Geological and Geochronological Studies in the Middle River - Leonard MacLeod Brook Area, Central Cape Breton Island, Nova Scotia

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Introduction

The Middle River - Leonard MacLeod Brook area in central Cape Breton Island, Nova Scotia, lies on the inferred boundary between the Aspy and Bras d'Or terranes, both of which are part of the microcontinent of Ganderia (Fig.1) (Barr and Raeside, 1989; Barr et al., 1998). The Aspy terrane is composed mainly of Late Ordovician to Devonian metavolcanic, metasedimentary, and plutonic rocks (Dunning et al., 1990; Barr et al., 1998; Horne et al., 2003; Lin et al., 2007) but older plutonic and metamorphic rocks with ages of ca. 620, 567, and 480–490 Ma have been recognized in the western part of the terrane (Lin et al., 2007; White et al., 2016a; Slaman et al., 2017; Barr et al., 2018). In contrast to the Aspy terrane, the Bras d'Or terrane is dominated by Neoproterozoic low-pressure amphibolite- to greenschist-facies metasedimentary and minor metavolcanic rocks, intruded by abundant Ediacaran and Cambrian plutons (Raeside and Barr, 1990; White et al., 1994, 2003, 2016b; van Rooyen et al., 2017; Barr et al., 2018). The Bras d'Or terrane is considered to be part of Ganderian basement on which the Aspy terrane was built (e.g. van Staal et al., 1996; Barr et al., 1998; van Staal and Barr, 2012; White et al., 2016a, b).

In the Middle River-Leonard MacLeod Brook area (Fig. 1), the location of the boundary between these two terranes is not well constrained and geological relationships are complicated by numerous mylonitic and brittle shear zones (e.g. Barr et al., 1992; Lin, 1993; Horne, 1995; O'Neill, 1996). Farther north the boundary area between the Aspy and Bras d'Or terranes hosts significant gold-bearing quartz veins (e.g. Slauenwhite, 1990; Mengel et al., 1991) and hence defining the location and nature of the boundary in the southern highlands is of potential economic interest. Relationships among rock units in this area, however, as well as the timing of deformation, metamorphism, and plutonism, are poorly understood.

To begin to resolve these issues, the 2017 field season focused on 1:10 000-scale bedrock mapping of the Sarach Brook Metamorphic Suite and associated plutonic units in an area along the northern and southern parts of NTS map areas 11K/02 and 11K/07 in the Middle River - Leonard MacLeod Brook area (Fig. 1). This report summarizes the geological, structural, and U-Pb zircon age results from the 2017 field season. Granitic rocks in the map area form part of an ongoing M.Sc. thesis project at Acadia University by the third author.

Background

The majority of the map area is composed of greenschist-facies metavolcanic and metasedimentary rocks previously assigned to the Ordovician-Silurian Sarach Brook Metamorphic Suite (SBMS) by Jamieson et al. (1987) and Barr et al. (1992). The kyanite-bearing Middle River Metamorphic Suite to the northwest was interpreted to be a higher-grade equivalent of the SBMS (Jamieson et al., 1987; Barr et al., 1992). Jamieson et al. (1987) and Barr et al. (1992) also recognized a spatially associated Leonard McLeod Brook Complex (LMBC), which included both metavolcanic rocks of the Sarach Brook

