Geochronological Studies of Pre-Carboniferous Rocks in the Cobequid Highlands, Northern Mainland Nova Scotia

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Introduction

The Cobequid Highlands of northern mainland Nova Scotia occupy a unique position along the outboard part of Avalonia, with the southern boundary marked by the Cobequid Fault and the northern boundary marked by the unconformably overlying sedimentary rocks of Late Carboniferous Cumberland Group (Fig. 1). Previous studies have shown the Highlands to be predominantly Neoproterozoic to Early Carboniferous volcanic, sedimentary and plutonic rocks (e.g. Nance and Murphy 1990; Murphy et al. 1997; Pe-Piper and Piper 2002). In 2011, geologists of what was then the Mineral Resources Branch of the Nova Scotia Department of Natural Resources began a major, multi-year mapping, geochemical, and geochronological study to better understand the geological evolution of the Cobequid Highlands (MacHattie, 2011, 2013, 2017, 2018; MacHattie and White, 2012, 2014a, b; MacHattie et al., 2013a, b). This report summarizes the new U-Pb zircon geochronological results from pre-Carboniferous units in the Cobequid Highlands.

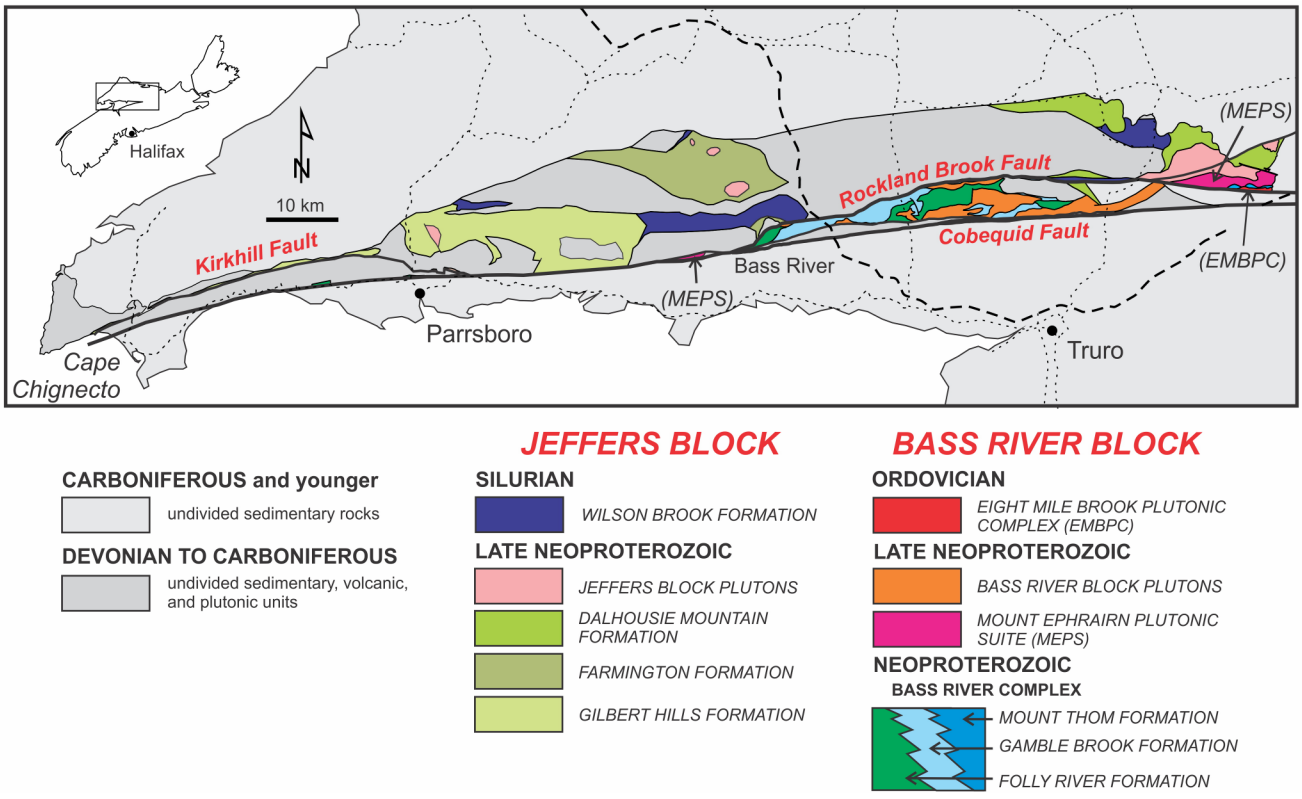

Figure 1. Simplified geological map of the Cobequid Highlands.

