U–Pb GEOCHRONOLOGY, PETROGENETIC RELATIONSHIPS AND INTRUSION-RELATED PRECIOUS-METAL MINERALIZATION IN THE NORTHERN MOUNT PEYTON INTRUSIVE SUITE: IMPLICATIONS FOR THE ORIGIN OF THE MOUNT PEYTON TREND, CENTRAL NEWFOUNDLAND (NTS 2D/04)

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ABSTRACT

Extensive exploration, west of Glenwood in the Mount Peyton intrusive suite (MPIS), has outlined a 13.5-km, north-northwest-trending corridor termed the Mount Peyton trend, which is anomalous in gold, silver, arsenic and antimony. In the southsoutheast part of the trend, mineralization occurs at the Corsair, Hurricane and Peyton prospects and the Sabre and Commanche showings; in the north-northwest, mineralization occurs at the Slip and associated showings. Mineralization at Corsair and Hurricane consists of narrow (typically <2 cm), sulphide-poor quartz veins that have broad (cm- to 13 m-scale) pyrite-arsenopyrite-sericite-siderite-silica alteration envelopes in fine-grained quartz diorite, locally intruded by monzogranite. The alteration zones and mineralized veins are northeast trending and moderately southeast dipping, and veins at surface correlate with one set of conjugate regional joint surfaces. Mineralization at Hurricane–Corsair has elevated concentrations of As, Au, Sb, Ag and locally Cd. At the Slip showing, granophyric monzogranite cupolas exhibit classic magmamingling relationships with gabbro-diorite. The latter is also cut by straight margined, miarolitic monzogranitic dykes containing pyrite-muscovite-calcite-chalcopyrite \pm galena \pm arsenopyrite-filled miarolitic cavities that have anomalous Au, As, Sb, and Ag, and minor enrichment in Cu, Pb, Zn, Mo and Bi. The data show that the mineralized monzogranite at the Slip showing is a late-stage, deuteric fluid-enriched and metal-bearing residual magma that intruded a slightly older gabbro-diorite. A CA-TIMS U–Pb zircon crystallization age of 418 ± 1.6 Ma constrains the age of the miarolitic monzogranite and 'intrusion-related' gold mineralization and places a minimum age on the gabbro-diorite and granophyric monzogranite. Petrologically similar gabbro at Norris Arm yielded a TIMS U–Pb zircon crystallization age of 422 ± 1.2 Ma, overlapping, within error, with an age of 423.6 ± 1.8 Ma for a layered gabbro near Rolling Pond. These ages constrain magmatism in the MPIS to the interval 425–418 Ma. Similar metal enrichments along the length of the Mount Peyton trend suggest that the metal endowment of this mineralized corridor may be, at least, in part, a result of contributions from such, 'intrusion-related' fluids. Mineralization at Hurricane–Corsair may represent more distal, vein-related, disseminated mineralization structurally above miarolitic granite dykes and cupolas.

INTRODUCTION

Exploration for gold and precious metals in the eastern Exploits Subzone, in the north central Newfoundland Dunnage Zone (Figure 1), was part of an Island-wide, grass-roots gold exploration boom in the late 1980s. This exploration phase, driven by financial market conditions and the price of precious metals, resulted in the discovery of many new gold showings throughout Newfoundland. Of relevance here are those mineralized zones within and proximal to the Siluro-Devonian Mount Peyton intrusive suite (MPIS; Blackwood, 1982). The discovery of auriferous mineralization in the MPIS along the Salmon River (Tallman, 1990, 1991a; Figure 2) occurred synchronously with the discovery of numerous other Au–As–Sb–Ag mineralized zones including the antimony mineralization at the Beaver Brook Mine (Tallman, 1991b; Tallman and Evans, 1994; Lake and Wilton, 2006). Subsequent exploration programs resulted in the identification of many gold (\pm Ag \pm As \pm Sb) mineralized zones in the region, including orogenic and epithermal quartz vein and vein-breccia-style Au–Ag–As \pm Sb mineralization in the Glenwood–Appleton area (Evans, 1996; Figure 2), and

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Figure 1. Simplified geological map of Newfoundland showing the location of the study area with respect to major geological terranes and tectonic boundaries (after Colman-Sadd et al., 1990).

southward along the west side of Gander Lake (see Evans, 1996; House and McConnell, 2003; Barbour and Churchill, 2004; Churchill, 2004; House and Buchanan, 2004; O'Reilly and Churchill, 2004; Squires, 2005; House, 2003, 2005, 2007a, b; O'Reilly et al., 2008, 2010; Quinlan, 2013). Persistent grass-roots, and follow-up, exploration led to the more recent discovery of granite-hosted auriferous mineralization in the eastern margin of the MPIS at the Yellow Fox showing (Figure 2; Reid and Myllyaho, 2012), Clarkes Brook west (Metals Creek Resources press release, November 1, 2016) and the Contact showing (Squires, 2005), all of which appear to have distinct, epithermal assemblages and textures as well as granitophile (Sillitoe and Thompson, 1998; Thompson et al., 1999; Hart, 2007) metal associations (Evans, 1996; Barbour and Churchill, 2004; O'Driscoll and Wilton, 2005; Squires, 2005; O'Reilly et al., 2010).

This report forms a component of an ongoing, broader study of mineralization in, and around, the MPIS. These investigations build upon the extensive mapping, geochronology, biostratigraphy and lithogeochemical work of Dunning (1992, 1994), Dunning and Manser (1993), Dickson (1993, 1994, 2006), Boyce and Ash (1994), Dickson et al. (2000), O'Brien (2003), Boyce and Dickson (2006), McNicoll et al. (2006), Dickson et al. (2007), and the more detailed mineral deposit studies of O'Driscoll and Wilton (2005), Squires (2005) and Lake and Wilton (2006), which collectively provide a framework upon which a better understanding of the mineralized systems of the region may be constructed. Two areas of gold mineralization exposed in the northeastern sector of the MPIS, at the juncture of four 1:50 000-scale NTS map areas (2D/14, 15, 2E/3, 4) are examined in greater petrological detail. These are the Corsair and Hurricane prospects along the Salmon River and the Slip showing in the Nevles Brook quarry (Figure 2). The mineralization occurs in the dioritic and monzogranitic rocks of the MPIS, for which the age, contact relationships and petrological character are contentious (see Dickson, 1993, 1994, 2006; Lake and Wilton, 2006; O'Driscoll and Wilton, 2005; Squires, 2005; McNicoll et al., 2006; Dickson et al., 2007).

New field, petrographic and robust lithogeochemical data, along with Mineral Liberation Analysis (MLA) electron beam mapping and imagery, of the mineralized and unmineralized rocks from the Hurricane-Corsair and Slip mineralized zones are presented. These are supplemented by new lithogeochemical data for selected intrusive rocks of the region (H. Sandeman, unpublished data, 2017) and are also compared to historical government (Dickson and Kerr, 2007) and industry assessment report data (Tallman, 1990, 1991a; Hoffe and Sparkes, 2003; House, 2007; Quinlan, 2009). The new lithogeochemical data, including precious and associated trace metals, represent some of the first complete high-precision data for rocks of the northern parts of the MPIS and, along with additional observations from industry assessment reports enhances our collective knowledge-base for these intrusion-hosted precious-metal mineralized zones. Two unpublished, but literature cited U-Pb TIMS ages for multigrain zircon fractions extracted from gabbro-diorite of the MPIS (Dunning, 1992, 1994) are documented fully for the first time. A new U-Pb CA-TIMS zircon age is presented for a precious-metal-mineralized miarolitic monzogranite dyke at the Slip showing. Collec-

Figure 2. Simplified geology of the northern parts of the MPIS and surrounding country rocks (modified after Blackwood, 1982; Evans et al., 1992; Dickson, 1993, 1994; Dickson et al., 2000; O'Brien, 2003; Dickson et al., 2007). Interpreted map patterns incorporate detailed airborne magnetic data from industry (House and McConnell, 2003; Moore and Smith, 2003). All gold showings are red dots (MODS database). The Slip showing and the Hurricane and Commanche zones at Salmon River are yellow dots. Yellow stars are locations of samples dated (this study) by U–Pb geochronology. U–Pb sample LD91-063-1 is located south of Figure 2, approximately 1 km southeast of Rolling Pond.



