence were emplaced after the greenschist-facies metamorphism and deformation that affected their host rocks. Given the low pressures and rapid cooling indicated by their abundant amygdales and quench-type textures, their host rocks must have been cold and close to the surface when the sills were emplaced.

Rhyolite Sill

Rhyolite occurs only in hole GM-05-08 at a depth of 45 to 48.5 m (Fig. 2). Two varieties of rhyolite are present but apparently constitute a single sill. The upper 50 cm of the rhyolite is dark pink and aphanitic and displays only faint banding. The underlying rhyolite, which is 3 m thick in the core, is light pink and shows prominent flow-banding. In thin section, the upper rhyolite unit shows well preserved spherulitic texture, and the lower rhyolite has spherulite layers that are separated by layers of fine-grained feldspar (sanidine?) and quartz. Like the amygdaloidal basalt sills, the rhyolite looks like an extrusive rock but shows none of the effects of deformation and metamorphism evident in the overlying and underlying metawacke, and hence was emplaced as a sill when its host rocks were close to the surface, likely long after they were deformed and metamorphosed.

Geochemistry

Geochemical data from the meta-igneous units in the core show that they have low SiO_2 (45–50 wt.%) typical of basalt and gabbro (Vibert, 2018). They are subalkaline and tholeiitic, but like other analyses of metabasalt from the Faribault Brook Formation, they show a range from low to very low Nb/Y ratios (Fig. 3a). Their chemical characteristics are consistent with those of mid-ocean ridge basalt, but with anomalously low concentrations of light rare-earth elements (Vibert, 2018). Similar results in earlier studies were interpreted to indicate that the rocks were affected by pervasive hydrothermal alteration prior to deformation and metamorphism (Tucker, 2011; Poirier, 2016).

The abundant sills of basalt and rhyolite had not been reported previously in descriptions of the Faribault Brook Formation. Like the metabasalt, the basalt in the sills is subalkalic and tholeiitic, but with chemical characteristics indicative of volcanic-arc basalt or within-plate tholeiite (Fig. 3a, b). Based on their petrographic evidence for near-surface emplacement and lack of metamorphism and deformation, the most likely correlatives of the sills are the basalt and rhyolite in the Fisset Brook Formation (Fig. 1). The Fisset Brook Formation is a widespread Late Devonian (ca. 373 Ma; Dunning et al., 2002) unit that unconformably overlies the older rocks units in the Chéticamp area. Like the basalt sills, basalt in the Fisset Brook Formation is tholeiitic and plots in the overlapping volcanic-arc and within-plate basalt field (Fig. 3a, b). The chemical characteristics of the rhyolite sill samples indicate that they formed in a within-plate tectonic setting (Vibert, 2018).

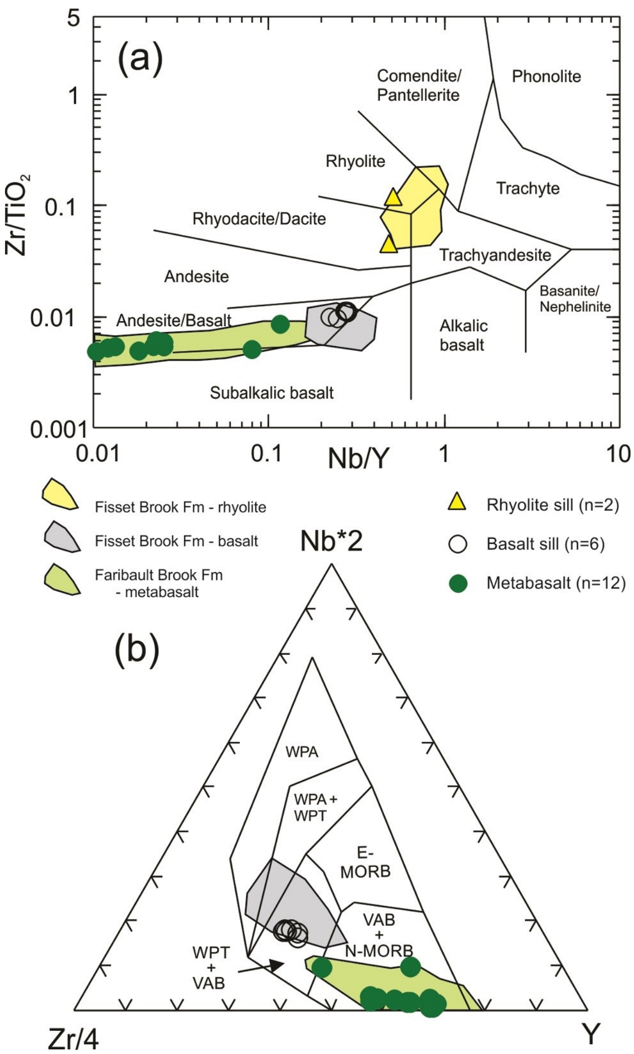

Figure 3. Selected chemical diagrams illustrating whole-rock chemical data from meta-igneous and igneous samples. The data are compared to fields enclosing most analyses from metabasic rocks in the Faribault Brook Formation from Tucker (2011) and Poirier (2016), and basalt and rhyolite in the Fisset Brook Formation from Barr and Peterson (1998). Tectonic setting fields in (a) are after Winchester and Floyd (1977) as modified by Pearce (1996). Tectonic setting fields in (b) are from Meschede (1986). Abbreviations: N-MORB, normal mid-ocean ridge basalt; E-MORB, enriched mid-ocean ridge basalt; VAB, volcanic-arc basalt; WPA, within-plate alkalic; WPT, within-plate tholeiitic.