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Geological Framework

Bedrock mapping combined with geochemistry and geochronology (MacHattie and White, 2012, 2014b; MacHattie et al., 2013a, b; White et al. 2019) has better defined the distribution of geological units and their stratigraphy in the highlands and confirmed previous interpretations (e.g. Pe-Piper et al. 1996; Pe-Piper and Piper 2002) that the pre-Carboniferous rocks can be divided into two distinct geological assemblages termed the Bass River and Jeffers blocks (Fig. 1).

The Bass River block forms the area between the Cobequid Fault to the south and the Rockland Brook Fault to the north. The Jeffers block is bounded on the south by the Rockland Brook Fault and on the north by unconformably overlying Lower Carboniferous sedimentary rocks of the Cumberland Group. Pre-Carboniferous units in the Bass River block include (1) metasedimentary and metavolcanic rocks of the Gamble Brook, Folly River, and Mount Thom formations of the Neoproterozoic Bass River Complex; (2) the Neoproterozoic Mount Ephrairn plutonic suite; (3) the Late Neoproterozoic Frog Lake, Debert River, and McCallum Settlement plutons, collectively termed the Bass River block plutons; and (4) the Ordovician Eight Mile Brook plutonic complex (MacHattie and White, 2014a, b; White et al., 2019). Pre-Carboniferous units in the Jeffers block include Neoproterozoic volcanic rocks of the Dalhousie Mountain, Farmington, and Gilbert Hills formations (together known as the Jeffers Group) and related plutonic units (Gunshot Brook, Six Mile Brook, Jeffers Brook, New Prospect, and McCormack Lake plutons, collectively termed the Jeffers block plutons) (Pe-Piper and Piper, 2002; MacHattie and White, 2014a, b; MacHattie and White 2015; White et al., 2019). A fault-bounded sliver of Neoproterozoic volcanic rocks in the Bass River block is interpreted to be part of the Dalhousie Mountain Formation that was faulted into its present position (White et al., 2019). Overlying or in faulted contact with the older units in the Jeffers block are sedimentary rocks of the Silurian Wilson Brook Formation (MacHattie et al., 2013a, b; MacHattie and White, 2014a, b; MacHattie and White, 2015).

These unit names are currently considered informal as mapping and geochronological work in the Cobequid Highlands have not been completed and may result in the necessity of further changes in terminology.

Geochronological Studies

Introduction

Uranium-lead age determinations from zircon grains in standard polished petrographic thin section and grain mounts were completed using the laser-ablation microprobe–inductively coupled plasma–mass spectrometry (LAM-ICP-MS) method at the University of New Brunswick and the Isotope Geology Laboratory at Boise State University in Idaho following the procedure outlined by McFarlane and Luo (2012), Archibald et al. (2013), and J. Crowley, written communication (2019). These data were integrated with previously published data (e.g. Murphy et al., 1997; Keppie et al., 1998; Barr et al., 2003; Henderson, 2016; Henderson et al., 2016). Previous Rb-Sr, K-Ar, $^{40}Ar/^{39}Ar$, and U-Pb geochronological studies in the highlands (up to 1991) were summarized in Murphy et al. (2001) and geologically valid data are incorporated in the probability plots used in this report (Fig. 2, 3).

Bass River Block

Bass River Complex

Single grain detrital zircon analyses (TIMS) from a quartzite bed in the Gamble Brook Formation suggested a maximum depositional age of 1189.3 ± 2.0 Ma (Keppie et al., 1998). A follow-up U-Pb TIMS detrital zircon study on the same sample by Barr et al. (2003) yielded a slightly younger single zircon age of 996.6 ± 2.2 Ma. Henderson et al. (2016) collected two samples from near the same location and, using the LAM-ICP-MS method, defined the youngest population (three overlapping concordant zircon ages) at 975 ± 33 Ma.

