Ages of Plutons Associated with Economic Mineralization in Cape Breton Island, Nova Scotia[1]

D. van Rooyen[2] and S. M. Barr[3]

Introduction

Plutonic rocks ranging in composition from gabbro to granite are major components of the bedrock in Cape Breton Island (Barr and White 2017a, b, c). In recent years, the availability of a laser ablation–inductively coupled plasma–mass spectrometer facility at the University of New Brunswick in Fredericton has resulted in a cost-effective way to determine the absolute ages of these plutons, which range from Mesoproterozoic to Carboniferous (e.g. Barr et al., 2018). However, many plutons remain undated, and their approximate ages are inferred or assumed based only on comparison with dated plutons or on field relations. Isotopic dating can significantly change these interpretations even in well known areas (e.g. van Rooyen et al.,2019). The purpose of this study was to obtain precise absolute ages for six undated plutonic units, each of which is associated directly with economic mineralization (sulphides and/or gold) or is located in an area of such mineralization where the age of the plutonic rocks contributes toward constraining the timing of deformation and mineralization. The study also included new major and trace element data for dated samples for comparison with existing data and to characterize chemical affinity and tectonic setting.

Methods

The target plutons have been mapped and sampled previously by S. Barr and students or colleagues, and hence their field relations are known (e.g. Thicke, 1987; Barr et al., 1992, 1996; Grecco and Barr, 1999; Barr et al., 2018). However, the plutons were examined in the field again by the authors to confirm field relations and then sampled for dating at representative locations. Pieces of each selected sample were retained for petrographic and chemical study (major and trace elements), and the remainder sent to Overburden Drilling Management in Ottawa, Ontario, for electro-pulse disaggregation and zircon separation. Zircon grains were hand-picked at Cape Breton University and then taken to the University of New Brunswick (Fredericton) where they were mounted in an epoxy-covered thin section, polished to expose the centres of the zircon grains, and imaged using backscatter electron microscopy (BSE) to identify internal zoning and inclusions. These images were used to select ablation points (30 µm diameter), avoiding any visible inclusions, cracks, or other imperfections. U and Pb isotopic compositions were measured using the Resonetics S-155-LR 193 nm Excimer laser ablation system connected to an Agilent 7700x quadrupole inductively coupled plasma–mass spectrometer. Data interpretation followed the method described by Barr et al. (2018).

The six target units and their geological setting are shown in Figure 1, listed in Table 1, and summarized below.

Coxheath Hills Pluton (Dioritic and Granitic Units)

The historically mined Coxheath porphyry-style Cu (-Mo-Au) deposit is hosted by the Coxheath Group and comagmatic Coxheath Hills pluton (Thicke, 1987; Barr et al., 1996). The geology and ore mineralization of the Coxheath deposit have been extensively documented (e.g. Thicke, 1987; Lynch and Ortega, 1997; Kontak et al., 2003; O'Sullivan and Hannon, 2007). Rhyolite from the Coxheath Group gave an age of ca. 620 Ma (Barr et al. 1996), and dioritic rocks and molybdenite mineralization have been dated at ca. 620 Ma ($^{40}Ar/^{39}Ar$) and 626 Ma ± 3 Ma (Re-Os), respectively (Keppie et al., 1990; Kontak et al., 2004, 2008).

[1]This project was supported by a grant from the Nova Scotia Mineral Resources Development Fund (2019-2020)
[2]Department of Mathematics, Physics, and Geology, Cape Breton University, Sydney, NS, B1P 6L2
[3]Department of Earth and Environmental Science, Acadia University, Wolfville, NS, B4P 2R6

van Rooyen, D. and Barr, S. M. 2020. in Geoscience and Mines Branch, Report of Activities 2019-2020; Nova Scotia Department of Energy and Mines, Report ME 2020-002, p. 123-129.

