The Mount Ephraim Block, Cobequid Highlands, Nova Scotia, Canada: Evidence for 750-735 Ma and 630 Ma Active Continental Margins

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Introduction

Pre-Carboniferous rocks in the Cobequid Highlands of northern mainland Nova Scotia have been separated previously into two parts: the Jeffers and Bass River blocks (e.g. Pe-Piper et al., 1996; Pe-Piper and Piper, 2002; MacHattie and White, 2012, 2014; White et al., 2019). The Jeffers block forms the northern part of the highlands, bounded on the north by unconformably overlying Lower Carboniferous sedimentary rocks, and on the south by the Rockland Brook Fault, whereas the Bass River block forms the southern highlands between the Rockland Brook and Cobequid faults (Fig. 1, inset).

Mapping, petrological studies, and U-Pb dating during 2019 in the eastern part of the Cobequid Highlands have shown that the rocks in that area differ in character and age from those in both the Jeffers and Bass River blocks, and hence they are assigned here to a third block, for which the name Mount Ephraim is proposed (Fig. 1). The Mount Ephraim block is located between the Rockland Brook Fault on the south and a major thrust fault on the north, and contains some rocks (Dalhousie Mountain Formation) previously included in the

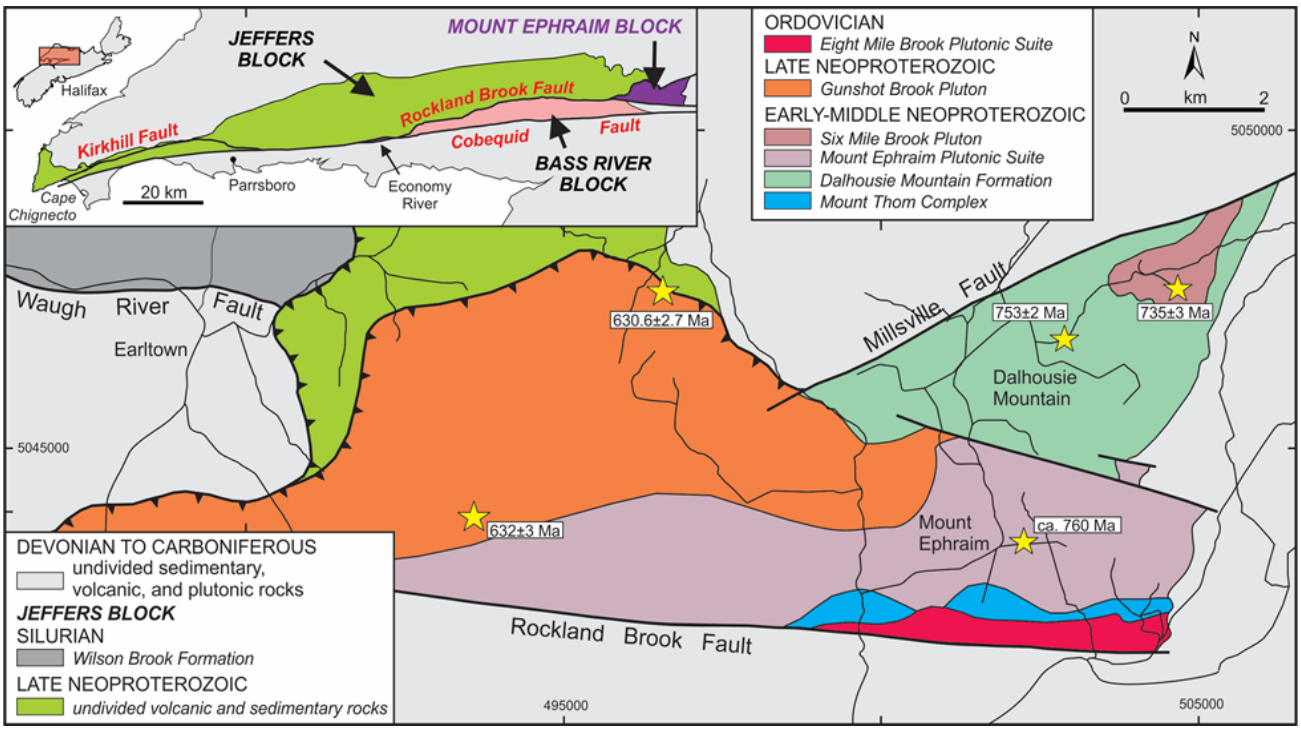

Figure 1. Simplified geological map of the Mount Ephraim block in the eastern Cobequid Highlands. Inset shows simplified geology of the Cobequid Highlands. Yellow stars indicate locations of samples with new U-Pb age dates reported in this paper.