During the present study, detrital zircon grains were dated from two quartzite samples and a metawacke sample from the Gamble Brook Formation and quartzite, metawacke, and paragneiss samples from the Mount Thom Formation. The similarity in Mesoproterozoic to Paleoproterozoic patterns (Fig. 2) suggests the same (or similar) source areas for detritus in all of these samples and hence supports field observations that the Gamble Brook and Mount Thom formations are likely correlative (e.g. MacHattie and White, 2012). The patterns are also similar to detrital zircon signatures from basins proximal to and on the West African Craton

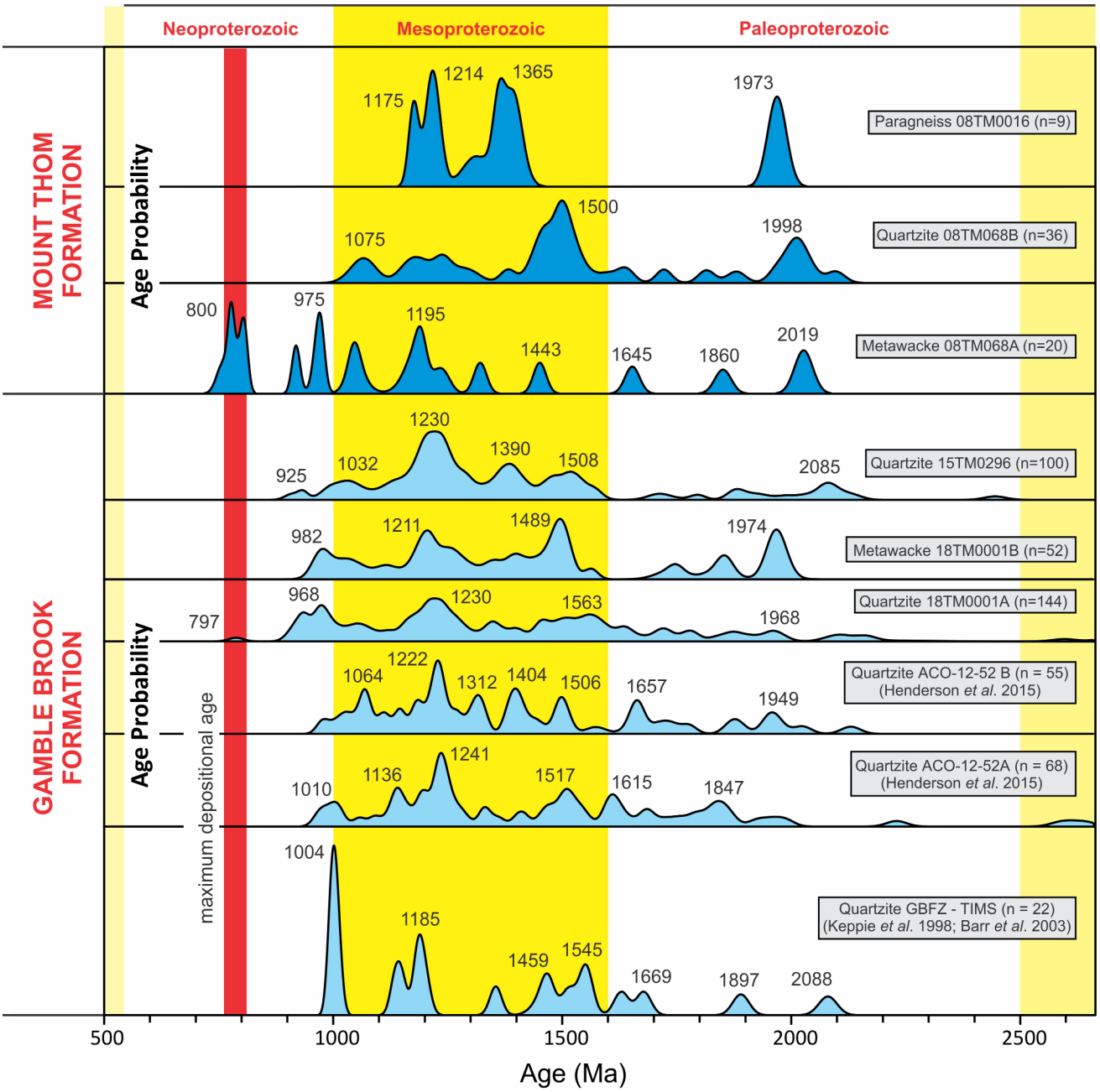

Figure 2. Age probability plots for samples from the Gamble Brook and Mount Thom formations.