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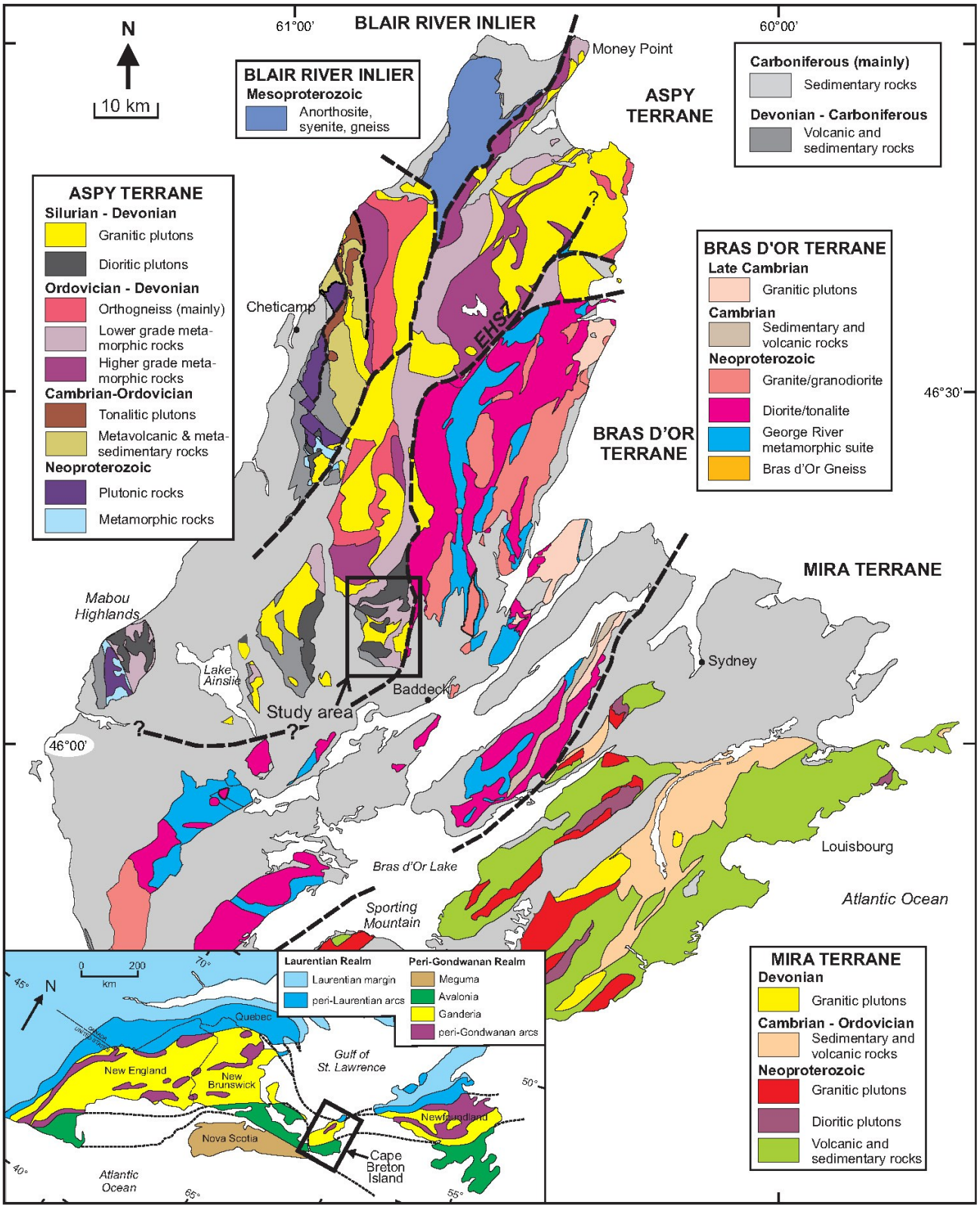

Figure 1. Simplified geological map of Cape Breton Island, modified after Barr (2010), showing the location of the study area. Inset map showing divisions of the northern Appalachian orogen is from Hibbard et al. (2006).

Metamorphic Suite and fine-grained syenogranite that they inferred to be Devonian to Carboniferous. The SBMS is intruded by the Bothan Brook pluton (O'Beirne-Ryan and Jamieson, 1986; Barr et al., 1992; Horne, 1995), which yielded a U-Pb zircon crystallization age of 376 ± 3 Ma (Horne et al., 2003).

Along the eastern margin of the map area, the SBMS and LMBC are observed in contact with tonalitic and dioritic rocks of the North Branch Baddeck River leucotonalite and Kathy Road diorite, which were interpreted to be Neoproterozoic to Cambrian and part of the Bras d'Or terrane exposed farther to the east (Barr et al., 1992; Lynch et al., 1995; O'Neill, 1996; Barr and White, 2017).

A volcanic package of rocks along the southern margin of the LMBC, named the MacMillian Mountain Volcanic Suite, was considered to be related to the Late Devonian Fisset Brook Formation exposed elsewhere in the Aspy and Bras d'Or terranes (Jamieson et al., 1987; Barr et al., 1992). Along the western, southern, and eastern flanks of the Middle River - Leonard MacLeod Brook map area the older units are overlain by or in faulted contact with sedimentary rocks of the Carboniferous Horton and Windsor groups (Fig. 1; e.g. Barr and White, 2017).