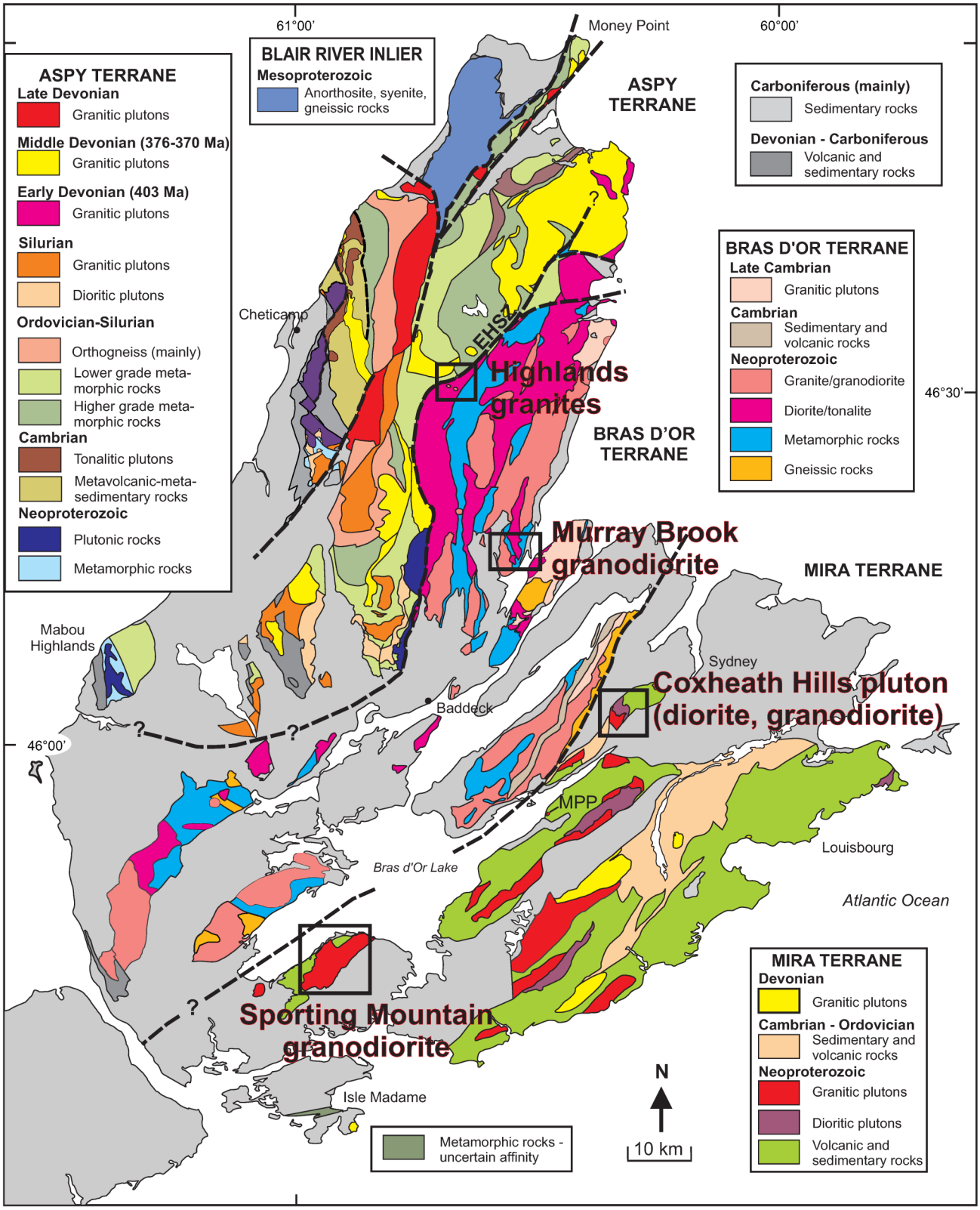

Figure 1. Geological map of Cape Breton Island showing areas sampled for dating. Specific sample locations are listed in Table 1. Map is based on Barr et al. (2017a, b, c). Dashed lines are shear zones. Abbreviations: EHSZ, Eastern Highlands shear zone; MPP, MacDougall Point pluton.

Table 1. Sample and location list with U-Pb ages obtained in this study.

Sample	Number	Easting	Northing	Age
Coxheath Hills pluton (quartz diorite)	DVR19-021	704490	5106233	622.9 ± 1.8 Ma
Coxheath Hills pluton (granodiorite)	DVR19-019	702938	5102971	620.0 ± 2.0 Ma
Sporting Mountain granodiorite	SMB19-270	661252	5067245	642.8 ± 4.8 Ma inherited age, crystallization age ca. 620 Ma based on field relations
Murray Brook granodiorite	DVR19-037	686268	5128814	541.7 ±2.0 Ma
Highlands granite (1)	SMB19-261	675268	5154594	Inherited age 574.8 ± 4.2 Ma Crystallization age 555.6 ± 4.5 Ma
Highlands granite (2)	SMB19-262	675332	5152608	Inherited age 576.9 ±4.2 Ma Crystallization age 548.3 ±5.9 Ma

We dated samples from both the dioritic and granodioritic units that dominate the pluton. Sample DVR19-021 is a grey, fine- to medium-grained quartz diorite. It contains very few zircon crystals, and most are small (50–75 µm). Some crystals are subhedral and rectangular, whereas others are more euhedral and acicular. Faint oscillatory zoning is visible in BSE imaging but no overgrowths or metamict textures are visible. The concordia age for this sample based on 27 grains between 98 and 101% concordant is 622.9 ± 1.8 Ma with an MSWD of concordance of 0.91 and probability of concordance of 0.34.