(Bradley et al., 2015). The youngest population of detrital zircons from our data suggests a maximum depositional age of ca. 800 Ma. This ca. 800 Ma population of zircon ages are not recorded in the West African data.

Mount Ephrairn Plutonic Suite

The dioritic parts of the Mount Ephrairn plutonic suite were first recognized by Donohoe and Wallace (1982) who considered them to be latest Neoproterozoic, like the other plutonic units in the block. Pe-Piper and Piper (2005) also considered the suite to be latest Neoproterozoic and included the more granitic and dioritic units with the Debert Lake and Frog Lake plutons, respectively. Based on field observations, MacHattie and White (2012) recognized the distinct character of the suite and dated four samples that yielded concordant LAM-ICP-MS zircon ages that ranged from ca. 755 to 735 Ma, confirming its uniqueness. Two additional samples (monzogranite and gabbro) analyzed at

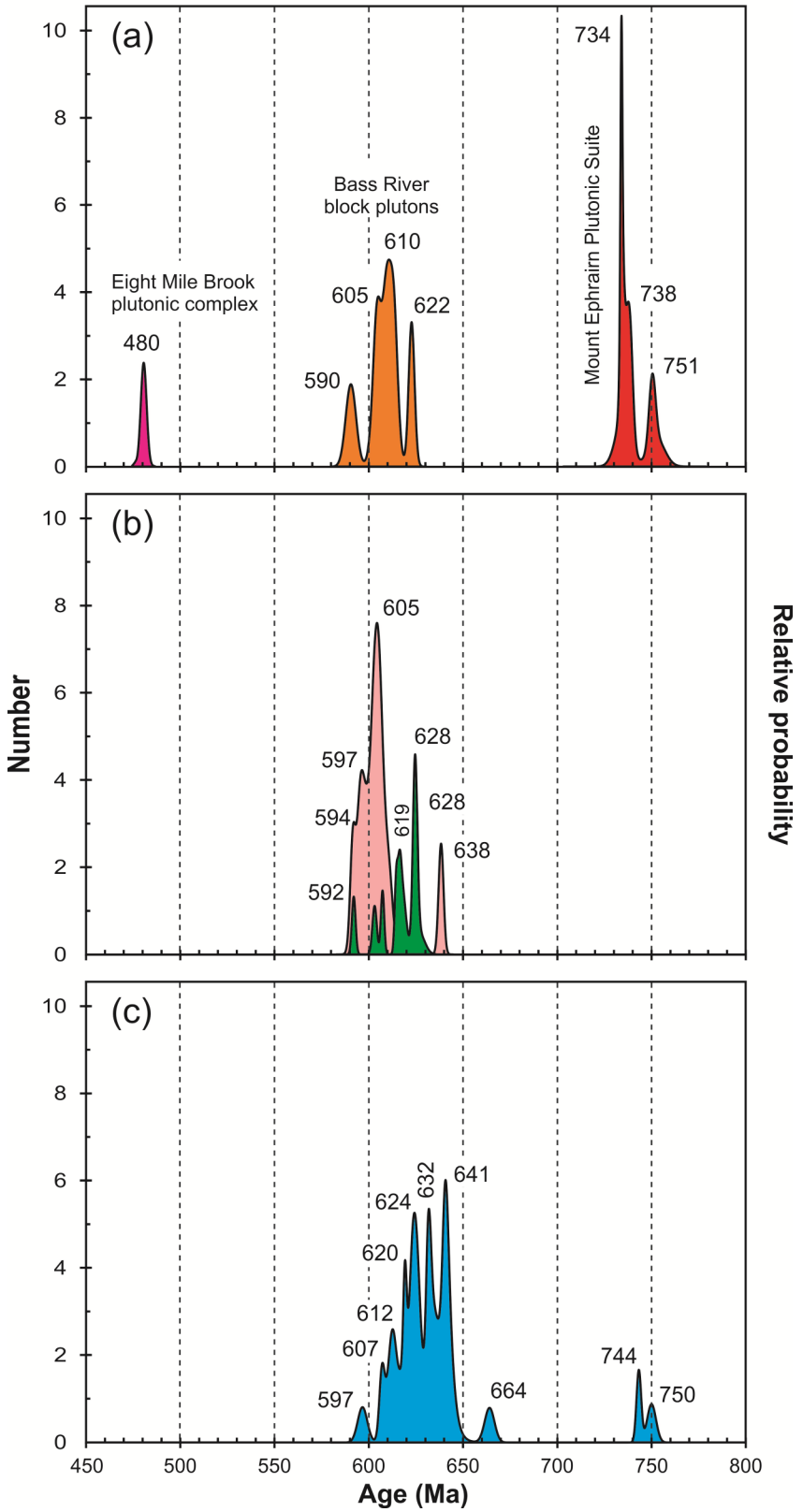

Figure 3. Age probability plots for units in the Cobequid Highlands. (a) Plot of crystallization ages for the Mount Ephrairn Plutonic Suite, Bass River block plutons, and the Eight Mile Brook plutonic complex. (b) Plot of crystallization ages for volcanic rocks in the Jeffers Group (green) and related plutonic units (pink). (c) Plot of inherited zircons from the Late Neoproterozoic and Carboniferous volcanic and plutonic units.

Boise State University yielded similar ca. 735 Ma results (Fig. 3a).

Although the Economy River Gneiss was considered to be basement to the Avalon Zone (Nance and Murphy, 1990), it is protomylonitic granodiorite with numerous xenoliths of quartzite and metavolcanic rocks. It yielded a TIMS U-Pb zircon age of 734.3 ± 1.9 Ma (Doig et al., 1991) and a LAM-ICP-MS zircon age population of 733.98 ± 0.96 (Henderson, 2016). Hence, we consider the 'gneiss' to be a more deformed part of the Mount Ephrairn plutonic suite (White et al., 2019).

Plutons in the Bass River Block

