Geological Mapping and Resource Assessment

Natural Resources

Geology Matters 2012

A NEW GEOLOGICAL INTERPRETATION OF THE ANTIGONISH HIGHLANDS, NORTHERN NOVA SCOTIA

Chris E. White[1], Sandra M. Barr[2], Donnelly B. Archibald[2], Justin Drummond[2], Katherin Voy[2], Edwin A. Escarraga[2] and Chris R.M. MacFarlane[3]

[1] Nova Scotia Dept. Natural Resources, 1701 Hollis Street, PO Box 869, Halifax, Nova Scotia B3J 2T9; [2] Department of Earth and Environmental Science, Acadia University, Wolfville, Nova Scotia B4P 2R6; [3] Department of Earth Sciences, UNB, Fredericton, New Brunswick E3B 5A3

INTRODUCTION

The Antigonish Highlands are part of Avalonia (e.g., Hibbard *et al*., 2006), a fault-bounded terrane that occurs inboard of Meguma and outboard of Ganderia throughout the northern Appalachian orogen. The Antigonish Highlands are located along the southern margin of Avalonia in northern mainland Nova Scotia (Fig. 1). Traditionally, the Antigonish Highlands have been characterized as a package of rift-related Late Neoproterozoic volcanic, sedimentary and plutonic rocks overlain by Cambrian to Lower Ordovician sedimentary and volcanic rocks, and Silurian and younger Carboniferous sedimentary units, locally intruded by Devonian to Carboniferous plutonic rocks (e.g., Murphy *et al*., 1991).

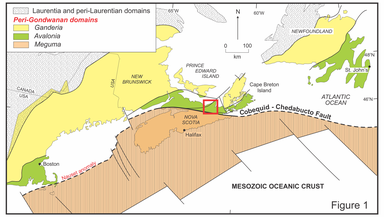


Figure 1

PURPOSE

A recent study of plutonic units in the southern Antigonish Highlands by Escarraga *et al*. (2011) showed that the spatial distribution and age of many of the plutonic and associated volcanic units needed to be revised. Escarraga (2010) also recognized the potential for rare earth element mineralization and the presence of Zn anomalies in the highlands. As a result, the Nova Scotia Department of Natural Resources has undertaken a bedrock mapping program in the Antigonish Highlands (White *et al*., 2011; White in press). This mapping, combined with geochemistry, petrography and geochronology will add to the understanding of the stratigraphy, structure, tectonic setting, age and mineral deposits of the Antigonish Highlands (Fig. 2).

GEOCHRONOLOGY

U-Pb age determinations from zircons in a standard petrographic thin section were completed using the laser-ablation microprobe – inductively coupled plasma – mass spectrometry (LAM-ICP-MS) system at the University of New Brunswick.

Zircons from a sample of quartz-feldspar porphyry in the Burroughs Lake pluton yielded concordant ages of 615.2 ± 2.8 Ma (Fig. 3a) that is interpreted as the crystallization age of pluton. This age is identical to the U-Pb age of ca. 618 Ma reported from a lithologically similar "rhyolite" in the Keppoch Formation by Murphy *et al*. (1997), confirming a coeval relationship between the pluton and Keppoch Formation of the Georgeville Group.

A granite sample from the Antigonish Harbour pluton yielded zircons with a concordant age of 609 ± 5.7 Ma (Fig. 3b), identical to the U-Pb ages of ca. 605 Ma from the Ohio and Sandy Gunns Lake plutons in the southern highlands (Fig. 2).

Several gabbroic to syenitic samples from the West Barneys River plutonic suite (Fig. 2) yielded concordant zircon ages from ca. 493 to 457 Ma (Figs. 3c-g), confirming a protracted Ordovician igneous history for the suite.