Sample DVR19-019 is a medium- to coarse-grained hornblende biotite granodiorite. The zircon crystals in this sample are mostly clear grains in the 100–150 µm size range. Most of the grains are subhedral and have short stubby rectangular shapes. Some grains have bipyramidal terminations and euhedral shapes. Clear oscillatory zoning is visible in BSE imaging with no overgrowths or metamict textures visible. The concordia age for this sample using 21 grains between 98 and 102% concordant is 620.0 ± 2.0 Ma with an MSWD of concordance of 0.22 and a probability of concordance of 0.64.

Both dated samples are calc-alkalic and have chemical characteristics consistent with formation in a continental margin subduction zone, as previously shown for the Coxheath volcanic-plutonic belt (e.g. Thicke, 1987; Barr et al., 1996).

The results show that the dioritic and granodioritic units of the pluton are the same age within error and hence are interpreted as comagmatic. They are also the same age as their host rocks and, combined with earlier $^{40}Ar/^{39}Ar$ dating, confirm that the pluton cooled rapidly. The data show no evidence for a younger intrusive event and that the associated mineralization is cogenetic with its host rocks.

Sporting Mountain Granodiorite

The Sporting Mountain pluton and associated volcanic rocks of the Pringle Mountain Group are likely to be part of the same belt as the Coxheath Hills, based on their positions near the present-day northern edge of the Mira terrane and their similar rock types. Rhyolite from the Pringle Mountain Group yielded a U-Pb (zircon) age of ca. 620 Ma (White et al., 2003), but the plutonic rocks have no U-Pb ages. Given the demonstrated presence of mineralization and the potential for porphyry-style mineralization similar to the Coxheath belt (Sexton, 1988; Layne et al., 2019), confirming the age of the granodiorite that forms most of the Sporting Mountain pluton is important.

Dated sample SMB19-270 is a grey to pink, fine- to medium-grained hornblende-biotite granodiorite. Zircon grains are scarce, and most are small (50–75 µm). Some of the crystals are subhedral and rectangular, whereas others are more euhedral and

acicular. Faint oscillatory zoning is visible in BSE imaging with no overgrowths or metamict textures visible. The concordia age for the dominant zircon population in this sample using eight grains between 98 and 102% concordant is 642.8 ± 4.8 Ma with an MSWD of concordance of 0.96 and a probability of concordance of 0.33. However, the sample has a few younger grains around 620 Ma, but not enough to define a cluster of ages that can be used either for a concordia age or weighted mean age. We think that the actual age of emplacement of the granodiorite is ca. 620 Ma, based on the fact that it intruded volcanic rocks dated at that age (White et al., 2003). The interpretation consistent with these field relationships is that the 640 Ma grains are inherited from an older magmatic event.

This pattern of inherited grains is also evident in other Ediacaran rocks in the Mira terrane. For example, the MacDougall Point pluton to the northeast in the East Bay Hills (Fig. 1) contains two groups of zircon grains: an older group with a concordia age of 645.6 ± 2.7 Ma and a younger group with a concordia age of 625.2 ± 3.1 Ma (Barr et al., 2018). The chemical characteristics of the dated Sporting Mountain granodiorite are similar to those of the MacDougall Point pluton and also those of the Coxheath Hills pluton.