Based on field relations and geochemistry, the Frog Lake, Debert River, and McCallum Settlement plutons and related smaller intrusions are similar and are collectively referred to as the Bass River block plutons (White et al., 2019). Previous U-Pb zircon and $^{40}Ar/^{39}Ar$ amphibole ages on plutonic units have yielded ages that range from ca. 622 to 590 Ma (Keppie et al., 1990; Doig et al., 1991). Combined with the six additional concordant zircon ages from this study, the results show that the Frog Lake pluton is the oldest Bass River block pluton with similar $^{40}Ar/^{39}Ar$ amphibole and U-Pb ages of ca. 622 (Fig. 3a). The Debert River and McCallum Settlement plutons fall into a 610 to 605 Ma age range, but exhibits a younger peak at ca. 590 Ma (Fig. 3a) that coincides with the ages of two samples of strongly deformed igneous rocks analyzed by Doig et al. (1991). This younger peak could be attributed to a younger pulse of intrusion but is more likely related to Pb-loss during mylonitization.

Eight Mile Brook Plutonic Complex

The Eight Mile Brook pluton (Donahoe and Wallace, 1982), or plutonic complex (MacHattie and White, 2012), is a suite of co-mingled syenite and gabbro that intrudes the Mount Thom Formation and Mount Ephrairn plutonic suite. Donahoe and Wallace, (1982) considered these rocks to be latest Neoproterozoic. Pe-Piper and Piper (2005) also considered them to be Neoproterozoic but included them with metasedimentary rocks in a tectonic-slice unit. To better constrain the age, two alkali-feldspar granite samples and a syenite sample were collected for U-Pb analysis. All three rocks yielded concordant zircon ages of ca. 480 Ma (Fig. 3a) (MacHattie and White, 2012, 2014b). This early Ordovician plutonic unit is similar to the West Barneys River plutonic suite in the Antigonish Highlands (Archibald et al., 2013; White, 2017)

Jeffers Block

Jeffers Group

The Dalhousie Mountain, Farmington, and Gilbert Hills formations constitute the Jeffers Group and, although geographically dispersed, contain rocks with similar lithological characteristics. They include dacitic to andesitic crystal to crystal lithic tuff and minor rhyolitic lapilli tuff and flows, as well as rare basaltic tuffaceous rocks and flows (MacHattie and White, 2014a, b, 2015; MacHattie 2016). All three formations also include distinctive laminated 'cherty siltstone' interpreted to represent volcanic ash layers (MacHattie and White, 2014a, b), similar to components of the Georgeville Group in the Antigonish Highlands (e.g. White, 2017).

