NEW U–Pb ZIRCON GEOCHRONOLOGY FOR THE MEASLES POINT GRANITE, AILLIK DOMAIN, MAKKOVIK PROVINCE, LABRADOR (NTS MAP AREA 13O/03)

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ABSTRACT

Quartz–feldspar-porphyritic intrusions are present throughout the Aillik domain of the Makkovik Province. These intrusions are regionally extensive linear bodies that bisect the Aillik Group. One of these intrusions, the Measles Point Granite, is a fine-grained quartz–feldspar-porphyritic granite that is preserved in coastal outcrops along the western edge of Makkovik Bay. New U–Pb geochronological data from the Measles Point Granite yielded an igneous crystallization age of 1873 ± 10 Ma and a metamorphic overprinting age of 1787 ± 5 Ma. This new U–Pb date supports the interpretation that the Measles Point Granite is part of the Paleoproterozoic synvolcanic quartz–feldspar-porphyritic granite suite(s) that cut the Aillik Group. Previous studies had suggested that it may represent basement to the Aillik Group; however, this new U–Pb date, coupled with field evidence, indicates that this is not the case. The Measles Point Granite is interpreted to be part of the suite of sill-like bodies that intruded synchronous with deposition of the Aillik Group and was subsequently deformed and metamorphosed with the sequence during the compressional stages of the Makkovikian orogeny at ca. 1800 to 1780 Ma.

INTRODUCTION

The Aillik domain, which is one of three domains that divide the Makkovik Province, is dominated by Paleoproterozoic metasedimentary and metavolcanic supracrustal sequence of the Aillik Group and by Paleoproterozoic intrusive suites (Kerr et al., 1996; Figure 1). The Aillik domain is contained entirely within the Central Mineral Belt of Labrador (Ryan, 1984), an area known for its abundant and varied base-metal and uraniumiferous mineral occurrences. The Aillik Group, as originally mapped, was initially divided into the Upper and Lower Aillik Group (Kranck, 1939; King, 1963; Marten, 1977; Clark, 1979). However, recent work (Ketchum et al., 2002), which included lithological, geochronological and geochemical studies, redefined the group as the Aillik Group (previously Upper Aillik Group) and the Post Hill Group (previously Lower Aillik Group). Recent geological mapping focused on characterizing the Aillik Group and the abundant Paleoproterozoic plutonic suites that intrude the group, including the Measles Point Granite (Hinchey, 2007; Hinchey and LaFlamme, 2009). The Aillik domain also contains abundant pre- and posttectonic mafic dykes.

This study presents in situ Sensitive High-Resolution Ion Microprobe (SHRIMP) U–Pb zircon geochronology from a sample of Measles Point Granite. Constraining the timing of crystallization of the Measles Point Granite is critical to evaluating tectonic models in the region. It has previously been suggested that the granite represents basement to the Aillik Group (Sinclair et al., 2002). This interpretation was questioned by Hinchey (2007), who suggested that the Measles Point Granite was a synvolcanic intrusion based on more recent mapping and also that basement to the Aillik Group has not yet been identified in the field (Hinchey, 2007; Hinchey and LaFlamme, 2009). Understanding the relationship between the Aillik Group and the Measles Point Granite is critical to distinguishing between tectonic models for the formation of the Aillik Group and Makkovik Province.