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Jeffers block, and some rocks (Mount Thom Formation, Mount Ephraim plutonic suite) previously included in the Bass River block (White et al., 2019). The Mount Ephraim block also includes rocks previously of uncertain affiliation (the Gunshot and Six Mile Brook plutons, Fig. 1).

The components of the Mount Ephraim block are described briefly here, including both new ages and previously reported ages (as summarized by White et al., 2019) as well as results of petrological studies by Vaccaro (2020).

Mount Thom Formation

The Mount Thom Formation (formerly Mount Thom complex) consists of quartzofeldspathic, semipelitic, and pelitic gneiss with minor calc-silicate gneiss and rare amphibolite (MacHattie and White, 2012, 2014). The maximum depositional age is about 800 Ma, based on the age of the youngest detrital zircon population from a metawacke sample (White et al., 2019). Paragneiss and quartzite samples contain only Mesoproterozoic to early Paleoproterozoic zircon grains. The similarity in Mesoproterozoic to early Paleoproterozoic detrital zircon patterns suggest the same (or similar) source areas for detritus as those of the Gamble Brook Formation in the Bass River block (MacHattie et al., 2013; White et al., 2019). A minimum age for the Mount Thom Formation is provided by the cross-cutting ca. 755 to 735 Ma Mount Ephraim plutonic suite described below. It is interpreted to represent a passive margin formed between 800 Ma and 760 Ma on the edge of Rodinia prior to and during the break-up of that supercontinent. It was deformed and metamorphosed prior to its intrusion by the ca. 555-535 Ma Mount Ephraim plutonic suite, described below.

Dalhousie Mountain Formation

The Dalhousie Mountain Formation underlies the northeastern part of the Mount Ephraim block (Fig. 1). It consists of weakly cleaved green to grey, dacitic to andesitic, crystal to crystal lithic tuff; minor pale pink to grey, rhyolitic lapilli tuff with abundant crystal and lithic fragments, and green-grey laminated ash. Also present are rare green basaltic tuffaceous rocks and amygdaloidal basalt flows (MacHattie and White, 2014). Prior to the present work, these rocks were included in the ca. 620 Ma Jeffers Group (e.g. White et al., 2019). A sample of rhyolitic crystal lithic tuff dated as part of the present study, however, yielded a late Tonian age of 752±3 Ma. Although its contact with the Mount Ephraim plutonic suite is faulted, it is intruded by the Six Mile Brook pluton of similar late Tonian age as the Mount Ephraim suite. Petrological characteristics of both the volcanic rocks and the associated plutons are indicative of an active continental margin setting (Vaccaro, 2020).

Mount Ephraim Plutonic Suite

The Mount Ephraim plutonic suite consists dominantly of diorite to quartz diorite with textures that range from fine- to coarse-grained and equigranular to porphyritic. More felsic units are a minor component of the suite and consist of medium- to coarse-grained, slightly porphyritic granodiorite to granite; phenocrysts are quartz and K-feldspar. Mingling between mafic and felsic phases of the plutonic suite is common, demonstrating that they are co-magmatic. Earlier workers in the area generally considered these rocks to be latest Neoproterozoic, like other dioritic and granitic plutons of the Bass River block (Donohoe and Wallace, 1982; Pe-Piper and Piper, 2005). MacHattie and White (2012) recognized the distinctive characteristics of the suite, subsequently confirmed by U-Pb zircon ages between 755 and 735 Ma (White et al., 2019). In the present study, an additional granitic sample was dated by LA-ICP-MS from an area characterized by abundant dioritic xenoliths with compositions like diorite in the Mount Ephraim suite (Vaccaro. 2020). Although the age is imprecise due to Pb loss, it is approximately 760 Ma, confirming that these rocks are part of the Mount Ephraim suite and not the Gunshot Brook pluton as previously assumed.

The Economy River Gneiss consists of 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 Ma (Henderson et al., 2016). Based on its age and compositional similarity, the protomylonitic granodiorite is now interpreted to be a more deformed part of the Mount Ephraim plutonic suite (White et al., 2019).

The petrological features of the Mount Ephraim plutonic suite are consistent with origin in a continental margin subduction zone (Vaccaro, 2020).