Prior to this study, the only U-Pb zircon age from these formations was from a rhyolite in the Gilbert Hills Formation, which yielded an upper intercept U-Pb zircon age of 628.5 ± 2.6 Ma (Murphy et al., 1997). Eleven additional rhyolitic samples were collected for the present study, consisting of five from the Gilbert Hills Formation, five from the Farmington Formation, and one from the Dalhousie Mountain Formation. The concordant zircon ages form four main peaks on the probability plots at ca. 628, 619, 609 to 605, and 592 Ma (Fig. 3b).

Plutonic Units in the Jeffers Block

Based on field relations and geochemistry, the Gunshot Brook, Six Mile Brook, Jeffers Brook, New Prospect, and McCormack Lake plutons are similar and are collectively referred to as the Jeffers block plutons (White et al., 2019).

In the western Cobequid Highlands, the Gilbert Hills Formation is intruded by the Jeffers Brook pluton (Pe-Piper and Piper, 2002; MacHattie and White, 2015; McCulloch, 2017). Hornblende from dioritic parts of the pluton yielded $^{40}Ar/^{39}Ar$ plateau ages of 607.1 ± 3.4 and 604.5 ± 4.4 Ma (Keppie et al., 1990). In the eastern Cobequid Highlands, the Gunshot Brook pluton, which intruded the Dalhousie Mountain Formation, has yielded a U-Pb zircon age of 605 ± 5 Ma (R. Doig in Murphy et al., 2001; no data were published for this age).

To better understand the plutonic history of plutons in the Jeffers block, seven additional samples were collected for U-Pb zircon analysis: three granodiorite samples from the Jeffers Brook pluton; two samples of fault-bounded granodiorite associated with the Kirkhill Fault (New Prospect pluton); one sample of granite from the McCormack Lake pluton that intrudes the Farmington Formation; and one sample from the Gunshot Brook pluton. The resulting concordant zircon ages show that the Gunshot Brook pluton is the oldest at 638.6 ± 2.5 Ma and that the previously reported date of ca. 605 Ma (cited above) may be unreliable. The combined data on the probability plots show additional peaks at ca. 628 and 605 to 594 Ma, similar to the ages of the associated volcanic units (Fig. 3b).

Zircon Inheritance

Many of the Late Neoproterozoic volcanic and plutonic units in the Jeffers block contain abundant older (inherited) concordant zircon grains. These ages, along with those of inherited zircon grains from Carboniferous plutonic and volcanic units, can be used to gain some insight into the geological evolution of the Cobequid Highlands. In this study we used three or more overlapping concordant zircon analyses to justify the definition of 'population' following the method cited by Slaman et al. (2017) and use those ages. As a result, 30 inherited ages yielded several peaks (Fig. 3c) that show a cluster between 641 to 597 Ma which covers the crystallization ages for many of the volcanic and plutonic units in the Jeffers and Bass River blocks, the likely sources of these grains. The ca. 750 and 744 Ma peaks are from inherited zircons in volcanic rocks from the Farmington and Gilbert Hills formations; their similarity to the ages of plutons in the Mount Ephrairn plutonic suite suggests that the Jeffers block may have been in close proximity to the Bass River block during the Late Neoproterozoic.

Future Work

Results from the new U-Pb zircon analyses are intriguing but retain some ambiguity in terms of understanding relationships of units in both the Jeffers and Bass River blocks and ages of associated plutonic units. Hence work is ongoing to further resolve the remaining uncertainties, including additional lithogeochemical interpretations and isotopic and geochronological studies, with the aim of further characterizing the geological history of the area and its mineral occurrences.

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