Figure 2. Caption see page 190.

tively, these data provide new constraints on the composition and age of the granitoid rocks of the MPIS and its granitophile mineralization.

REGIONAL SETTING AND PREVIOUS WORK

The study area lies in the northeastern Exploits Subzone of the Newfoundland Appalachians, immediately west of the terminal Iapetan suture termed the Dog Bay Line (Currie, 1993; Williams, 1993; Williams et al., 1993; Pollock et al., 2007). The greater Mount Peyton area (Figures 1 and 2) has been the subject of extensive governmental and industry work since the initial geological survey investigations of Murray and Howley (1881). Much of the governmental and academic work in the area has been summarized by Dickson (1993, 1994, 1996, 2006), O'Driscoll and Wilton (2005), McNicoll et al. (2006) and Dickson et al. (2007) and the character and styles of mineralization in the region have been documented by Tallman and Evans (1994), Evans (1996), O'Driscoll and Wilton (2005), Squires (2005) and Lake and Wilton (2006). The Hurricane and Corsair zones of the Salmon River area and the Slip showing in the Neyles Brook quarry all occur in the granitoid rocks of the MPIS. Previous investigations in the region pertaining to the age, petrochemistry and contact relationships of the granitoid rocks are briefly reviewed below.

Baird *et al.* (1951) recognized that a large part of north central Newfoundland is underlain by gabbroic and granitic rocks that intrude adjacent sedimentary units. The first 1:250 000-scale map of the region (Williams, 1962) outlined a large gabbro to diorite intrusion cut by monzogranite and lying to the south of the community of Norris Arm (Figures 1 and 2). Williams (*op. cit.*) proposed a Devonian age for these intrusive rocks, but stated that 'the relationships of these various rock types are not well known'.

The first radiometric age dates for the MPIS included three distinct K–Ar ages including 418 ± 21 and 369 ± 21 Ma for biotite separates, and 270 ± 52 Ma for hornblende from three widespread localities (Wanless et al., 1967). A subsequent Rb-Sr whole-rock isochron for four granitic (s.l.) rocks of the MPIS yielded a Devonian age of 380 ± 30 Ma (Bell et al., 1977). A reconnaissance petrological study (Strong, 1979), focused mainly on the northern part of the intrusive complex and determined that the granitoid rocks comprise a bimodal geochemical assemblage of granite and gabbro. The earlier radiometric dates (e.g., Wanless et al., 1967; Bell et al., 1977) were revised by Reynolds et al. (1981) who also provided ⁴⁰Ar-³⁹Ar step-heating ages for hornblende and biotite from two samples near Norris Arm. These data indicated that the Norris Arm gabbro is Silurian. Strong and Dupuy (1982) conducted further petrological investigations and demonstrated that the intrusive suite comprises gabbro, formed from mantle-derived melts, and granite (s.l.) that formed *via* anatexis resulting from introduction of the mafic magma into the crust. The few intermediate compositions noted were considered to have formed either by magma mixing between the magmatic endmembers and/or contamination of the gabbroic magma by the surrounding sedimentary country rocks. At this time, while mapping the Gander Lake sheet, Blackwood (1982) coined the term Mount Peyton intrusive suite for these diverse plutonic rocks.

Subsequent to the release of a government regional lake-sediment survey that covered the Mount Peyton area (Davenport *et al.*, 1988), Noranda Exploration Ltd. staked claims and conducted reconnaissance prospecting and regional-till and lake/stream-sediment sampling programs in the northeastern parts of the MPIS (Tallman, 1990). These investigations resulted in the discovery of a number of bedrock gold showings that yielded up to 25.8 g/t Au and accompanying elevated Sb and As (Tallman, 1990). In 1990, geophysics, trenching and diamond drilling were completed that led to the discovery of a number of north- and north-northeast-striking, moderately east-dipping mineralized zones including the Hurricane and Corsair prospects (Tallman, 1991a).

The mid-1990s saw only modest exploration for gold in central Newfoundland. However, Forex Resources discovered the Slip showing in 1993 (Clarke, 1996), hosted by intrusive rocks of the MPIS and located off Highway 1 in the Neyles Brook Quarry (Figure 2). Renewed gold exploration in 1999, particularly in the Shirley Lake area (Figure 2; Evans and Dimmell, 2001; Evans *et al.*, 2001), revealed numerous lake-sediment, soil and bedrock samples defining an approximately 13.5-km-long corridor that hosts numerous occurrences anomalous in gold, arsenic and antimony. This northwest-trending corridor of mineralized bedrock is known as 'the Peyton' or 'the Mount Peyton' trend (Tallman, 1991a; Evans, 1996; Evans and Dimmell, 2001; Evans *et al.*, 2001; Hoffe and Sparkes, 2003; House, 2003, 2005, 2007a, b).

From 2002 to 2007, Rubicon Minerals explored much of the area around the northeastern part of the MPIS and completed regional, detailed (75-m and 50-m-line spacing), helicopter-borne aeromagnetic programs, soil-sampling surveys and two diamond-drill holes on the Hurricane prospect (House and McConnell, 2003; Moore and Smith, 2003; House 2007a). Rubicon Minerals also conducted a detailed examination of the phases of the MPIS at the Slip showing that comprised a B.Sc. (Hons.) thesis (Hoffe, 2003) and formed a significant component of a mineral-exploration industry assessment report (Hoffe and Sparkes, 2003). Further work in the area around the Slip showing (Quinlan, 2009) resulted in the discovery of two additional bedrock and float occurrences of which fourteen samples returned anomalous gold values ranging from 12 to 12 880 ppb. Those samples consisted of mineralized quartz veins, or quartz vein breccia hosted by gabbro of the MPIS (Quinlan, *op. cit.*).

To the east and southeast, along the margins of the MPIS, many new mineralized zones consisting of epithermal quartz-veins, vein breccias and disseminated mineralization in altered wall rock were concurrently discovered and explored (Barbour and Churchill, 1999, 2004; Churchill, 2004; O'Reilly and Churchill, 2004; O'Driscoll and Wilton, 2005; Squires, 2005; House, 2005, 2007a, b; O'Reilly et al., 2008, 2010; Quinlan, 2013). Results outlined northeast-trending zones of veining, silicification and brecciation with disseminated and vein-hosted Au-Ag-As-Sb mineralization at the Mustang and Piper zones (Barbour and Churchill, 2004) as well as epithermal, vuggy and chalcedonic vein- and vein-breccia-related Au \pm As \pm Ag \pm Sb \pm Mo mineralization at the O'Reilly showing (O'Reilly et al., 2008, 2010). A number of other discoveries including the Cherry Hill, Clarkes Brook East and Contact showings (O'Reilly et al., 2008; Squires, 2005) all appear to have metal associations similar to those described above.

GEOLOGICAL RELATIONSHIPS

During regional examination of the MPIS, three lithogeochemical samples of gabbro were collected from exposures near the western Norris Arm access road (Figure 2) and hydroelectric dam, proximal to the location of U-Pb geochronological sample 93GD08 (see below). These are all fresh, fine- to medium-grained hollocrystalline biotiteclinopyroxene-hornblende gabbro having trace quartz (Plate 1A). The gabbro consists of roughly equal proportions of intergrown anhedral clinopyroxene and hornblende with subhedral plagioclase laths, anhedral ilmenite and anhedral biotite (Plate 1B). Clinopyroxene and hornblende have been locally replaced by mantles of actinolite. Plagioclase rarely forms large (3 mm) subhedral phenocrysts having complex zoning. Tiny elongate apatite, euhedral zircon, anhedral pyrite, and chalcopyrite inclusions occur locally throughout (Plate 1C).