O'Neill (1996) remapped the LMBC and separated the volcanic rocks into the MacRae Brook Formation, which he assumed to be broadly equivalent to the SBMS. He interpreted the associated plutonic rocks, including tonalite and alkali-feldspar granite to syenogranite and monzogranite, to be comagmatic and assigned them to the Devonian Easach Ban Complex and Leonard MacLeod Brook Plutonic Suite. The more mafic plutonic rocks he assigned to the Gillis Brook Diorite, which he assumed to also be Devonian. He still retained the earlier defined MacMillian Mountain Volcanic Suite as another Devonian unit in the southern part of his map area.

Like earlier workers (e.g. Jamieson and Doucet, 1983; Barr et al., 1992), O'Neill (1996) recognized the widespread presence of mylonitic shear zones throughout the area and assigned various names to these structural features. He also interpreted the shear zones to be Late Devonian and more or less synchronous with plutonic emplacement.

Results

The summer of 2017 was one of the driest in recent memory on Cape Breton Island and as a result, exceptional outcrop exposure in streams and rivers helped in the collection of geological data, especially in areas that were previously lacking data. This new information helped to better define the distribution of geological units and their structural relationships. About 300 samples were collected and most were thin sectioned for petrographic study. About 40 igneous samples were analyzed by X-ray fluorescence (XRF) and inductively coupled plasma mass spectrometry (ICP-MS) at Bureau Veritas Commodities Canada Ltd., Vancouver, B.C., and are included in an ongoing M.Sc. thesis project at Acadia University by the third author (e.g. Moning et al., 2018). In addition, all samples were analyzed using a Reflex portable XRF (pXRF) unit to obtain a larger chemical database focused mainly on elements of economic interest. New U-Pb (zircon) dating and geochemistry clarified the ages and tectonic setting (e.g. Barr et al., 2018; Moning et al., 2018).

Based on structural data, cross-cutting plutonic relationships, and new U-Pb ages, rocks previously assigned to the MacRae Brook and MacMillian Mountain Volcanic unit (e.g. Jamieson and Doucet, 1983; O'Neill, 1996) are now included in the Sarach Brook Formation (Fig. 2). (Note: the 'metamorphic suite' designation has been discontinued). North of the map area, a rhyolite sample from the formation previously yielded a U-Pb zircon age of 433 +7/-4 Ma (Dunning et al., 1990). A rhyolite sample collected during this study from the MacRae Brook area (Fig. 2) yielded a U-Pb zircon age of 424.4 ± 5.7 Ma, slightly younger than the age from the rhyolite to the north but still Silurian.

The North Branch Baddeck River Leucotonalite (Fig. 2) consists of medium- to course-grained leucotonalite cut by numerous mafic dykes (Goodwin-Bell, 1995; O'Neill, 1996). As noted by these workers, and this study, the relationship to