Murray Brook Granodiorite

The St. Anns area in the Bras d'Or terrane of central Cape Breton Island contains varied plutonic rocks intruded into volcanic rocks of the Price Point Formation (Macdonald and Barr, 1985; Grecco and Barr, 1999). Sulphide showings in the St. Anns area include polymetallic quartz-calcite veins and barren pyritic occurrences in both granitoid and older volcanic rocks. The volcanic rocks consist of intermediate lithic-crystal tuffs and flows of calc-alkalic affinity, which have been dated at 576.5 ± 2.3 Ma (Barr et al., 2018). Cu-Mo-Au-bearing veins are hosted mainly by the granitoid rocks and rarer Cu-Zn-Pb-Ag veins by the volcanic rocks, but both vein types exhibit similar orientations and morphological and textural features, suggesting a common origin. The most significant showing may be the Murray Brook Cu-Mo occurrence, a mineralized quartz-calcite vein swarm in the Murray Brook granodiorite that displays some of the characteristics of a porphyry copper deposit (Kirkham and Soregaroli, 1975; Macdonald and Barr, 1985). Other than the Indian Brook granodiorite farther north (age ca. 565 Ma; Dunning et al., 1990), none of the plutons in the St. Anns area have U-Pb zircon ages.

Dated sample DVR19-037 is medium-grained biotite-hornblende granodiorite. It contains abundant zircon, and most grains are clear and euhedral and have bipyramidal terminations and a rectangular 3:1 aspect ratio. The concordia age calculated using 36 grains is 541.7 ± 2.0 Ma with an MSWD of concordance of 0.046 and a probability of concordance of 0.83.

This age is younger than the main plutonic components of the Bras d'Or terrane, and also younger than the volcanic rocks of the Price Point Formation. The younger age is consistent with field relations that suggest that the Murray Brook granodiorite intruded the other plutonic rocks of the St. Anns area (Macdonald and Barr, 1985). Plutonic rocks of that age occur widely in the Bras d'Or terrane (Barr et al., 2018; van Rooyen et al., 2019) and indicate that the continental margin subduction zone in which they formed was long-lived. The chemical characteristics of dated sample DVR19-037 are consistent with that tectonic setting.

Highlands Granite Plutons

Two small bodies of deformed granite were mapped and described by Barr et al. (1992) and Raeside and Barr (1992) as being intruded into the ca. 560 Ma Kathy Road diorite and its host rocks, then termed the Bateman Brook Gneiss. Limited exposure and proximity to the Eastern Highlands Shear Zone continue to make this area enigmatic in geological interpretations of the highlands (Fig. 1), and yet the well documented occurrences of gold make the area of particular interest. The Highlands gold occurrences (at least one of which is in the dated plutons) have yielded high gold values, but exploration has been unsuccessful in part because of the lack of a deposit or exploration model (e.g. Baldwin 2019). Baldwin (2019) suggested that the mineralization may be of IOCG-type and linked to Devonian intrusions in the region. Hence the ages and chemical characteristics of these two small granite plutons may be important in understanding the nature of these gold occurrences.

Two samples were dated, one from each granitic body. Zircon grains in sample SMB19- 261 are mostly euhedral and clear but have some surficial red staining. In BSE the grains showed faint

oscillatory zoning with no significant overgrowths or metamict textures. Their age distribution shows two peaks, one older and one younger. The concordia age using eight grains from the older group of grains is 574.8 ± 4.2 Ma with an MSWD of concordance of 0.63 and a probability of concordance of 0.43. The concordia age using six grains from the younger group is 555.6 ± 4.5 Ma with an MSWD of concordance of 0.058 and a probability of concordance of 0.81. The older age is interpreted to represent inheritance and the younger age is the age of crystallization of the granite.

The second dated sample, SMB19-262, contains zircon grains that are mostly euhedral and clear but has some surficial red staining. In BSE the grains showed faint oscillatory zoning and no significant overgrowths or metamict textures. They also show two peaks in the age distribution. The concordia age using 10 grains from the older group of zircons is 576.9 ± 4.2 Ma with an MSWD of concordance of 0.17 and a probability of concordance of 0.68. The concordia age using four grains for the younger group of zircons is 548.3 ± 5.9 Ma with an MSWD of concordance of 0.39 and a probability of concordance of 0.53. As in the previous sample, the older age is interpreted to represent inheritance and the younger age is the age of crystallization of the granite.

The crystallization ages indicated by the two samples overlap within error and indicate emplacement at ca. 550 Ma. Both samples contain large populations of grains that were likely inherited from the ca. 560 to 575 Ma subduction-related plutons characteristic of the Bras d'Or terrane (Grecco and Barr, 1999; Barr et al., 2018; van Rooyen et al., 2019, 2020). The crystallization ages of ca. 550 Ma are similar to those of other plutons in the Bras d'Or terrane such as Creignish Hills and West Bay (White et al., 2016). As is the case with other plutons of this age in the Bras d'Or terrane, the chemical characteristics of the dated samples from the Highlands plutons are consistent with a continental margin subduction zone. These age data show no evidence that gold occurrences in the area of these plutons are linked to the Silurian-Devonian magmatism that characterizes the Aspy terrane to the northwest of the Eastern Highlands Shear Zone. Those younger plutonic events do not appear to have affected the now-adjacent Bras d'Or terrane.