The Slip Showing

The Slip showing occurs in the Neyles Brook quarry near the northeastern margin of the MPIS (Figure 2). It was discovered by Forex Resources in 1993 (J. Clark, personal communication, 2016) who reported assays containing up to 28.6 ppm Au, 22.9 ppm Ag, 14700 ppm Pb, 18000 ppm Zn, 2809 ppm Cu, 331 ppm Sb and >2200 ppm As. However, it was not until follow-up work during regional exploration for



Plate 1. Photograph and photomicrographs of the fine- to medium-grained gabbro exposed near Norris Arm. A) Massive, homogenous, fine- to medium-grained diorite exposed on Highway 1 at the western Norris Arm access road (HS08-012; coin for scale is 2.8 cm); B) A photomicrograph of the same sample in planepolarized light; C) The same sample in reflected light. Key: Ap apatite; Bt - biotite; Ccp - chalcopyrite; Cpx - clinopyroxene; Hbl - hornblende; Ill - illmenite; Pl - plagioclase; Py - pyrite.

gold (Hoffe, 2003; Hoffe and Sparkes, 2003), that the first detailed observations for this mineralization were reported. Hoffe conducted a petrological Bachelor's thesis on the rocks of the Neyles Brook quarry, the results of which were partially presented in Hoffe and Sparkes (2003). Contributions included mapping and lithological description of the rocks of the Neyles Brook quarry and recognition that the mineralization occurs in an altered, sulphide-bearing, miarolitic monzogranite dyke that cuts fine- to mediumgrained gabbro–diorite. The relationships between mineralized and non-mineralized intrusions and other petrological relationships recorded by Hoffe (2003) and Hoffe and Sparkes (2003) have, however, not yet been placed in a temporal or petrological context.

Five distinct rock types occur in the Neyles Brook quarry and all are massive and lack a tectonic fabric. Fine- to medium-grained, biotite-hornblende \pm clinopyroxene gabbro, varying to quartz diorite, is volumetrically dominant and forms most of the quarry walls (Plate 2A). The gabbro-diorite is composed of subhedral, elongate prismatic crystals of extensively saussuritized plagioclase intergrown



with subhedral, moderately chloritized biotite and subhedral hornblende replaced by actinolite (Plate 2B). Quartz occurs interstitially and typically contains acicular, elongate prismatic apatite crystals (Plate 2C). Saussuritization of feldspars, chloritization of biotite and replacement of hornblende by actinolite in the gabbro-diorite increases with proximity to the monzogranite intrusions.

The gabbro-diorite is intruded by red to locally pink, typically fine-grained, homogenous, and granophyric-textured, biotite \pm hornblende monzogranite (Plate 3A, B). The monzogranite consists of 5–10% subhedral plagioclase surrounded by granophyric intergrowths of anhedral quartz and alkali feldspar. Siderite and radial muscovite locally fill small grain interstices; the granite is also locally cut by narrow calcite veins. Subhedral hornblende and biotite are rare, and typically form mineral clusters with magnetite. This unit forms irregular, domal or flat-lying exposures in the western end of the quarry (Figure 3). The granophyric monzogranite is exposed along the base of the quarry walls and is overlain by gabbro-diorite. The gabbro-diorite preserves irregular, lobate contacts with the monzogranite



Plate 2. Photograph and photomicrographs of the volumetrically dominant, fine- to medium-grained gabbro-diorite exposed at the Slip showing. A) Massive, homogenous, fine-to medium-grained diorite exposed in the walls of Neyles Brook quarry (HS13-003D; coin for scale is 2.5 cm); B) A photomicrograph of the same sample in plane-polarized light. Note the subhedral, elongate prismatic, extensively saussuritized plagioclase, subhedral biotite and clinopyroxene and, anhedral interstitial quartz; C) Closer detail of same sample showing elongate acicular apatite in quartz. Key: Ap - apatite; Bt - biotite; Hbl - hornblende; Pl - plagioclase; Qtz - quartz.



Plate 3. Representative photomicrographs of the granophyric monzogranite at the Slip showing. A) Fine-grained, granophyric monzogranite (HS13-003D). Note the altered alkali feldspar (AFld), anhedral quartz, altered and rare plagioclase as well as sparse muscovite and pyrite. The rock is dominated by relatively coarse, granophyric intergrowth of quartz and alkali feldspar (cGT); B) Same field of view under crossed-polarized light. Key: Mu – muscovite; Pl – plagioclase; Py – pyrite; Qtz – quartz.



(Figure 3) and also forms metre-scale or smaller, globular, scalloped 'pillows' that appear to have sagged into the underlying monzogranite. The granophyric monzogranite does not appear to be mineralized, although some samples exhibit weakly anomalous metal abundances (*e.g.*, 0.6 ppm Ag, 18 ppm Mo, 5 ppm Sb, 28 ppm As).

A thin (<5 cm), planar dyke of white to pale-pink, medium-grained granodiorite that cuts the gabbro–diorite was sampled for petrographic and lithogeochemical analysis (Hoffe, 2003). This medium-grained granodiorite contains subhedral to anhedral intergrowths of saussuritized plagioclase and quartz, and less abundant anhedral alkali feldspar. Fine-grained, chloritized biotite, minor epidote, magnetite and calcite fill the intersticies. Granophyric

Figure 3. A) Geological map of the western wall (in 2003) of the Neyles Brook quarry. Note the differing intrusive shapes and contacts of the two types of monzogranite; B) Photograph of the relationships between the granophyric monzogranite and the gabbro-diorite; C) Geological map of (B), demonstrating the ascending monzogranite vs. the foundering gabbro-diorite. texture is absent. Locally, apophyses and irregular dykes or veins of granodiorite exhibit diffuse, irregular and scalloped contacts with the gabbro–diorite. The interfaces between the two rock types consist of a cm-scale reaction zone with intergrown quartz and albite dominating the outer margin of the granodiorite and increased biotite and quartz occurring in the outermost margins of the gabbro–diorite (Plate 4A). In plan-view, many of the upward-narrowing, granodiorite apophyses terminate at the horizontal surface as pale, irregular monzogranite to granodiorite pegmatite patches and pods (Plate 4B).

The fourth rock type exposed in the Neyles Brook quarry is miarolitic monzogranite that occurs as three, broadly west (~290°) and north-northwest-trending (~340°) irregular and branching dykes, up to 10 m in thickness. This fineto medium-grained biotite-muscovite monzogranite is pink to buff and locally rusty (Plate 5A), commonly exhibits a coarse granophyric texture (Plate 5B), but most distinctively, contains abundant miarolitic cavities that are filled with muscovite-siderite-pyrite-chalcopyrite-arsenopyrite ± galena (Plate 5C, D). The 290°-trending miarolitic monzogranite dyke (Figure 4) is the major host of highly anomalous, precious metals and As, Sb, Cd, and locally, Te mineralization (up to 28.6 ppm Au, 22.9 ppm Ag). Monzogranitic dykes up to 500 m thick were mapped by Dickson (1994) and Dickson et al. (2000) to the south, west and east of the Neyles Brook quarry, however, it is not known if these comprise miarolitic monzogranite. Most dykes narrow upward, have abrupt, irregular contacts with the host gabbro-diorite, and exhibit an increase in the abundance and size of miarolitic cavities toward the top of the dykes. Lobate irregular contacts or chill margins were not noted. Mutual relationships between the miarolitic monzogranite and the granophyric monzogranite have not been observed. A sample of the miarolitic monzogranite from the centre of the mineralized dyke (03GD-NBMM: Figure 4) was collected for CA-TIMS U–Pb zircon geochronology.