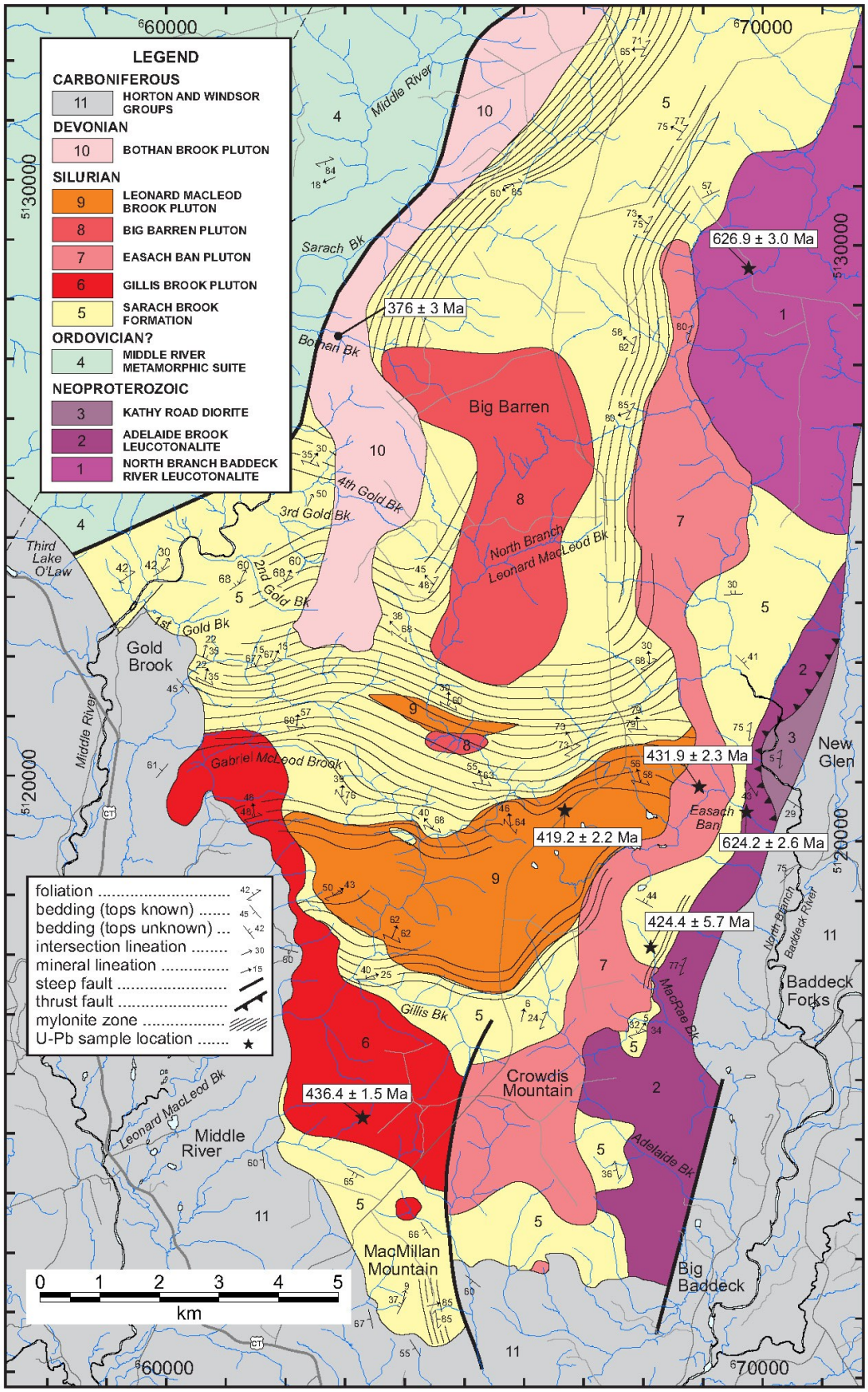

Figure 2. Geological map of the study area.

the Sarach Brook Formation is unclear as contacts are not exposed. Previous U-Pb zircon analyses from the leucotonalite yielded a poorly constrained Neoproterozoic age (Jamieson et al., 1986). A sample collected during this study yielded a more precise U-Pb zircon age of 626.9 ± 3.0 Ma, thus confirming a Neoproterozoic age.

The Adelaide Brook Leucotonalite, as defined by O'Neill (1996), forms a linear body to the south of the North Branch Baddeck River Leucotonalite (Fig. 2). Although O'Neill (1996) was uncertain about the relationship between these two tonalitic units, a new U-Pb zircon age of 624.2 ± 2.6 Ma for a sample of the Adelaide Book Leucotonalite confirms that they are of the same age, consistent with their petrological similarity. Although not confirmed during this study, O'Neill (1996) reported that rocks of his "MacRae Brook Formation" unconformably overlie the Adelaide Brook Leucotonalite, consistent with the new U-Pb zircon ages. A small body of medium-grained diorite to quartz diorite that outcrops in the North Branch Baddeck River is separated by a shallow west-dipping thrust from the Adelaide Brook Leucotonalite (Fig. 2). Based on petrological similarities it is interpreted to be part of the ca. 560 Ma Kathy Road Diorite, which is exposed farther to the north, and hence the thrust may mark the Bras d'Or – Aspy terrane boundary in that area.