REGIONAL GEOLOGY

OVERVIEW

The Makkovik Province is part of the Paleoproterozoic accretionary orogen that is bounded to the northwest by the Archean Nain Province and to the south by the Mesopro-
terozoic Grenville Province (Figure 1). It is divided into three domains, namely (from northwest to southeast), the Kaipokok, the Aillik and the Cape Harrison domains (Kerr et al., 1996). The Kaipokok domain consists of reworked Archean gneiss of the Nain Province, overlying Paleoproterozoic metavolcanic and metasedimentary supracrustal sequences of the Moran Lake and the Post Hill groups, and Paleoproterozoic granitoid intrusions (Kerr et al., 1996; Ketchum et al., 2001) and is interpreted to be the foreland zone of the Makkovik Province (Kerr et al., 1996). The boundary between the Kaipokok and Aillik domains is marked by several high-strain shear zones that cumulatively comprise the Kaipokok Bay shear zone (defined by Ketchum et al., 1997; cf., Kaipokok Bay structural zone of Kerr et al., 1996; Culshaw et al., 2000). The Aillik domain is dominated by Paleoproterozoic metasedimentary and metavolcanic supracrustal rocks (Aillik Group) and Paleoproterozoic intrusive suites (Kerr et al., 1996). The Cape Harrison domain is dominated by syn- and posttectonic Paleoproterozoic intrusive suites, a package of reworked orthogneiss (Cape Harrison Metamorphic Suite), and rare enclaves of supracrustal rocks interpreted to be correlative with the Aillik Group (Gower and Ryan, 1986; Kerr et al., 1996). The boundary between the Aillik domain and the Cape Harrison domain is obscured by abundant plutonic intrusions and the boundary may be transitional at deeper crustal levels (Kerr et al., 1996). The Aillik and Cape Harrison domains are interpreted to be part of a composite arc to rifted-arc terrane that formed prior to, and after, the start of accretion to the Nain cratonic margin (Ryan, 1984; Kerr et al., 1996; Culshaw et al., 1998). The accretion of this terrane marked the initiation of the 1.9–1.78 Ga Makkovikian orogeny, resulting in the development of a regional penetrative tectonic fabric, regional-scale shear zones and greenschist- to amphibolite-facies metamorphism (Gandhi et al., 1969; Sutton, 1972; Marten, 1977; Clark, 1979; Gower et al., 1982; Kerr, 1994; Ketchum et al., 1997, 2002; Culshaw et al., 2000). Syn- to postorogenic granitic plutons and a

Figure 1. A simplified tectonic framework of south-central Labrador; the map highlights the three domains of the Makkovik Province: the Kaipokok, Aillik and Cape Harrison domains (simplified after Wardle et al., 1997). KBSZ – Kaipokok Bay shear zone; KKSZ – Kanairiktok shear zone; BFZ – Benedict fault zone; ABFZ – Adlavik Brook fault zone.
number of late, major, east-trending faults are found throughout the Makkovik Province.

The Aillik domain is underlain mainly by the ca. 1883–1852 Ma Aillik Group (Schärer et al., 1988; Hinchey and Rayner, 2008; LaFlamme et al., 2013), which is a supracrustal assemblage of metavolcanic and metasedimentary rocks (Figure 2). The group is intruded by granitoid plutons, including ca. 1858 Ma synvolcanic intrusions (Hinchey and Rayner, 2008) and younger suites that range in age from ca. 1805 to 1630 Ma (Kerr, 1994). The Aillik Group structurally overlies the Post Hill Group. This latter group is a highly strained, amphibolite-facies, supracrustal assemblage of metavolcanic and metasedimentary rocks (Figure 2). The group is intruded by synvolcanic porphyritic granite sheets and is deformed and metamorphosed. The stratigraphy of the Aillik Group is complex because of the discontinuous lithological units and along with folding and thrusting, has resulted in the repetition of stratigraphy (Hinchey, 2007).