The four granitoid rock types are cut by a southeasttrending (ca. 150-120°/90°), narrow (<50 cm) mafic dyke that is only exposed as discontinuous rubble in the floor of the quarry (Plate 6A). This dyke is composed of sectorzoned, and locally glass-inclusion-bearing, clinopyroxene phenocrysts (<6 mm) and serpentine pseudomorphs after olivine (<2 mm), set in a fine-grained groundmass of clinopyroxene microcrysts, tiny oxide minerals and devitrified glass (Plate 6B). The age of the dyke is not known, but it is fresh and clinopyroxene is well-preserved. A similar dyke noted by Dickson (1993) to cut the Red Rocks granite (informal name) on the eastern side of the MPIS has been sampled for lithogeochemistry. Dickson (1994) noted two comparable dykes that cut rocks of the Botwood Group at Killick and Martin Eddy Points near Botwood. These late dykes were suggested (Dickson, 1994) to be related to the Jurassic lamprophyre dykes and intrusions of the Notre Dame Bay region (e.g., Strong and Harris, 1974).

The Salmon River Prospects

The Hurricane, Corsair, Peyton, Commanche and Sabre mineralized zones are exposed in, and adjacent to, the Salmon River, near the northeastern margin of the MPIS (Figures 1 and 2). Exposure is poor and bedrock is covered by thick glacial deposits (Tallman, 1990; Batterson, 1999; Kirby *et al.*, 2011). The discovery, outcrops in



Plate 4. Outcrop photographs showing typical relationships between the granodiorite and the gabbro–diorite at the Neyles Brook quarry. A) An irregular diffuse vein-like intrusion of leucocratic granodiorite intruding gabbro–diorite. Note the rim of the gabbro–diorite has a higher colour index than the interior; B) Pegmatoidal patch of pale granodiorite exposed on the horizontal, glacially polished surfaces at the Neyles Brook quarry. Pen magnet in both photographs is 15 cm long.



Plate 5. Photograph and photomicrographs of the mineralized, medium-grained miarolitic and granophyric monzogranite at the Slip showing. A) Centimetre-scale, weakly sulphidic miarolitic cavities in the miarolitic monzogranite (HS13-003C; coin for scale is 2.5 cm); B) Plane-polarized light photomicrograph of the mineralized monzogranite with granophyric texture (quartz + alkali feldspar and subhedral sausuritized plagioclase in late anhedral quartz); C & D) Photomicrograph in plane-polarized light and crossed nicols of a miarolitic cavity in the mineralized monzogranite. Note the pyrite–chalcopyrite–siderite–muscovite grains filling the cavity. Key: Ccp – chalcopyrite; Mu – muscovite; Or – orthoclase; Pl – plagioclase; Py – pyrite; Sd – siderite; Qtz – quartz.

the riverbed, and is typically covered by water, even at low water levels (Plate 7A). Bedrock consists of fine- to medium-grained, hornblende-biotite quartz diorite that is locally intruded by sheets, veins and irregular intrusions of a locally aplitic or pegmatitic, but typically medium-grained biotite-hornblende monzogranite (Plate 7B). The crosscutting monzogranitic intrusions are pale buff to pink, lack chill margins, and typically have abrupt, but locally scalloped and/or gradational contacts. The diorite is very similar to that exposed at the Slip showing (Plate 7C); however, clinopyroxene is comparatively rare, hornblende is less abundant, and biotite and quartz are more common. As at the Slip showing, quartz forms anhedral interstitial patches containing abundant, acicular, elongate prismatic apatite crystals. Surface exposures of veins are relatively rare, however, four mm-scale veins with alteration haloes noted at surface (*e.g.*, Plate 7C) are cospatial with one population of a conjugate fracture set (Figure 5). Mineralized fractures have an average trend of $033/68^{\circ}$ whereas a second, barren set of fractures trends $275/82^{\circ}$. The average orientations for each of the two fracture/vein populations intersect with a dihedral angle of approximately 65° , suggesting that they constitute a set of regional conjugate shear fractures.

Industry work at the Salmon River mineralized zones has outlined a number of northeast-trending (035-050°) VLF-EM conductors coincident with magnetic lows and strong induced polarity anomalies (Tallman, 1990; Evans, 1996; House, 2007a). The majority of historical drillholes at the Salmon



Figure 4. *A)* Photograph of the relationships between the mineralized miarolitic monzogranitic dyke and the gabbro–diorite (in 2003); B) Geological map of the mineralized miarolitic dyke in the Neyles Brook quarry as well as the locations of lithogeochemical samples and the U–Pb geochronological sample (02GD-NBMM).



Plate 6. *Photograph (A) and plane-polarized light photomicrograph (B) of the young, olivine–clinopyroxene-phyric dyke that cuts all other rocks at the Slip showing (sample HS15-003E). Key: Cpx – clinopyroxene; Ol – olivine.*



River area were oriented on a 340° azimuth with moderate (45°) dip angles (Tallman, 1991; House, 2007a). These were collared in fine- to medium-grained hornblende-biotite quartz diorite, but commonly terminated at depth in medium-grained aplitic monzogranite (Tallman, 1991; House, 2007a). Mineralization consists of cm- to 13-m-scale envelopes of intensely quartz-sericite-pyrite-arsenopyrite-siderite-rutite-altered diorite surrounding thin, typically ≤5-cm-wide, sulphide-poor quartz-siderite veins (Plates 7C and 8A, B). Feldspars are largely replaced by sericite-saussurite-siderite and ferromagnesian minerals are replaced by sericite, albite, rutile and sulphide minerals (Plates 8C and 9). Pyrite is anhedral, locally spongy, and is likely paragenetically early whereas arsenopyrite is euhedral and appears to be a late phase (Plates 8 and 9). Visible gold was not identified in thin section, or in electron microprobe mapping.

U-Pb GEOCHRONOLOGY

Published U–Pb geochronological data for the MPIS are rare and are briefly summarized below. U–Pb determinations include:



Plate 7. Photographs of representative rock types that host mineralization at the Hurricane–Corsair zones. A) Discovery outcrop at the Hurricane prospect. Note the reddishorange sulphide staining of the diorite exposed in the riverbed; B) Massive, veins and irregular small-scale intrusions of medium-grained and pegmatoidal biotite \pm hornblende monzogranite cutting homogenous, fine-grained hornblende–biotite quartz–diorite of the MPIS (pen magnet is 13 cm long); C) Fine-grained hornblende–biotite quartz–diorite cut by a tabular, thin (<2 cm) quartz–siderite vein with margin parallel bleaching and sericitization. Vein trends 025/55° and is parallel to one prominent, regional joint surface (pencil in view is 7 cm long).

1) A pink-orange, fine-grained sample of the Red Rocks granite (Dickson, 1993; sample LD92-0152; Figure 2) was dated by multigrain TIMS U-Pb zircon geochronology by Dunning and Manser (1993), and the results were included in an internal report to the Geological Survey of Newfoundland and Labrador. The U-Pb isotope data suggested two possible interpretations. The first interpretation using zircon fractions 1, 2 and 3 defined a mixing line (37% probability of fit) from *ca*. 2680 Ma to 419 \pm 2 Ma. This interpretation was not preferred as the probability of fit was low, and in order for it to be correct, it required old inherited zircon in all three zircon fractions (Dunning and Manser, op. cit.). The favoured interpretation of the data, using fractions 1, 3, 4 and 5, yielded a Discordia line (56% probability of fit) that intersected Concordia at 31 ± 85 Ma and 439.5 + 9/-6 Ma. The ²⁰⁷Pb/ ²⁰⁶Pb ages for the four fractions agreed within error, and the latter age was preferred. A major issue with this 440 Ma age, however, is that the MPIS gabbro does not cut monzogranite, and this age is apparently older than many of the surrounding country rocks (Boyce and Dickson, 2006; Dickson et al., 2007).