Six Mile Brook Plutonic Suite

MacHattie and White (2012, 2014) recognized a small dioritic pluton intruded into the Dalhousie Mountain Formation, which they named Six Mile Brook (Fig. 1). The Six Mile Brook pluton consists of medium- to coarse-grained, equigranular to porphyritic, diorite to quartz diorite, with textural and mineralogical similarities to the mafic enclaves in the Gunshot Brook pluton. Classification based on normative mineralogy showed that samples from the Six Mile Brook pluton plot in the quartz diorite-tonalite-granodiorite fields, and hence differ from the Mount Ephraim suite. They also have some other chemical differences, such as lower rare-earth element compositions overall, which suggest that although the Six Mile Brook pluton is similar in age to the Mount Ephraim plutonic suite, it might not be co-genetic with that suite. All these rocks appear to have formed in a volcanic-arc setting, although Six Mile Brook has more volcanic-arc tholeiitic than calc-alkalic characteristics (Vaccaro, 2020).

Gunshot Brook Pluton

The Gunshot Brook pluton has a long and varied history. Donohoe and Wallace (1982) showed the pluton now mapped as Gunshot Brook (Fig. 1) as part of the larger Devonian Salmon River pluton, whereas Murphy et al. (2000, 2001) divided the pluton into a Devonian western part and a Neoproterozoic eastern part in contact at the Millsville Fault. Pe-Piper and Piper (2005) introduced the name Gunshot Brook for both the western and eastern parts of the pluton and assigned a Neoproterozoic age for both. MacHattie and White (2012, 2014) showed the Millsville Fault extending through the pluton as a splay from the Rockland Brook Fault, but retained the name Gunshot Brook for plutonic rocks on both sides of the fault. Subsequently, an age of 638.6 ± 2.5 Ma was reported from granodiorite south of the inferred fault (White et al., 2019), but reassessment of the data has resulted in a revised date of 632 ± 3 Ma (Fig. 1). In 2019, a second granodioritic sample from near the northern margin of the Gunshot Brook pluton yielded a U-Pb zircon age of 630.6 ± 2.7 Ma (Fig. 1), confirming the petrological observations of Vaccaro (2020) that the pluton is similar throughout.

Vaccaro (2020) showed that the pluton consists mainly of granodiorite, locally mingled with dioritic rocks. The granodiorite locally grades to monzogranite and tonalite, but all are characterized by a distinctive porphyritic texture with phenocrysts consisting of clusters of quartz grains. Chemical analyses showed chemical variations consistent with crystal fractionation of plagioclase and amphibole. The chemical characteristics are typical of a magnesian, calc-alkalic suite formed in a continental margin subduction zone.

Eight Mile Brook Plutonic Suite

The Eight Mile Brook pluton (Donahoe and Wallace, 1982) or plutonic complex (MacHattie and White, 2012) consists of co-mingled syenite and gabbro that intruded both the Mount Thom Formation and the Mount Ephraim plutonic suite. Although previously thought to be Neoproterozoic (Donahoe and Wallace, 1982; Pe-Piper and Piper, 2005), U-Pb zircon ages from alkali-feldspar granite and syenite samples of ca. 480 Ma showed that these rocks are early Ordovician and similar in age and rock types to the West Barneys River plutonic suite in the Antigonish Highlands (Archibald et al., 2013; White, 2017). Because of its range in composition, like West Barneys River, it is best termed a plutonic suite.

Future Work

The Mount Thom Formation provides direct evidence for a Tonian passive margin, but on what ancient continent that margin was located is unknown. The pre-755 Ma deformation recorded in the Mount Thom Formation, combined with evidence in the Dalhousie Mountain Formation and associated plutons (Mount Ephraim plutonic suite and Six Mile Brook pluton) provide some of the only evidence anywhere for continental margin subduction in the late Tonian (van Staal et al., 2020). After a gap of 100 million years with no record, the Gunshot Brook pluton again records subduction-related igneous activity in the Mount Ephraim. The relationship of the geological events recorded in the Mount Thom block to those in the Bass River and Jeffers blocks remains to be worked out. How do the mafic metavolcanic rocks,

quartzite, metawacke, and minor marble and ironstone of the Folly River and Gamble Brook formations, with maximum depositional age of ca. 1 Ga, relate to the Mount Thom Formation? Did the Gunshot Brook pluton form in the same subduction zone as the younger ca. 622 and ca. 610 Ma calc-alkalic arc-related plutonic rocks that intrude the Folly River and Gamble Brook formations? Is ca. 750 Ma inheritance in some igneous units in the Jeffers block (White et al., 2019) evidence that they formed on or near the Mount Ephraim block? How do the Gunshot Brook pluton of the Mount Ephraim block and ca. 622 and ca. 610 Ma calc-alkalic arc-related plutonic rocks of the Bass River block relate to the 625 to 590 Ma volcanic rocks and co-magmatic calc-alkaline granitoid rocks of the Jeffers block? Additional mapping, petrological studies, and U-Pb zircon dating are needed to answer these questions.

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