The Leonard MacLeod Brook Suite, Gillis Brook Diorite, and Easach Ban Complex, as defined by O'Neill (1996), are generally retained here but their distribution has been better defined. Following the North American Commission on Stratigraphic Nomenclature (2005) for naming intrusive bodies they are assigned the lithodemic 'pluton' designation. The Leonard MacLeod Brook, Easach Ban, and Gillis Brook plutons, as well as the newly defined Big Barren Pluton (Fig. 2), vary in composition from gabbro and diorite to tonalite and alkali-feldspar granite to syenogranite and monzogranite, and typically display co-mingling/ mixing textures. In addition, all these plutonic units are variably deformed, especially the northern and southern margin of the Leonard MacLeod Brook Pluton where several well developed mylonite zones are present (Fig. 2). The absolute timing of the deformation is unclear but based on field observations, the syenogranitic parts of the co-mingled units are foliated whereas the more mafic 'enclaves' are not, suggesting that plutonism was syntectonic. In less deformed areas, these plutonic units produced a cordierite-bearing hornfelsic contact metamorphic aureole in the surrounding Sarach Brook Formation.

The Gillis Brook, Easach Ban, and Leonard MacLeod Brook plutons yielded Silurian U-Pb zircon ages of 436.4 ± 1.5, 431.9 ± 2.3, and 419.2 ± 2.2 Ma, respectively (Barr et al., 2018). In contrast, the elongate monzogranitic Bothan Brook pluton in the northwestern part of the map area is Devonian (376 ± 3 Ma; Horne et al., 2003). The Bothan Brook pluton is in faulted contact along its western margin with the Middle River Metamorphic Suite. Earlier workers (e.g. Jamieson and Doucet, 1983; Horne, 1995) suggested a mylonitic contact along its eastern margin, but mapping in this study confirmed that the pluton intruded mylonitic country rocks. This observation confirms that the mylonitic deformation in the area had ceased by ca. 376 Ma.

Structural measurements in the central part of the map area indicate that bedding in the Sarach Brook Formation has been transposed parallel to mylonitic foliation and defines an east-west orientation with a moderate dip to the north (Figs. 3 a, b). Contoured poles to bedding and mylonitic foliations define a weak girdle distribution with similar calculated F_1 (07/45) and F_2 fold (11/52) axes (Figs. 3 a, b). In the Gold Brook area to the west, mylonitic deformation is less well developed (Fig. 2) and an intersection lineation (bedding/ cleavage) is preserved that has an average orientation (26/35) similar to the calculated fold axis. Contoured lineations measured from amphibole crystals and elongate quartz and lithic clasts, which are interpreted to reflect the stretching direction, define two populations: one similar to the intersection lineation (21/36) and the other steeper and down-dip (336/79) on the mylonitic fabric (Fig. 3c). All these structural data suggest a dip-slip component of movement and based on textural evidence observed in the field (e.g. asymmetric augen and quartz veins) a north-side-up and vergence to the south sense of movement is suggested, in agreement with observations by