Figure 5. Composite, lower hemisphere, equal area plot of poles to mineralized and non-mineralized fractures at the Salmon River area. Mineralized fractures have a mean orientation of 033/68°, comparable to the observed, northeast-trending, moderately southeast-dipping mineralized zones.

- 2) An imprecise LAM-ICP-MS analysis of zircon (O'Driscoll and Wilton, 2005) for the host diorite of the Corsair prospect at Salmon River yielded an age of 427.0 ± 8.4 Ma (2σ errors applied) and a sample of Red Rocks granite from Red Rock Brook yielded a very imprecise Discordia age of 424 ± 24 Ma.
- 3) In an attempt to address the conflicted age of granite sample LD92-0152 (*see* above), and the inherent problem of the granite intrusion being older than its biostratigraphically constrained host rocks, Dickson *et al.* (2007) sampled a monzogranite exposed immediately south of the Salmon River for geochronological study. This miarolitic and granophyric, fine-grained biotite-monzogranite was described as locally forming a netvein complex of angular gabbro-diorite blocks in narrower veins of the monzogranite (Dickson, 1993; Dickson *et al.*, 2007). The sample yielded a U-Pb SHRIMP zircon age of 411 ± 2.6 Ma (Figure 2).

4) Dunning (1992, 1994) presented U–Pb TIMS geochronological data for two samples of gabbro from the MPIS. These ages have been discussed and quoted in a number of contributions (O'Driscoll and Wilton, 2005; McNicoll *et al.*, 2006; Dickson *et al.*, 2007), however, the complete dataset has not yet been published. Herein we provide the complete TIMS U–Pb dataset along with slightly revised ages of these two MPIS gabbro samples.

ANALYTICAL METHODS

The three U–Pb geochronological samples discussed herein include: 1) the mineralized miarolitic monzogranite dyke at the Slip showing; 2) a phlogopite–hornblende– clinopyroxene-bearing gabbro of the MPIS from the western Norris Arm access road; and, 3) a coarse-grained, layered phlogopite–hornblende–clinopyroxene-bearing gabbro, exposed ~1 km south of Rolling Pond along the southwestern margin of the MPIS. The methods and analytical details for each sample are given below. Details of zircon morphology and quality along with the isotopic ratios are provided in Table 1. Age calculations were performed using ISO-PLOT (Ludwig, 2008). Universal Transverse Mercator coordinates are in NAD27 zone 21.

MIAROLITIC MONZOGRANITE DYKE (02GD-NBMM: 643525 E, 5438289 N)

A 2 kg sample of buff to pink and locally rusty, medium-grained miarolitic monzogranite containing abundant granophyric intergrowths of quartz and alkali feldspar was processed and hundreds of small euhedral zircon crystals recovered. The clearest grains were selected for physical abrasion (Krogh, 1982), followed by chemical abrasion (Mattinson, 2005), and then three fractions of 2, 4 and 5 grains were prepared for thermal ionization mass spectrometry (TIMS). All three analyses are concordant and overlapping with ${}^{206}\text{Pb}/{}^{238}\text{U}$ ages of 418.7 ± 2.4, 416.6 ± 2.9 and 418.4 ± 3.5 Ma (Table 1; Figure 6A). These produce a weighted average 206 Pb/ 238 U age of 418 ± 1.6 Ma (95% confidence interval (C.I.); mean square of weighted deviates (MSWD) = 0.63). The ages involving 207 Pb are of low reliability because of the very small amount of lead being measured in these low-uranium zircon crystals.

MOUNT PEYTON GABBRO–DIORITE: NORRIS ARM (93GD08: 624400 E, 5434400 N)

A 20 kg sample of gabbro obtained from a roadcut on the western access road to Norris Arm (near the Highway 1 intersection), yielded a large amount of coarse-grained zircon prisms and fragments. Four analyses of 30–40 grains each were carried out after physical abrasion (Krogh, 1982).





Plate 8. Images of the auriferous mineralization at the Hurricane–Corsair zones. A 20 cm piece of quartered core yielded 5719 ppm As, 55.9 ppm Sb, 0.3 ppm Ag and 1030 ppb Au. A) Plane-polarized light image of a 0.5 cm quartz + siderite vein cutting altered diorite (sample MP90-5_26.2m). Note the extensive sericitization of the host rock, the complete replacement of the host feldspars and the dispersed anhedral pyrite and euhedral arsenopyrite adjacent to the quartz vein; B) Same as A, but under reflected light; C) BSE image showing anhedral pyrite, euhedral arsenopyrite and anhedral rutile in an extensively silica-sericite-altered matrix. Key: Apy – arsenopyrite; Mu – muscovite; Py – pyrite; Rt – rutile; Qtz – quartz; Sd – siderite.



Plate 9. Back-scattered electron (BSE) image and corresponding simplified Xray map of an arsenopyrite-poor section of sample MP90-5_30.4 m in the Hurricane zone. A 20 cm piece of quartered core yielded 1839 ppm As, 17.5 ppm Sb, 10 ppm Sn and 181 ppb Au. Note the extensive replacement of the diorite by silica-muscovite-albitepyrite and arsenopyrite. Key: Ab – albite; Apy – arsenopyrite; Cpx clinopyroxene; Mu – muscovite; Py – pyrite; Qtz – quartz.

		Concen	tration	Measu	ured		Cor	rected .	Atomic Ra	tios*			Å	ge (Ma)	
				total											
Fraction	Weight (mg)	D	Pb rad (ppm)	common Pb (pg)	$\frac{^{206}\mathrm{Pb}}{^{204}\mathrm{Pb}}$	$\frac{^{208}\mathrm{Pb}}{^{206}\mathrm{Pb}}$	$\frac{^{206}\text{Pb}}{^{238}\text{U}}$	-++	$\frac{^{207}\text{Pb}}{^{235}\text{U}}$	++	$\frac{^{207}Pb}{^{206}Pb}$	H	$\frac{^{206}\text{Pb}}{^{238}\text{U}}$	$\frac{^{207}\text{Pb}}{^{235}\text{U}}$	$\frac{^{207}\text{Pb}}{^{206}\text{Pb}}$
Neyles Brook quarry -	– miaroli	tic mon	zograni	te (02GD-1	NBMM)										
Z1 5 clr euh prms abr	0.010	52	3.6	1.8	1206	0.1579	0.06711	40	0.5137	50	0.05552	46	418.7	421	433
Z2 4 clr euh prms abr	0.008	53	3.7	2.4	751	0.1512	0.06676	50	0.5108	99	0.05550	70	416.6	419	432
Z3 2 clr euh prms abr	0.004	78	5.5	3.3	413	0.1655	0.06706	60	0.5189	132	0.05612	136	418.4	424	457
Mount Pevton gabbro	- southy	vest lav	ered int	rusion (LD	91-63-1)										
Z1 lg angular frags abr	0.270	383	29.7	238	1858	0.2742	0.06760	36	0.5154	28	0.05530	12	422	422	424.2
Z2 clr pale frags abr	0.165	428	33.7	110	2729	0.2979	0.06758	28	0.5153	22	0.05531	8	422	422	424.7
Z3 angular frags abr	0.214	498	39.0	12	36514	0.2982	0.06725	28	0.5125	22	0.05526	9	420	420	423.0
Z4 coarse zircon frags	0.567	497	35.4	13	87122	0.2688	0.06240	24	0.4753	20	0.05524	9	390	395	421.9
Mount Pevton gabbro	-diorite -	- TCH	(93GD0	8)											
Z1 coarse frags abr	0.318	254	18.4	12	28042	0.1840	0.06790	26	0.5172	20	0.05525	10	423	423	422.4
Z2 coarse frags abr	0.333	235	17.3	8.9	37733	0.1958	0.06838	20	0.5209	16	0.05525	4	426	426	422.4
Z3 coarse gems abr	0.299	237	17.5	52	5823	0.2015	0.06812	36	0.5192	28	0.05528	8	425	425	423.6
Z4 coarse gems abr	0.255	260	19.0	34	8185	0.2056	0.06756	18	0.5144	14	0.05522	9	421	421	421.0
Notes: Z=zircon, 2,4,5 Weights were estimated	- =number so [] and	of grair I Ph con	is, clr=cl	lear, prms =	=prisms, et	ah=euhedra * Atomic ra	al, abr = phy atios correcto	/sically	abraded, f ractionatio	rags = f	ragments.	blank	of 1-2 nic	orams	of com-
mon lead, and initial co tainties are renorted aft	mmon les er the rati	ad at the	age of the	he sample c	calculated	from the m	odel of Stac	ey and	Kramers (1975), a o the fi	nd 0.3 picog	gram U	blank. Tv	vo sigm	a uncer-
ומוווורט מור זיקעיו מוו	רו חור זמוז	I NITR CO		an initiat ang	sup. Devo	ATTA TTI MACT	age calvula	מור	I LUDUINU		I ULULIAN IC	Jacc.			