The U–Pb zircon ages for felsic volcanic rocks within the Aillik Group include an age of 1856 ± 2 Ma from an ash-flow tuff at Michelin Ridge, an age of 1861 ±7/3 Ma from a rhyolite flow at Ranger Bight, and a much younger age of 1807 ± 3 Ma from a quartz–feldspar porphyry, collected from White Bear Mountain (Schärer et al., 1988; see Figure 2 for approximate locations of the U–Pb sample sites). The younger ca. 1807 Ma age suggests that not all of the porphyries are co-magmatic with felsic volcanism, and, in light of the widespread ca. 1800 Ma igneous activity in the area, it is likely that the dated porphyry is related to a younger magmatic event and is not part of the Aillik Group (Sinclair et al., 2002; Hinchey, 2007; Hinchey and Rayner, 2008). In addition, Hinchey and Rayner (2008) reported three U–Pb
zircon dates from the Aillik Group, including, 1) a felsic tuff from Aillik Bay that yielded a date of 1861 ± 6 Ma; 2) a rhyolite from the eastern side of Kaipokok Bay that yielded a date of 1883 ±7 Ma; and 3) a rhyolite from Ford’s Bight area that yielded a date of 1876 ± 6 Ma (Figure 2). These new dates for felsic volcanic rocks have extended the timing of the initiation of volcanism to ca. 1883 Ma. LaFlamme et al. (2013) reported U–Pb SHRIMP zircon geochronology from four felsic tuff samples from the Aillik Group collected from two different geographic areas yielding magmatic 207Pb/206Pb ages of 1852 ± 7 Ma, 1854 ± 7 Ma, 1861 ± 7 Ma, and 1862 ± 7 Ma. The ages fall within the range of previous U–Pb zircon dates reported for felsic volcanic rocks of the Aillik Group, which, taken together, indicate that felsic volcanism occurred over ca. 30 m.y. Volcanism was perhaps concentrated during the last 10 m.y. of that interval, based on the predominance of the younger ages; however, this may also represent a sampling bias.

Sinclair et al. (2002) reported a discordant, upper-intercept, ID-TIMS U–Pb zircon age of 1929 +10/-9 Ma for the Measles Point Granite, a deformed porphyritic granite exposed along the southeast coast of Makkovik Bay (Figure 2). The significance of this age has been questioned (Hinchey, 2007) because the Measles Point Granite is interpreted as a hypabyssal, foliated granite that is lithogeochemically similar to, and spatially associated with, the felsic volcanic rocks of the Aillik Group; the latter are reported (Hinchey and Rayner, 2008) to be approximately 70 Ma younger. Hinchey (2007) suggested that, based on field evidence, the intrusions are interfolded with the Aillik Group and the porphyritic granites are synvolcanic intrusions requiring them to have formed synchronous with, or shortly after, volcanism. A U–Pb date from a similar folded porphyritic granite occurring inland yielded an age of 1858 ± 6 Ma (Hinchey and Rayner, 2008) supporting this interpretation. New U–Pb geochronology from a sample of the Measles Point Granite, per se, is reported herein.

**ANALYTICAL METHODS**

Ion microprobe analysis of zircon was performed using the SHRIMP II at the Geological Survey of Canada, following the procedure described by Stern (1997), with standards and U–Pb calibration methods following Stern and Amelin (2003). Zircon grains were cast in 2.5-cm-diameter epoxy mounts (GSC #IP425) along with fragments of the GSC laboratory standard zircon (z6266), which has a 205Pb/204U date of 559 Ma. Internal sections of the grains were exposed by grinding and polishing using 9, 6, and 1 μm diamond compounds. The internal features of the zircon grains (such as zoning, internal domains and alteration) were characterized using backscattered electron (BSE) imaging utilizing a Cambridge Instruments scanning electron microscope. Grain-mount surfaces were evaporatively coated with 10 nm Au of high purity. The SHRIMP analyses were conducted using an 16O primary beam projected onto the zircons at 10 keV. The sputtered area used for analysis was ca. 16–25 μm in diameter with a beam current of ca. 2.5 nA. For the zircon analyses, the count rates of ten isotopes of Zr’, U’, Th’, and Pb’ were sequentially measured over 6–7 scans using a single electron multiplier and a pulse counting system that has a deadtime of 23 ns. Offline data processing was accomplished using SQUID version 2.23 software. A 1σ external error for 206Pb/238U ratios reported in the data tables incorporate a ± 1.0% error in calibrating the standard zircon (see Stern and Amelin, 2003). No fractionation correction was applied to the Pb-isotope data; common Pb correction utilized the Pb composition of the surface blank (Stern, 1997). Isoplot v. 3.00 (Ludwig, 2003) was used to calculate weighted means of the dates.