Implications

Plutons are commonly linked either directly or indirectly with economic mineralization, in large part because of the thermal anomalies with which they are associated. Knowing pluton ages helps in understanding the character of the mineral deposits, and hence in exploration for mineable resources in the target areas. The new ages presented here confirm that the porphyry-style mineralization in the Coxheath and similar belts in the Avalonian Mira terrane is hosted in ca. 620 Ma subduction-related volcanic-plutonic belts without evidence for younger thermal events. Similarly, the result from the Murray Mountain granodiorite in the Bras d'Or terrane shows that mineralization in that area is part of long-lived (at least ca. 575–540 Ma) subduction-related magmatism. Most surprising, the new ages from the Highlands granite plutons suggest that they are also part of this Bras d'Or terrane magmatism and not related to younger magmatism of the now-adjacent Aspy terrane.

The data in the Highlands plutons and Sporting Mountain also highlight the need for careful consideration of field relationships and the need to understand the full magmatic history of an area in order to correctly interpret inherited zircon populations. The pluton ages, both emplacement and inheritance, are significant in interpreting the tectonic setting into which they are emplaced and therefore the type and extent of possible mineralization.

Acknowledgements

A 2019–2020 Nova Scotia Mineral Resources Development Fund grant (MRDF-2019-RS-030) to D. van Rooyen and S. Barr supported this work. We thank Branden Boucher and Chris McFarlane for their assistance with age data acquisition. We thank Chris White for his thorough review of the report.

References

Baldwin, G., 2019. The Highlands Gold occurrences, eastern Cape Breton Highlands, Nova Scotia: an unrecognized IOCG district? Geological Association of Canada-Mineralogical Association of Canada, Abstracts, v. 42, p. 58.

Barr, S. M. and White, C. E., 2017a. Bedrock geology legend for Cape Breton Island, Nova Scotia; Nova Scotia Department of Natural Resources, Geoscience and Mines Branch, Open File Illustration ME 2017-001.

Barr, S. M. and White, C. E. 2017b., List of compilation sources for bedrock geology maps of Cape Breton Island, Nova Scotia (Open File Maps ME 2017-006 to 2017-031); Nova Scotia Department of Natural Resources, Open File Report ME 2017-002, 7 p.

Barr, S.M. and White, C. E. 2017c., Overview map showing locations of bedrock geology maps for Cape Breton Island, Nova Scotia; Nova Scotia Department of Natural Resources, Geoscience and Mines Branch, Open File Map ME 2017-006, scale 1:220 000.

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.

Barr, S.M., White, C.E., and Macdonald, A.S., 1996. Stratigraphy, tectonic setting, and geologic history of Late Precambrian volcanic-sedimentary-plutonic belts in southeastern Cape Breton Island, Nova Scotia; Geological Survey of Canada, Bulletin 468, 84 p.

Barr, S.M., van Rooyen, D., and White, C.E., 2018. Granitoid plutons in peri-Gondwanan terranes of Cape Breton Island, Nova Scotia, Canada: new U-Pb (zircon) age constraints; Atlantic Geology, v. 54, p. 21–80.

Dunning, G.R., Barr, S.M., Raeside, R.P., and Jamieson, R.A., 1990. U-Pb zircon, titanite, and monazite ages in the Bras d'Or and Aspy terranes of Cape Breton Island, Nova Scotia: implications for magmatic and metamorphic history; Geological Society of America Bulletin, v. 102, no. 3, p. 322–330.

Grecco, L. and Barr, S.M., 1999. Late Neoproterozoic granitoid and metavolcanic rocks of the Indian Brook area, southeastern Cape Breton Highlands, Nova Scotia; Atlantic Geology, v. 35, p. 43–57.

Keppie, J.D., Dallmeyer, R.D., and Murphy, J.B., 1990. Tectonic implications of $^{40}Ar/^{39}Ar$ hornblende ages from late Proterozoic-Cambrian plutons in the Avalon Composite Terrane, Nova Scotia, Canada; Geological Society of America Bulletin, v. 102, no. 4, p. 516–528.

Kirkham, R.V. and Soregaroli, A.E., 1975. Preliminary assessment of porphyry deposits in the Canadian Appalachians; *in* Report of activities, Part A; Geological Survey of Canada, Paper 75-1A, p. 249–251.