Economic Mineralization

Based on logs and assays of some mineralized sections in the core, MacKinnon (2008) was not able to make a strong case for the economic potential of the rocks in the drillcore, and this conclusion is consistent with the observations made in the present study. Disseminated pyrite was the main sulphide mineral observed, with small bands occurring sporadically throughout the cores. The most significant anomalies revealed in the pXRF data are in Zn (over 400 000 ppm at a depth of 17 m in a narrow band of massive sphalerite in metabasalt in hole GM-05-08. The Zn anomaly is accompanied by elevated Cu content (1597 ppm) but low Pb content (37 ppm). The pXRF analyses show relatively high Zn content (2070 and 3070 ppm) in the first 4 m of core in GM-03-08, which consists of a basalt sill and metabasalt; the high Zn contents are accompanied by elevated Cu contents of 332 and 330 ppm, respectively. Elevated Pb concentrations in the core tend to be associated with calc-silicate rocks where bands of sulphides are present, possibly indicating the presence of galena.

Conclusions

Based only on visible features in core samples, it is difficult to recognize and correctly identify the different rock types in the core, as evidenced by the differences between the initial core logs by company geologists and the results of this study. Magnetic susceptibility measurements were useful in identifying the basalt sills, which are highly magnetic, but the metabasic and metasedimentary units could not be distinguished as their magnetic susceptibilities are similar. Petrographic study was essential to identify six metamorphic units and unmetamorphosed basalt and rhyolite. Whole-rock chemical data then enabled documentation of diagnostic chemical features in these units, but a much larger chemical data set acquired using a portable X-ray fluorescence instrument had to be utilized to make more detailed subdivisions of the drill core.

Chemical characteristics of the metabasic rocks are consistent with those reported in earlier studies of the Faribault Brook Formation, and together with the association with metawacke indicate that the mafic protoliths formed from N-MORB magma erupted or intruded in a back-arc tectonic setting. Petrographic and chemical characteristics of the basalt and rhyolite sills indicate that they are likely related to the bimodal volcanic rocks of the Late Devonian Fisset Brook Formation. The core is disappointing from an economic perspective;

disseminated pyrite is the main sulphide mineral present, and only a few areas in the core showed elevated abundances of Zn and more rarely Pb and Cu.

Acknowledgments

We thank Perry MacKinnon for donating the core to us for this project and for permitting archiving in the Core Library at Stellarton, Nova Scotia, on completion of the study. Pam Frail provided beautiful thin sections for this project. The project was funded in part by a Discovery grant to S. Barr from the Natural Sciences and Engineering Research Council of Canada. We thank G. Baldwin for his helpful comments on an earlier version of the manuscript.

References

Barr, S.M. and Peterson, K.C.A., 1998. Field relationships and petrology of the Late Devonian Fisset Brook Formation in the Chéticamp area, western Cape Breton Island, Nova Scotia; Atlantic Geology, v. 34, p. 121–132.

Barr, S.M., Jamieson, R.A., and Raeside, R.P., 1992. Geology, northern Cape Breton Island, Nova Scotia; Geological Survey of Canada, Map 1752A, scale 1:100 000.

Connors, K., 1986. Relationships between the sulphide minerals, metamorphism, and deformation in the Faribault Brook area of the Cape Breton Highlands, Nova Scotia; B.Sc. Honours thesis, Dalhousie University, Halifax, Nova Scotia, 105 p.

Currie, K.L., 1987. Relations between metamorphism and magmatism near Chéticamp, Cape Breton Island, Nova Scotia; Geological Survey of Canada, Paper 85–23, 66 p.

Dunning, G.R., Barr, S.M., Giles, P.S., McGregor, D.C., Pe-Piper, G., and Piper, D.J.W., 2002. Chronology of Devonian to early Carboniferous rifting and igneous activity in southern Magdalen Basin based on U-Pb (zircon) dating; Canadian Journal of Earth Sciences, v. 39, p. 1219–1237.

Jamieson, R.A., Tallman, P.C., Marcotte, J.A., Plint, H.E., and Connors, K.A., 1987. Geology of the west-central Cape Breton Highlands, Nova Scotia; Geological Survey of Canada, Paper 87–13, 11 p.

Jamieson, R.A., Tallman, P.C., Plint, H.E., and Connors, K.A., 1989. Geological setting of pre-Carboniferous mineral deposits in the western Cape Breton Highlands, Nova Scotia; Geological Survey of Canada, Open File 2008, scale 1:50 000.