**U–Pb GEOCHRONOLOGY**

SHRIMP U–Pb data for each spot analysis of zircon, corrected for mass fractionation, are reported in Table 1. Uncertainties for the 207Pb/206Pb ratios and calculated 206Pb/238U dates for each analysis are quoted at 1σ. A concordia diagram (207Pb/235U versus 206Pb/238U) is shown in Figure 3 and individual analyses are plotted at the 2σ uncertainty level. Figure 4 plots Th/U ratios versus 207Pb/206Pb dates for individual analysis, where the bars represent 2σ uncertainty level. Figure 5 shows backscattered electron (BSE) and cathodoluminescence (CL) images of representative zircon grains and the SHRIMP pit locations.

**SAMPLE DESCRIPTION**

A sample of the Measles Point Granite (08AH247A03) was collected from a coastal outcrop in Makkovik Bay (Figure 2). The sample was collected from the same outcrop as the reported discordant, upper-intercept ID-TIMS U–Pb zircon date of 1929 +10/-9 Ma from Sinclair et al. (2002). The sample is from a massive, foliated magnetite–biotite–hornblende porphyritic monzogranite (Plate 1). The unit is fine to medium grained, weakly foliated, and contains plagioclase phenocrysts that are 1–3 mm in length. The unit is characterized by flattened mafic clots of intergrown hornblende and biotite, which define the foliation: the clots are 2–10 cm long, and represent 1% of exposure. Millimetre-scale discrete shear zones also occur throughout the outcrop.

The porphyritic monzogranite sample yielded a small amount of zircon. The zircon grains were generally of poor quality, containing abundant fractures and inclusions. Zircon grains range from stubby prisms to subrounded equant grains. In BSE images, many of the grains contain a weak, fine-scale oscillatory zoning, often rimmed by a micron-
Table 1. SHRIMP U–Pb data for each spot analysis of zircon, corrected for mass fractionation. Uncertainties for the 207Pb/206Pb ratios and calculated 207Pb/206Pb dates for each analysis are quoted at 1σ. Universal Transverse Mercator (UTM) location is from zone 21, NAD27. Excluded data are shaded grey

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Notes (see Stern, 1997):  
*Spot name follows the convention x-y-z, where x = sample number, y = grain number, and z = spot number. Multiple analyses in an individual spot are labelled as x-y-z. The U-Pb behaviour in these deeper pisas varies from the values used in the U-Pb calibration, as such only the Pb-Pb ages are considered accurate for these Uncertainties reported at 1σ and are calculated by using SQUID 2.23.08.10.21, rev, 21 Oct 2008. Ages reported at 1σ absolute.  
**206Pb/238U refers to mole fraction of total 238Pu that is due to common Pb, calculated using the 238U-method; common Pb composition used is the surface blank (4/6: 0.05770; 7/6: 0.89500; 8/6: 2.13840).  
*Corr Coef = correlation coefficient.  
**Disc (Difference relative to origin = 100 * (1-(207Pb/206U age)/(208Pb/206U age))).
scale homogenous rim (Figure 5). Other grains appear homogenous or have a patchy, irregular zoning in BSE images.

A total of 35 grains, varying in shape and internal structure, were analyzed. Forty-five analyzed resulted in two dominant age populations that correspond to distinct zircon textural types (Table 1). The first population consists of sixteen analyses, and has a $^{207}\text{Pb}/^{206}\text{Pb}$ date of $1873 \pm 10$ Ma (2σ error; weighted mean) (Figure 3). Thorium/uranium ratios range from 0.24–0.61 (Figure 4). These analyses are largely from grains having well-developed oscillatory zoning indicating magmatic growth (Figure 5), and, therefore, this date is interpreted as the igneous crystallization age of the monzogranite. One analysis has an Archean age of 2941 Ma that was excluded from the calculation and is considered to be inherited. The second population comprises thirty-one analyses, of which twenty-three were used to calculate a $^{207}\text{Pb}/^{206}\text{Pb}$ date of $1787 \pm 5.6$ Ma (2σ error, weighted mean;
A.M. HINCHEY AND W.J. DAVIS

Figure 3. Thorium/uranium ratios range from 0.01–0.11 (Figure 4). These analyses are from zircons that display an irregular, discontinuous or patchy zoning in BSE imaging (Figure 5). This phase of zircon is interpreted to be recrystallized during metamorphism. This interpretation is supported by the low Th/U ratios characteristic of metamorphically recrystallized zircon (Figure 4). Analyses with intermediate Th/U and Pb/Pb ages were excluded from the calculations and are interpreted to reflect incomplete recrystallization of older igneous zircon. Six analyses with the youngest ages (1747–1593 Ma) were excluded from the calculation and are assumed to have a significant component of a younger Pb-loss. Excluded data are presented in Table 1 and plotted in Figures 3 and 4, but are shaded grey.