Kontak, D.J., DeWolfe, J., and Finck, P.W., 2003. The Coxheath plutonic-volcanic belt (NTS 11K/01): a linked porphyry-epithermal mineralized system of Precambrian age; *in* Nova Scotia Department of Natural Resources, Mineral Resources Branch, Report 2003-1, p. 69–87.

Kontak, D.J., Finck P.W., and DeWolfe, J., 2004. Pyrophyllite occurrences in the Coxheath area, Cape Breton Island; Nova Scotia Department of Natural Resources, Open File Report ME 2004-1, 19 p.

Kontak, D.J., Horne, R., Creaser, R., and Archibald, D., 2008. Correlation of thermo-tectonic and metallogenic events in the Avalon and Meguma terranes of Nova Scotia with the use of $^{40}Ar/^{39}Ar$ and Re-Os geochronometry; Atlantic Geology, v. 44, p. 21.

Layne, G.D., Barr, S.M., and White, C.E., 2019. Metallogeny of the Avalonian Mira terrane, southeastern Cape Breton Island, Nova Scotia: A preliminary study; *in* Geoscience and Mines Branch, report of activities 2018-2019, (ed.) E.W. MacDonald and D.R. MacDonald; Nova Scotia Department of Energy and Mines, Report ME 2019-002, p. 23–34.

Lynch, J.V.G. and Ortega, J., 1997. Hydrothermal alteration and tourmaline-albite equilibria at the Coxheath porphyry Cu-Mo-Au deposit, Nova Scotia; Canadian Mineralogist, v. 35, p. 79–94.

Macdonald, A.S. and Barr, S.M., 1985. Geology and age of polymetallic mineral occurrences in volcanic and granitoid rocks, St. Ann's area, Cape Breton Island, Nova Scotia; *in* Current research, Part B; Geological Survey of Canada, Paper 85-1B, p. 117–124.

O'Sullivan, J.O. and Hannon, P.J., 2007, Coxheath Copper Project, Cape Breton County, Cape Breton, Nova Scotia (NTS 11K/01B), a compilation and review of exploration potential for Silvor Foxx Capital Corporation, NI43-101 Technical Report;

MineTech International Limited, 284 p. <https://sec.report/Document/0001062993-13-003190/exhibit2-5.htm>

Raeside, R.P. and Barr, S.M., 1992. Preliminary report on the geology of the northern and eastern Cape Breton Highlands, Nova Scotia; Geological Survey of Canada, Paper 89-14, 39 p.

Sexton, A., 1988. Geology of the Sporting Mountain area, southeastern Cape Breton Island, Nova Scotia; M.Sc. thesis, Acadia University, Wolfville, Nova Scotia, 215 p.

Thicke, M.J ., 1987, The geology of Late Hadrynian metavolcanic and granitoid rocks of the Coxheath Hills-northeast East Bay Hills areas, Cape Breton Island, Nova Scotia; M.Sc. thesis, Acadia University, Wolfville, Nova Scotia, 300 p.

van Rooyen, D., Barr, S.M., and White, C.E., 2019. Geochronology of Neoproterozoic to Cambrian rocks of the Bras d'Or terrane on Cape Breton Island, Nova Scotia: implications for the age and provenance of Ganderian basement rocks; Canadian Journal of Earth Sciences, v. 56, p. 829–847. doi:10.1139/cjes-2018-0248

van Rooyen, D., Barr, S.M., and White, C.E., 2020**.** Changing northern Appalachian geology, one U-Pb zircon date at a time; Atlantic Geoscience Society Colloquium, February 7-8, Truro, Nova Scotia.

White, C.E., Barr, S.M., and Ketchum, J.W.F., 2003. New age controls on rock units in pre-Carboniferous basement blocks in southwestern Cape Breton Island and adjacent mainland Nova Scotia; *in* Mineral Resources Branch, report of activities 2002, (ed.) D.R. MacDonald; Nova Scotia Department of Natural Resources, Report ME 2003-1, p. 163–178.

White, C.E., Barr, S.M., Davis, D.W., Swanton, D.S., Ketchum, J.W.F., and Reynolds, P.H., 2016. Field relations, age, and tectonic setting of metamorphic and plutonic rocks in the Creignish Hills – North Mountain area, southwestern Cape Breton Island, Nova Scotia, Canada; Atlantic Geology, v. 52, p. 35–57.