Table 1. U-Pb zircon data from a monzogranite dyke and gabbro-diorite of the Mount Peyton intrusive suite



Figure 6. U–Pb Concordia diagrams for: A) The miarolitic monnzogranite (02GD-NBMM); B) The Norris Arm gabbro–diorite (93GD08); C) The coarse-grained gabbro from south of Rolling Pond in the southwest of the MPIS (LD91-63-1).

These analyses are all concordant, but do not all mutually overlap. They display a range along the Concordia curve from 426 to 421 Ma. Z2 is above Concordia with the oldest ²⁰⁶Pb/²³⁸U age, which may, in this case, indicate minor elemental fractionation. Z4, at 421 Ma, may exhibit a small degree of lead-loss. The ²⁰⁷Pb/²⁰⁶Pb ages, however, are reliable and consistent between 423.6 and 421.0 Ma (Table 1; Figure 6B).

A weighted average 207 Pb/ 206 Pb age for all 4 analyses yields 422.3 ± 1.2 Ma (95% C.I., MSWD=0.51), and that for the three most closely clustered analyses (Z1–Z3) yields 422.5 ± 1.3 Ma (MSWD=0.23). Both ages are acceptable and not statistically different. The age of crystallization for this rock, derived from all four analyses is, therefore, 422.3 ± 1.2 Ma.

MOUNT PEYTON GABBRO: SOUTHWEST INTRUSION (LD91-63-1: 615020 E, 5389370 N)

This 20 kg sample of medium- to coarse-grained gabbro, obtained from approximately 1 km south-southeast of Rolling Pond, yielded a large amount of coarse angular zircon fragments. These are likely broken pieces of large skeletal igneous zircon grains that commonly grow in the late, trace-element enriched liquid in gabbro intrusions. Four large fractions were analyzed; Z1–Z3 were physically abraded (Krogh, 1982), and Z4 was not (Table 1; Figure 6C). Each fraction consisted of 30–40 high-quality clear fragments, and the 3 abraded fractions yield ²⁰⁷Pb/²⁰⁶Pb ages from 423.0 ± 1.4 to 424.7 ± 1.8 Ma. With such large fractions, the amount of ²⁰⁷Pb measured is sufficient to obtain very accurate and precise measurements. Z4 is 9% discordant down the line shown and has a younger ²⁰⁷Pb/²⁰⁶Pb age of 421.9 ± 1.4 Ma.

The calculated line using all 4 analyses has an upper intercept age of crystallization of 424 + 2.3/-2 Ma (95% C.I.; 78% probability of fit), and a lower intercept of 29 ± 38 Ma. The weighted average ²⁰⁷Pb/²⁰⁶Pb age of the 3 abraded near-concordant fractions, is 423.6 ± 1.8 Ma (95% C.I.; MSWD =0.56). This is adopted as the best calculated age for crystallization of this rock.

PETROCHEMISTRY

ANALYTICAL METHODS

Sixty three lithogeochemical and petrographic samples were obtained from a wide range of mineralized and nonmineralized intrusive rocks from the northern parts of the MPIS. From the Slip showing these include: 11 samples of fine- to medium-grained gabbro–diorite, 10 samples of red granophyric monzogranite, 19 samples of miarolitic monzogranite, 1 granodiorite sample and 1 sample of the young, east–west, olivine + clinopyroxene-phyric mafic dyke. From the Salmon River area, 16 samples of both altered and unaltered fine- to medium-grained quartz diorite, and one sample of granodiorite were obtained from both bedrock exposures and historical drillcore (Tallman, 1991a). These data are supplemented with 3 samples of monzogranite and one sample of a medium-grained gabbro from the eastern margin of the MPIS, and three samples of medium-grained gabbro from near Norris Arm.

All samples were submitted for determination of their major-, trace-, rare-earth element (REE) and gold pathfinder-element contents. Samples with the prefix HS were analyzed at the Department of Natural Resources, Government of Newfoundland and Labrador, Geochemical Laboratory (Howley Building, Higgins Line) for their major and trace elements following the methods outlined in Sandeman (2015). The rest were analyzed at ALS Chemex, Activation Laboratories and Eastern Analytical Limited following the methods outlined in Hoffe and Sparkes (2003). These data (H. Sandeman, unpublished data, 2017) are supplemented by ICP-ES multi-element analyses of industry rock samples from both the Salmon River area (House, 2007a) and the Slip showing (Hoffe and Sparkes, 2003; House, 2007b; Quinlan, 2009).

COMMENTS ON ELEMENT MOBILITY AND ALTERATION

Although the gabbro-diorite at the Slip showing exhibits some petrographic evidence of alteration, it is relatively minor and only the most mobile elements have been modified. Intense alteration at the Slip showing is entirely restricted to the irregular dyke of miarolitic monzogranite that intrudes the gabbro-diorite. Sericite-siderite-pyritechalcopyrite-galena-silica bearing miarolitic cavities indicate that the primary lithogeochemistry of these miarolitic monzogranite samples may have been modified. At the Hurricane-Corsair prospects, only the diorite is mineralized and many samples exhibit intense sericite-siderite-arsenopyrite-pyrite alteration proximal to the northeast-trending quartz veins. This visible alteration indicates that many elements may have been mobile during introduction of the hydrothermal fluids.

Altered rocks show more variability in their SiO₂, CaO, K_2O , Na_2O and large-ion-lithophile element (LILE: Rb, Sr, Ba, Cs) abundances than unaltered rocks. Unaltered samples display less variation in the abundances of the major elements and LILE, and appear to represent relatively pristine magmatic compositions. The immobile major and trace elements, along with the high field strength elements (HFSE)

and rare-earth elements (REE), show more systematic behaviour for all samples and these provide the firmest basis for petrogenetic interpretation of the rocks.