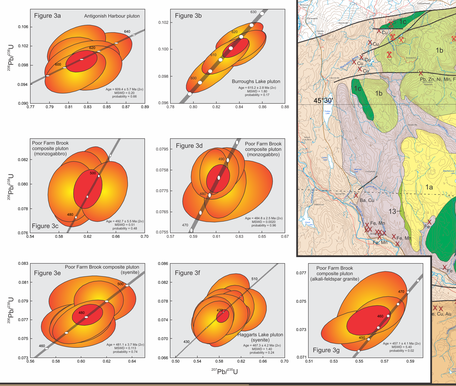


Figure 3

LEGEND

CARBONIFEROUS

- 33 **CUMBERLAND and PICTOU GROUPS:** undivided clastic rocks
- 32 **CANSO GROUP:** undivided clastic and carbonate rocks
- 31 *COLLEGE GRANT PLUTON* medium-grained quartz diorite

WINDSOR GROUP

- 30e *HOOD ISLAND FORMATION AND EQUIVALENT UNITS:* undivided clastic and carbonate rocks
- 30d *McARAS BROOK FORMATION:* basalt, sandstone and conglomerate/breccia
- 30c *ADDINGTON FORMATION AND EQUIVALENT UNITS:* undivided clastic and carbonate rocks
- 30b *BRIDGEVILLE FORMATION:* anhydrite, gypsum and limestone
- 30a *GAYS RIVER AND MACUMBER FORMATIONS:* limestone