Jamieson, R.A., Tallman, P.C., Plint, H.E., and Connors, K.A., 1990. Regional geological setting of pre-Carboniferous mineral deposits in the western Cape Breton Highlands, Nova Scotia; Geological Survey of Canada, Paper 90-8, p. 77–99.

Lin, S., Davis, D.W., Barr, S.M., van Staal, C.R., Chen, Y., and Constantin, M., 2007. U-Pb geochronological constraints on the evolution of the Aspy Terrane, Cape Breton Island: Implications for relationships between Aspy and Bras d'Or terranes and Ganderia in the Canadian Appalachians; American Journal of Science, v. 307, p. 371–398.

Lynch, G., 1996. Tectonic burial, thrust emplacement, and extensional exhumation of the Cabot nappe in the Appalachian hinterland of Cape Breton Island, Canada; Tectonics, v. 15, p. 94–105.

Lynch, J.V.G. and Tremblay, C., 1992. Imbricate thrusting, reverse-oblique shear, and ductile extensional shear in the Acadian Orogen, central Cape Breton Highlands, Nova Scotia; *in* Current research, Part D; Geological Survey of Canada, Paper 92-1D, p. 91–100.

MacKinnon, P., 2008. Cheticamp Highlands drilling program, Globex Mining Enterprises Limited 2008; Nova Scotia Department of Natural Resources, Assessment Report ME 2008-234, 137 p.

Meschede, M., 1986. A method of discriminating between different types of mid-ocean ridge basalts and continental tholeiites with the Nb-Zr-Y diagram; Chemical Geology, v. 56, p. 207–218.

Pearce, J.A., 1996. A user's guide to basalt discrimination diagrams; *in* Trace Element Geochemistry of Volcanic Rocks: Applications for Massive Sulphide Exploration, (ed.) D.A. Wyman;

Geological Association of Canada, Short Course Notes, v. 12, p. 79–113.

Poirier, S., 2016. Geological setting and petrology of Cu-Au-Pb-Zn occurrences in the Rocky Brook area, western Cape Breton Island, Nova Scotia; B.Sc. Honours thesis, Acadia University, Wolfville, Nova Scotia, 130 p.

Sangster, A.L., Thorpe, R.I., and Chatterjee, A.K., 1990. A reconnaissance lead isotopic study of mineral occurrences in pre-Carboniferous basement rocks of northern and central Cape Breton Island, Nova Scotia; *in* Mineral Deposits Studies in Nova Scotia, volume 1, (ed.) A.L. Sangster; Geological Survey of Canada, Paper 90-8, p. 101–114.

Shute, J., 2017. Field relations, petrology, and tectonic setting of mafic rocks in the northwestern Aspy terrane, Cape Breton Island, Nova Scotia, Canada; M.Sc. thesis, Acadia University, Wolfville, Nova Scotia, 236 p.

Slaman, L.R., Barr, S.M., White, C.E., and van Rooyen, D., 2017. Age and tectonic setting of granitoid plutons in the Chéticamp belt, western Cape Breton Island, Nova Scotia, Canada; Canadian Journal of Earth Sciences, v. 54, p. 88–109.

Tucker, M., 2011. Geology and mineral occurrences in the Faribault Brook area, Cape Breton Island, Nova Scotia; M.Sc. Thesis, Acadia University, Wolfville, Nova Scotia, 259 p.

Vibert, B., 2018. Comparison among four drill holes in the Faribault Brook Formation near the Road 2 showing, western Cape Breton Highlands, Nova Scotia; B.Sc. Honours thesis, Acadia University, Wolfville, Nova Scotia, 130 p.

White, C.E., Slaman, L., Barr, S.M., and Tucker, M., 2015. Preliminary geology and related economic mineralization potential of Chéticamp area, Cape Breton Island, Nova Scotia; *in* Geoscience and Mines Branch, Report of Activities 2014; Nova Scotia Department of Natural Resources, Report ME 2015-001, p. 103–117.

White, C.E., Barr, S.M., van Rooyen, D., McCarron, T., Slaman, L.R., and Shute, J.M., 2016. New age controls on rock units in the Chéticamp area, western Cape Breton Island, Nova Scotia, Canada; *in* Geoscience and Mines Branch, Report of Activities 2015, (ed.) E.W. MacDonald and D.R. MacDonald; Nova Scotia Department of Natural Resources, Report ME 2016-001, p. 131–142.

White, C. E., Shute, J., Sombini dos Santos, G., Barr, S.M., and van Rooyen, D., 2017. Progress report on geological and geochronological studies in Chéticamp area, Aspy terrane, Cape Breton Island, Nova Scotia; *in* Geoscience and Mines Branch, Report of Activities 2016–2017; Nova Scotia Department of Natural Resources, Report ME 2017-001, p. 89–93.

Winchester, J.A. and Floyd, P.A., 1977. Geochemical discrimination of different magma series and their differentiation products using immobile elements; Chemical Geology, v. 20, p. 325–343.