COMMENTS ON ELEMENT ASSOCIATIONS IN MINERALIZATION

Lithogeochemical results from monzogranite and gabbro-diorite from the Mount Peyton trend, including industry ICP and fire assay data for rocks from the area, are plotted in log-log plots (Figure 7). The data indicate that gold (Au), antimony (Sb), silver (Ag) and bismuth (Bi), and less convincingly so copper (Cu), molybdenum (Mo), lead (Pb), cadmium (Cd) and tellurium (Te) are correlated with arsenic (As). At the Slip showing, anomalous metal concentrations are directly related to the volume % of miarolitic cavity material that comprises a sample. Sample NFR20192 contained the highest proportion of miarolitic cavity material (+sulphides) of any sample in this study and it was highly anomalous in many of the metals of interest (e.g., 5935 ppb Au, 1.3 ppm Ag, 134 ppm Sb, 14 ppm Mo and 14.2 ppm Bi and >2000 ppm As). The Hurricane-Corsair zones are characterized by correlations between Au, Ag, Sb and locally Cd and Te with As, but Mo, W, Cu and Pb are not elevated. The Slip showing is typically characterized by lower As, Ag, Sb, Cd and Bi, but is elevated in Cu and Mo relative to the mineralization at the Hurricane-Corsair zones. For both areas, gold and arsenic have an approximately 1:10 ratio, likely indicating a paragenetic association with arsenopyrite.

ROCK CLASSIFICATION AND MAJOR-AND TRACE-ELEMENT VARIATIONS

All of the mafic rocks are calc-alkaline clinopyroxene-biotite-hornblende gabbro ranging to quartz diorite, with the exception of the young clinopyroxene-phyric mafic dyke, which is an alkaline basalt. The granophyric monzogranite and miarolitic monzogranite from the Slip showing, along with the silicic rocks from the Hurricane-Corsair zones and the eastern margin of the MPIS, are all monzogranite whereas the granodiorite from the Slip showing plots as granodiorite (Figure 8A, B). The gabbro to quartz diorite exhibits relatively low Nb/Y characteristic of subalkaline basalt and basaltic andesite, whereas the silicic rocks are rhyolite and dacite and have elevated Zr/TiO₂ (Figure 8C). The late clinopyroxene-phyric mafic dyke has high Nb/Yb but low SiO₂ and is an alkaline basalt (Figure 8A-C). With the exception of the mineralized miarolitic monzogranite and the gabbro of the Eastern MPIS, all rocks plot in the calc-alkaline field in the Th/Yb vs. Zr/Y diagram (Ross and Bédard, 2009). The mineralized miarolitic monzogranite has very low and variable Zr/Y, but constant Th/Yb (Figure 8D).







Figure 8. Chemical classification of intrusive rocks that host the mineralized zones of the Mount Peyton trend. A) Total alkalies vs. SiO_2 (wt. %) plutonic rock classification diagram (Wilson, 2001); B) Q-A-P diagram (Streckeisen, 1976); C) TiO_2/Zr vs. Nb/Y immobile element classification plot (Pearce, 1996); D) Th/Yb vs. Zr/Y plot (Ross and Bédard, 2009). Shown for comparison are selected regional lithogeochemical data for the granitoid rocks of the area (open symbols: Dickson and Kerr, 2007).

Selected major, compatible and incompatible trace elements for all samples are plotted against SiO_2 wt. % (Figure 9). The unaltered rocks define restricted clusters or arrays in major- and trace-element space. For the mafic rocks, these arrays appear to delineate a number of compositionally distinct magma batches, each exhibiting distinct bulk compositions. MgO, FeO^T, CaO and less so Sr and Eu/Eu*(Eu*= $\sqrt{Gd_N*Sm_N}$: Taylor and McLennan, 1985) all decrease with increasing SiO₂, likely reflecting fractional crystallization of clinopyroxene + hornblende ± plagioclase in the gabbro–diorite in the west, and hornblende + biotite + plagioclase ± clinopyroxene in the quartz diorite of the Salmon River area.



Figure 9. Selected major and trace elements vs. SiO_2 for the rocks of the investigation. Symbols as in Figure 8. Solid lines represent approximate mineral-liquid fractionation trends whereas grey arrows depict proposed "fluid-separation" trends associated with miarolitic cavity development. Grey boxes are altered diorite from the Hurricane–Corsair zones.

The major- and trace-element variations indicate that the Salmon River diorite, the gabbro-diorite at the Neyles Brook quarry and the Norris Arm and the eastern MPIS cannot be easily petrogenetically related through progressive fractional crystallization. Altered samples of the gabbro-diorite (represented by grey squares in Figure 9) have much more variable compositions trending toward higher silica and lower contents of all other elements. These variations are interpreted to reflect the effects of dilution of the bulk rock diorite compositions by the addition of quartz-carbonate veins, sulphides and local intense silicification and carbonate alteration (Figure 9).

Fresh granophyric monzogranite from the Neyles Brook quarry and the monzogranite from the eastern MPIS are very similar in composition, varying only slightly in their CaO, Rb, U, Th, Y and REE concentrations (Figure 9). Granodiorite from both the Neyles Brook quarry and the Salmon River area typically exhibit bulk compositions intermediate between the gabbro-diorite and the monzogranite. The two samples have LILE and REE abundances very similar to the granophyric and eastern MPIS monzogranites, but are enriched in Zr and Hf.

Miarolitic monzogranite exhibits elevated concentrations of, and a wider range in, SiO₂ than the other monzogranites. These samples exhibit broadly linear trends or elongate clumps in major- and trace-element space, with the exception of the most intensely mineralized sample NFR20192, which contains the lowest SiO₂, Al₂O₃, MgO, CaO, Na₂O, TiO₂, P₂O₅ but highest FeO^T and LOI of any rock analyzed. Miarolitic monzogranite is also characterized by variable and typically lower abundances of all of the incompatible trace elements relative to granophyric monzogranite and monzogranite of the eastern MPIS (Figure 9).

The sample of the late mafic dyke is geochemically distinct from all other mafic rocks (Figure 9) in having lower SiO_2 , Al_2O_3 and Na_2O , but higher MgO, CaO, FeO^T , P_2O_5 and TiO_2 than the majority of all other rocks under investigation. It is also characterized by the highest Cr, Ni and light-REE, and the lowest Y and heavy-REE of any rock.

The REE and incompatible trace-element abundances of the rocks are displayed as normal mid-ocean-ridge basalt (N-MORB) normalized multi-element plots (Sun and McDonough, 1989; Figure 10A-E). All unaltered samples of each rock type are mutually similar, defining closely grouped patterns (Figure 10). In contrast, mineralized samples of the miarolitic monzogranite from the Slip showing and the altered mineralized diorite from the Hurricane-Corsair zones are characterized by significantly more variation in their large ion lithophile element (LILE: Rb, Ba, Sr) and HFSE abundances, in particular TiO₂, P₂O₅, Sr and Zr. The following descriptions avail of the lithogeochemical signatures of the unaltered samples for petrogenetic interpretations. With the exception of Y and the heavy rare-earth elements (HREE) in a few samples, gabbro-diorite from Norris Arm and the Neyles Brook quarry have incompatible trace-element concentrations higher than average N-MORB (Figure 10A). These rocks have elevated LILE and Th, modest Nb, Sr, P and Ti troughs and shallow negative slopes from La-Lu (Figure 10A, B). The gabbro-diorite from Norris Arm, the Neyles Brook quarry and the single sample from the eastern MPIS are modestly light rare-light-element (LREE) enriched ($[La/Yb]_{CN} = 2.47-3.54$: CN denotes chondrite normalized after Sun and McDonough, 1989), have a gentle, negative slope from the middle- to the HREE $([Gd/Yb]_{CN} = 1.29-1.59)$ and exhibit minor negative Eu anomalies ($[Eu/Eu^*] = 0.78-0.95$, mean = 0.87). Diorite from the Hurricane-Corsair zones has broadly parallel multi-element patterns, but exhibits elevated abundances of all of the incompatible trace elements, with the exception of Sr and Ti (Figure 10B).