DEVONIAN to CARBONIFEROUS

- 29 **HORTON GROUP:** undivided clastic rocks

DEVONIAN

- 28 *BALLANTYNES COVE FORMATION:* basalt and rhyolite with minor clastic rocks

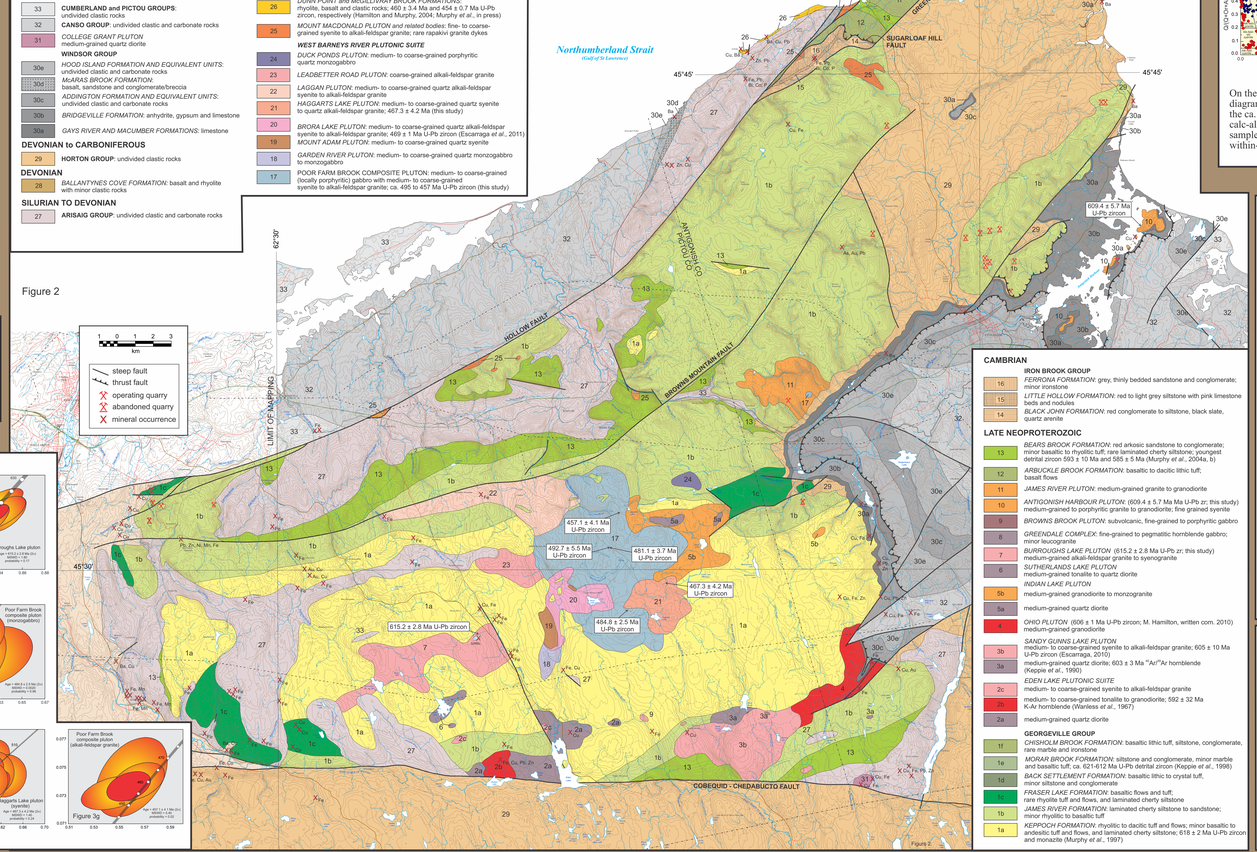
SILURIAN TO DEVONIAN

- 27 **ARISAIG GROUP:** undivided clastic and carbonate rocks

ORDOVICIAN

- 26 *DUNN POINT and McGILLIVRAY BROOK FORMATIONS:* rhyolite, basalt and clastic rocks; 460 ± 3-4 Ma and 454 ± 0.7 Ma U-Pb zircon, respectively (Hamilton and Murphy, 2004; Murphy *et al*., in press)
- 25 *MOUNT MACDONALD PLUTON and related bodies:* fine- to coarse-grained syenite to alkali-feldspar granite; rare rapakivi granite dykes
- 24 ***WEST BARNEYS RIVER PLUTONIC SUITE***
- 24 *DUCK PONDS PLUTON:* medium- to coarse-grained porphyritic quartz monzogabbro
- 23 *LEADBETTER ROAD PLUTON:* coarse-grained alkali-feldspar granite
- 22 *LAGGAN PLUTON:* medium- to coarse-grained quartz alkali-feldspar syenite to alkali-feldspar granite
- 21 *HAGGARTS LAKE PLUTON:* medium- to coarse-grained quartz syenite to quartz alkali-feldspar granite; 467.3 ± 4.2 Ma (this study)
- 20 *BRORA LAKE PLUTON:* medium- to coarse-grained quartz alkali-feldspar syenite to alkali-feldspar granite; 469 ± 1 Ma U-Pb zircon (Escarraga *et al*., 2011)
- 19 *MOUNT ADAM PLUTON:* medium- to coarse-grained quartz syenite
- 18 *GARDEN RIVER PLUTON:* medium- to coarse-grained quartz monzogabbro to monzogabbro
- 17 *POOR FARM BROOK COMPOSITE PLUTON:* medium- to coarse-grained (locally porphyritic) gabbro with medium- to coarse-grained syenite to alkali-feldspar granite; ca. 495 to 457 Ma U-Pb zircon (this study)

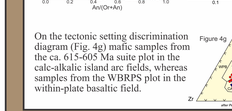
Figure 2



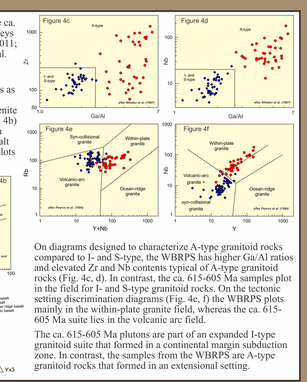
GEOCHEMISTRY

Whole-rock data were obtained from typical samples from the ca. 615-605 Ma plutonic units and the ca. 485-470 Ma West Barneys River plutonic suite (WBRPS) (Escarraga, 2010; Archibald, 2011; Murry, 2011). Previous whole-rock samples from Murphy et al. (1991) were not used due to lack of location information.