DISCUSSION

A sample from the Measles Point Granite dated herein, has a complex zircon population. The $^{207}$Pb/$^{206}$Pb date of $1873 \pm 10$ Ma is interpreted as the igneous crystallization age of the body. This is based on the internal zircon morphology and Th/U ratios with both being characteristic of igneous zircon (see Corfu et al., 2003; Hoskin and Schaltegger, 2003). The granite also contains a second zircon pop-
ulation with a $^{207}\text{Pb}/^{206}\text{Pb}$ date of 1787 ± 5.6 Ma that is largely from recrystallized rims of the older zircon grains as well as from homogenous structureless grains. This date is interpreted as representing the timing of deformation and metamorphism of the Measles Point Granite.

The Measles Point Granite’s chemical composition is similar to the felsic volcanic rocks of the Aillik Group (Hinchey, 2007). The Aillik Group and associated synvolcanic intrusion(s) were subsequently deformed and metamorphosed during the latter compressional stages of the Makkovikian Orogeny. The 1787 ± 5.6 Ma age of zircon recrystallization in the granite is coincident with the timing of regional Makkovikian metamorphism (Ketchum et al., 2002).

Previous studies (Sinclair, 1999; Sinclair et al., 2002) have suggested that the Measles Point Granite is ca. 1929 Ma and may represent the basement rocks of the Aillik Group. The age reported by Sinclair et al. (2002) was determined by linear regression of several, multi-grain, discordant, ID-TIMS analysis of zircon. The data are all greater than 10% discordant, and the linear regression yielded an upper intercept age of 1929 +10/-9 Ma and a lower intercept age of 956 +36/-35 Ma. Based on the complex zircon morphologies and mixed age populations reported above, it is apparent that the Measles Point Granite contains a complex zircon population not ideally suited for multi-grain ID-TIMS analysis. Based on the isotopic data presented above and field relationships, the previous age of ca. 1929 Ma is most likely inaccurate due to the combined effects of multiple zircon growth events and discordance, and that the best estimate of the age of the granite is 1873 ± 10 Ma, as reported herein.

The Measles Point Granite is part of a group of foliated porphyritic granites that occur throughout the Aillik domain (Hinchey, 2007; Hinchey and LaFlamme, 2008; Hinchey and Rayner, 2008). These intrusions have been infolded and metamorphosed with the Aillik Group. The intrusions are interpreted as being synvolcanic requiring them to have formed synchronous with, or shortly after, volcanism (Hinchey, 2007). A U–Pb age of 1858 ± 6 Ma (Hinchey and Rayner, 2008) from a similar folded porphyritic granite occurring inland, some 20 km to the southeast of the Measles Point Granite, supports the regional and contemporaneous distribution of these intrusions with felsic volcanism within the Aillik Group, which lasted from ca. 1883–1852 Ma (Schärer et al., 1988; Hinchey and Rayner, 2008; LaFlamme et al., 2013).

**CONCLUSION**

The Measles Point Granite has an igneous crystallization $^{207}\text{Pb}/^{206}\text{Pb}$ zircon age of 1873 ± 10 Ma, and is interpreted as a sill-like, hypabyssal, porphyritic granite. It is lithochemically similar to, and spatially associated with, the felsic volcanic rocks of the Aillik Group. It is part of a series of porphyritic bodies that intruded synchronously with formation of at least part of the Aillik Group and was subsequently deformed and metamorphosed during the Makkovikian Orogeny at ca. 1787 Ma.

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