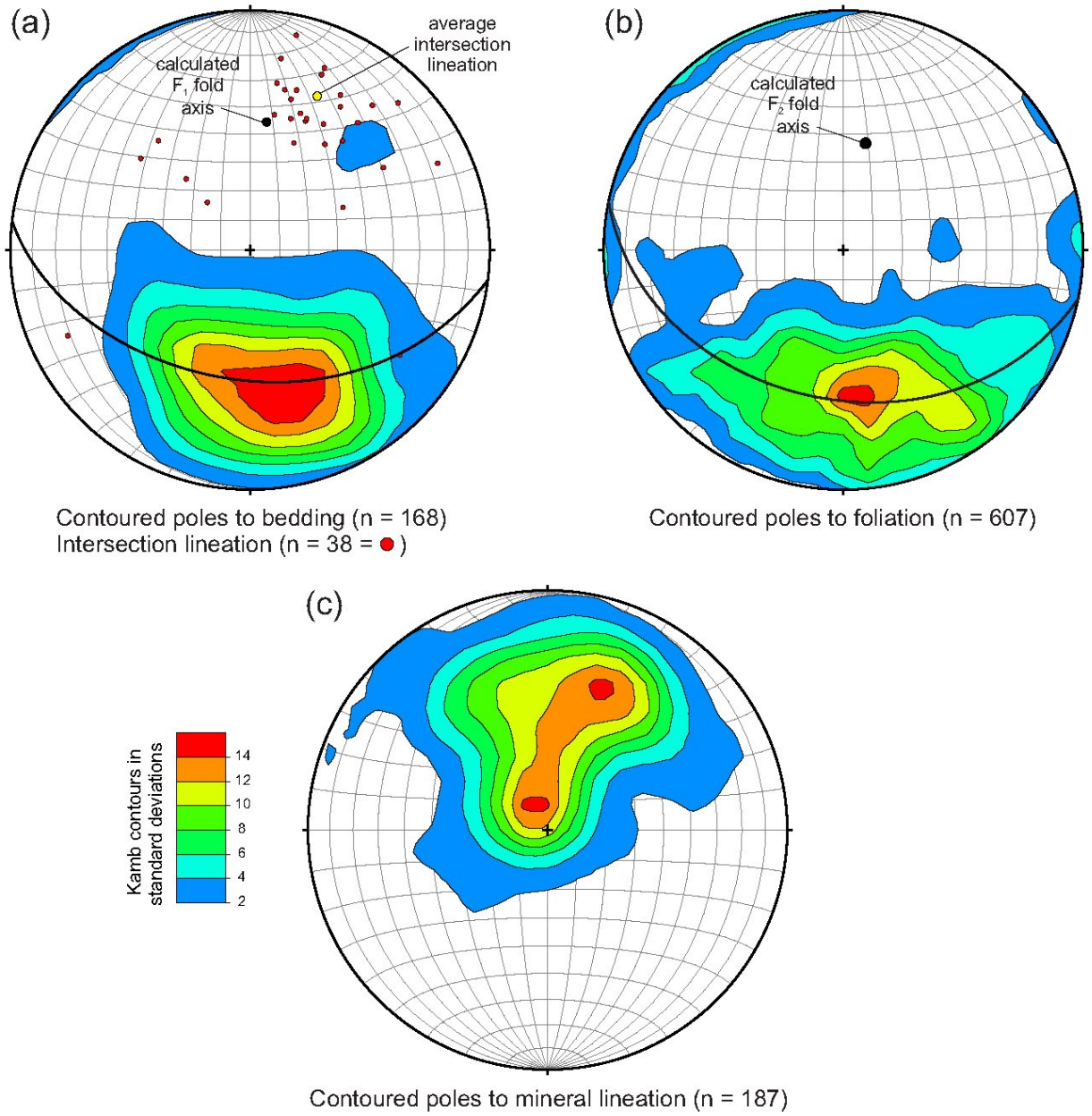

Figure 3. Equal-area stereonets of structural data from the Middle River – Leonard MacLeod Brook area. (a) Contoured poles to bedding and intersection lineation (red circles) orientations; solid great circle shows the calculated orientation of S_0 and calculated average F_1 fold axis. (b) Contoured poles to foliation; solid great circle shows the calculated orientation of the mylonitic S_1 and calculated average F_2? fold axis. (c) Contoured mineral lineation measurements.

Jamieson and Doucet (1983). More detailed kinematic studies are needed, however, to confirm this interpretation.

Analyses of samples representing all of the rock types in the map area by pXRF showed low background levels of Cu (<100 ppm), Pb (<20 ppm), Zn (<180 ppm), and Ni (<200 ppm) in metavolcanic, metasedimentary, and plutonic units, as well as in associated quartz veins. The highest levels were obtained in samples from the area of historical mining, drilling, and exploration in Second Gold Brook (Chew, 2017; Chew and Barr, 2017), which may suggest that the economic mineralization is confined to that area.

Conclusions

Recent geological mapping combined with geochronology and structural studies have better defined the geology in the Middle River – Leonard MacLeod Brook area. The previously enigmatic Leonard MacLeod Brook Complex of Barr et al. (1992), and subdivisions documented by O'Neill (1996), have been demonstrated to consist of Silurian volcanic, sedimentary, and plutonic rocks, likely emplaced in a volcanic arc setting (Moning et al., 2018). The Neoproterozoic ages (ca. 625 Ma) of the North Branch Baddeck River and Adelaide Brook leucotonalite plutons are older than plutonic units in the Bras d'Or terrane and hence indicate that they are part of the Aspy terrane, where similar ages have been recorded (Lin et al., 2007). It also suggests that these older plutonic rocks extend to the eastern edge of the Aspy terrane and hence that the Eastern Highlands Shear Zone is mostly buried under Carboniferous cover in the area. The mylonitic deformation that was interpreted previously to be directly related to the Eastern Highlands Shear Zone (e.g. O'Neill, 1996) is likely Devonian and internal to the terrane, like shear zones documented elsewhere in the Aspy terrane (e.g. White et al., 2017).

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