Geochemical classification based on a normative Q'-ANOR diagram (Fig. 4a) designates the ca. 615-605 Ma plutonic units as ranging from diorite to granodiorite to alkali-feldspar granite, whereas the WBRPS ranges from diorite to alkali-feldspar syenite to alkali-feldspar granite. A plot of Zr/TiO$_2$ against Nb/Y (Fig. 4b) shows a higher Nb/Y for the WBRPS than the ca. 615-605 Ma suite and the samples plot in the alkalic rhyolite to alkalic basalt fields. In contrast the ca. 615-605 Ma suite is subalkalic and plots in the andesite to rhyolite/dacite field.



On the tectonic setting discrimination diagram (Fig. 4g) mafic samples from the ca. 615-605 Ma suite plot in the calc-alkalic island arc fields, whereas samples from the WBRPS plot in the within-plate basaltic field.



On diagrams designed to characterize A-type granitoid rocks compared to I- and S-type, the WBRPS has higher Ga/Al ratios and elevated Zr and Nb contents typical of A-type granitoid rocks (Fig. 4c, d). In contrast, the ca. 615-605 Ma samples plot in the field for I- and S-type granitoid rocks. On the tectonic setting discrimination diagrams (Fig. 4e, f) the WBRPS plots mainly in the within-plate granite field, whereas the ca. 615-605 Ma suite lies in the volcanic arc field.

The ca. 615-605 Ma plutons are part of an expanded I-type granitoid suite that formed in a continental margin subduction zone. In contrast, the samples from the WBRPS are A-type granitoid rocks that formed in an extensional setting.

RESULTS TO DATE

- detailed (1:10 000-scale) bedrock mapping and related studies have greatly enhanced the understanding of the geology in the Antigonish Highlands.

- lithogeochemistry demonstrates calc-alkaline affinity for the ca. 615-605 Ma plutonic units and associated volcanic rocks in the Georgeville Group, not rift-related.

- volcanic rocks in the southern Antigonish Highlands previously interpreted to belong to volcanic units in the Bears Brook Formation (basal part of the Ordovician to Devonian Arisaig Group) are Late Neoproterozoic and included with the Keppoch Formation of the Georgeville Group. This interpretation is further supported by the intrusive relationship with the ca. 615 Ma Burroughs Lake pluton.

- the redefined Bears Brook Formation is now used for the dominantly sedimentary part of the former unit, combined with sedimentary rocks of the former Malignant Cove Formation, previously included in the basal part of the Cambrian sedimentary-volcanic succession. This interpretation is substantiated by previously published detrital zircon U-Pb ages, which indicate pre-585 Ma ages for these rocks.

- the redefined Iron Brook Group in the northern Antigonish Highlands consists of a fault-bound package of sedimentary rocks that has yielded early Cambrian macro- and microfossils. The previously interpreted interlayered mafic flows in this group are mafic sills, whereas the volcanic rocks (Arbuckle Brook Formation) are now considered to be Late Neoproterozoic and not part of the Iron Brook Group.

- all of the Neoproterozoic and Cambrian rocks are intruded by the previously unrecognized but widespread ca. 493 to 457 Ma West Barneys River plutonic suite (and related dykes and sills), which consists of syenite to alkali-feldspar granite and tholeiitic transitional to alkalic gabbro formed in an extensional setting.

- north of the Hollow fault, extension continued until at least ca. 454 Ma with the deposition of the bimodal volcanic rocks of the Dunn Point and McGillivary Brook formations.

- the redefined Early Silurian to Early Devonian Arisaig Group is conformable with the McGillivary Brook Formation, but south of the Hollow fault it unconformably overlies the older units. Other than a few bentonite beds and rare mafic dykes, the Arisaig Group contains no volcanic rocks, as previously described.

- syenitic and gabbroic rocks in the West Barneys River plutonic suite are elevated in Zn and rare earth elements and provide excellent targets for future REE exploration.

-the Arisaig Group and the Cambrian Iron Brook Group locally contain ironstone beds with elevated Pb, Bi, Co and P_2O_5 that have been under-explored.

- elevated concentrations of Cu, Zn, Pb and Ni have been documented along the Cobequid-Chedabucto, Browns Mountain and Hollow faults, likely related to IOGC style of mineralization. Elevated concentrations of Cu and Pb have been recognized in the Devonian mafic flows in the Ballantynes Cove formation.

- these new field observations, petrological data and ages have dramatically changed the previously published geological map, and hence our understanding of the tectonic evolution of this part of Avalonia in the northern Appalachian orogen.

CAMBRIAN

IRON BROOK GROUP

- 16 *FERNOMA FORMATION:* grey, thinly bedded sandstone and conglomerate; minor ironstone
- 15 *LITTLE HOLLOW FORMATION:* red to light grey siltstone with pink limestone beds and nodules
- 14 *BLACK JOHN FORMATION:* red conglomerate to siltstone, black slate, quartz arenite

LATE NEOPROTEROZOIC

- 13 *BEARS BROOK FORMATION:* red arkosic sandstone to conglomerate; minor basaltic to rhyolitic tuff; rare laminated cherty siltstone; youngest detrital zircon 593 ± 10 Ma and 585 ± 5 Ma (Murphy *et al*., 2004a, b)
- 12 *ARBUCKLE BROOK FORMATION:* basaltic to dacitic lithic tuff; basalt flows
- 11 *JAMES RIVER PLUTON:* medium-grained granite to granodiorite
- 10 *ANTIGONISH HARBOUR PLUTON:* (609.4 ± 5.7 Ma Ma U-Pb zr; this study) medium-grained to porphyritic granite to granodiorite; fine grained syenite
- 9 *BROWNS BROOK PLUTON:* subvolcanic, fine-grained to porphyritic gabbro
- 8 *GREENDALE COMPLEX:* fine-grained to pegmatitic hornblende gabbro; minor leucogranite
- 7 *BURROUGHS LAKE PLUTON:* (615.2 ± 2.8 Ma U-Pb zr; this study) medium-grained alkali-feldspar granite to syenogranite
- 6 *SUTHERLANDS LAKE PLUTON* medium-grained tonalite to quartz diorite
- *INDIAN LAKE PLUTON*
- 5b medium-grained granodiorite to monzogranite
- 5a medium-grained quartz diorite
- 4 *OHIO PLUTON* (606 ± 1 Ma U-Pb zircon; M. Hamilton, written com. 2010) medium-grained granodiorite
- *SANDY GUNNS LAKE PLUTON*
- 3b medium- to coarse-grained syenite to alkali-feldspar granite; 605 ± 10 Ma U-Pb zircon (Escarraga, 2010)
- 3a medium-grained quartz diorite; 603 ± 3 Ma $^{40}Ar/^{39}Ar$ hornblende (Keppie *et al*., 1990)
- *EDEN LAKE PLUTONIC SUITE*
- 2c medium- to coarse-grained syenite to alkali-feldspar granite
- 2b medium- to coarse-grained tonalite to granodiorite; 592 ± 32 Ma K-Ar hornblende (Wanless *et al*., 1967)
- 2a medium-grained quartz diorite

GEORGEVILLE GROUP

- 1f *CHISHOLM BROOK FORMATION:* basaltic lithic tuff, siltstone, conglomerate, rare marble and ironstone
- 1e *MORAR BROOK FORMATION:* siltstone and conglomerate, minor marble and basaltic tuff; ca. 621-612 Ma U-Pb detrital zircon (Keppie *et al*., 1998)
- 1d *BACK SETTLEMENT FORMATION:* basaltic lithic to crystal tuff, minor siltstone and conglomerate
- 1c *FRASER LAKE FORMATION:* basaltic flows and tuff; rare rhyolite tuff and flows, and laminated cherty siltstone
- 1b *JAMES RIVER FORMATION:* laminated cherty siltstone to sandstone; minor rhyolitic to basaltic tuff
- 1a *KEPPOCH FORMATION:* rhyolitic to dacitic tuff and flows; minor basaltic to andesitic tuff and flows, and laminated cherty siltstone; 618 ± 2 Ma U-Pb zircon and monazite (Murphy *et al*., 1997)

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Opportunities on the ground

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NOVA SCOTIA

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