The multi-element patterns of the granophyric monzogranite from the Slip showing are all essentially identical (Figure 10C). The profiles are strongly enriched in the LILE and Th, enriched in the LREE and have weakly inclined HREE patterns. These rocks have modest Nb, but deep Sr, P, and Ti troughs. The rocks are LREE enriched $([La/Yb]_{CN} =$ 4.4-5.7) and have a shallow slope from the middle- to the HREE ($[Gd/Yb]_{CN} = 1.2-1.5$). The granophyric monzogranite have modest negative Eu anomalies ($[Eu/Eu^*] = 0.41$ -0.49, mean = 0.41). The granophyric monzogranite and the easten MPIS granites have very similar multi-element patterns (Figure 10C, D), but the former have higher concentrations of the REE. In contrast, the miarolitic monzogranite exhibits roughly parallel, but more variable multi-element patterns with lower overall abundances of most incompatible elements (Figure 10C), and deep Nb, Sr, P and Ti and prominent Zr troughs. The most intensely mineralized sample has the lowest incompatible element abundances. The late mafic dyke has the most distinct, steeply inclined multielement pattern with elevated LILE and LREE and the lowest abundances of the HREE and Y.

The petrochemistry of the rocks is further examined using established trace-element discrimination diagrams. The gabbro-diorite from Norris Arm, the Neyles Brook quarry and the eastern MPIS plot as volcanic arc granitoids whereas the Salmon River diorite straddles the boundary of the volcanic arc and within-plate fields (Figure 11A). Most of the silicic rocks plot in the within-plate field. All rocks of the MPIS have moderate Nb/Yb ratios but strongly elevated Th/Yb ratios and plot well above the mantle array (Figure 11B) indicating Th contributions from a lithospheric component. The young mafic dyke has elevated Nb/Yb and Th/Yb, characteristic of alkaline oceanic-island basalts. The gabbro-diorite from Norris Arm, the Neyles Brook quarry and the eastern MPIS have low TiO₂/Yb and moderate Nb/Yb, plot in the shallow-melting, asthenospheric mantle array and were derived from an undepleted mantle source (Figure 11C). The late mafic dyke has very high TiO_2/Yb and plots in the deep mantle, OIB array.

DISCUSSION

The results of this investigation have implications for the nature and timing of precious-metal mineralization at the Hurricane–Corsair and Slip mineralized zones, and likely for the mineralization along the entire length of the Mount Peyton trend. Moreover, these observations also have significant implications for the understanding of the age, magmatic infrastructure and petrochemical and temporal complexity of the intrusive rocks comprising the northern portion of the MPIS.

Field relationships at the Neyles Brook quarry (Slip showing) demonstrate 5 distinct intrusive rock types. The oldest unit is the biotite-hornblende \pm clinopyroxene gabbro-diorite. This was invaded, while still a crystal mush (semi-solidified), by the granophyric monzogranite. Textural features between the two rock types such as globular, rounded to subrounded, non-quenched pillows of gabbrodiorite in granophyric monzogranite, and scalloped, undulating subhorizontal interfaces are indicative of magmatic contemporaneity, commingling and possibly minor hybridization. These observations indicate that the relative temperatures of the two compositionally distinct magmas were similar and, therefore, their ages are also comparable as they are broadly comagmatic. Moreover, the widespread presence of acicular elongate apatite inclusions in late interstitial quartz in the gabbro-diorite represents a mineralogical feature that has been interpreted to be associated with rapid cooling and magma hybridization (Wyllie et al.,



Figure 10. *N-MORB normalized multi-element plots (Sun and McDonough, 1989) for rocks of the Mount Peyton trend. A)* Gabbro–diorite from the Slip showing; B) Diorite from the Hurricane–Corsair zones; C) Granophyric monzogranite and miarolitic monzogranite from the Slip showing; D) Granodiorite from the Hurricane–Corsair and Slip zones and monzo-granite from the eastern MPIS; E) The late, olivine–clinopyroxene-phyric dyke at the Slip showing. Average, enriched mid-ocean-ridge basalt (EMORB) and oceanic-island basalt (OIB: Sun and McDonough, 1989) as well as average alkaline lamprophyre (Rock, 1990) are shown for comparison. Grey boxes are altered diorite from the Hurricane–Corsair zones. Open triangles in (E) are mafic dykes from the MPIS (Dickson and Kerr, 2007).



Figure 11. Trace-element paleotectonic discrimination diagrams. A) Rb vs. Y + Nb (Pearce et al., 1984); B) Th/Yb vs. Nb/Yb (Pearce, 2008); C) TiO₂/Yb vs. Nb/Yb (Pearce, 2008). UC – upper crust, LC – lower crust (Rudnick and Gao, 2003).

1962). Therefore, the relationships observed in the Neyles Brook quarry strongly suggest, as previously proposed by Dickson (1994), that the granophyric monzogranite and gabbro-diorite preserve an essentially horizontal contact where the granophyric monzogranite has stoped upward into the gabbro-diorite.

The mineralized miarolitic monzogranite dyke at the Slip showing intrudes the gabbro–diorite; however, its spatial and temporal relationships with the granophyric monzogranite are unclear. The new CA-TIMS U–Pb zircon age of 418 ± 1.6 Ma constrains the age of the mineralized miarolitic monzogranite as well as the precious-metal mineralization. The mineralized dyke exhibits distinct major, compatible and incompatible trace-element abundances relative to the granophyric monzogranite. Collectively, the incompatible trace-element patterns of the miarolitic monzogranite, albeit at relatively lower, and more variable, elemental concentrations. Each of the miarolitic monzogranite samples

consisted of variable volumes of both 'original' monzogranite and miarolitic cavity fill. These observations, therefore, suggest that the two different monzogranites mapped in the Neyles Brook quarry, the granophyric monzogranite and miarolitic monzogranite, may have possibly originated from similar parental granitic magmas (granophyric monzogranite?), but their differing compositions are the result of dilution of the primary silicate components of the magma by silica, muscovite, carbonate, H₂O and sulphide phases filling the miarolitic cavities. The cavities likely formed during magma ascent in vertical conduits where, under $P_{magma} > P_{lithostatic}$ conditions, a metalliferous hydrothermal fluid was exsolved from the parental monzogranite magma. Thus, the miarolitic monzogranite dyke contains 'intrusionrelated' mineralization, as the arsenopyrite– pyrite–muscovite-filled miarolitic cavities represent the late-stage hydrothermal fluids derived from "second boiling" and rapid cooling of the intrusion. The monzogranitic dykes may have persisted as vertical conduits for younger hydrothermal fluids.

Figure 12 shows available TIMS U–Pb zircon, SHRIMP U–Pb zircon, LAM-ICP-MS zircon and historical 40 Ar– 39 Ar step-heating ages for rocks exposed in the northern parts of the MPIS. Also shown are the ranges in biostratigraphic ages for fauna of the eastward-lying Indian Islands Group (Boyce and Dickson, 2006). The TIMS U–Pb ages for the Norris Arm gabbro–diorite (422.3 ± 1.2 Ma:



Figure 12. Diagram summarizing geochronological constraints on the rocks of the northern MPIS. Time-scale from the International Commission on Stratigraphy stratigraphic chart (Cohen et al., 2013, updated 2016). Also outlined are the approximate estimates for the orogenic events of the Newfoundland Appalachians (Zagorevski et al., 2007) and the age of the "intrusion-related" mineralized miarolitic monzogranitic dykes at the Slip showing. Note the refined, middle to late Silurian macrofossil ages for the eastward-lying Indian Islands Group (Boyce and Dickson, 2006) are permissible with the new ages for the MPIS (viz. Dickson et al., 2007).

Figure 6) and the coarse-grained gabbro from the south of the MPIS near Rolling Pond (423.6 \pm 1.8 Ma) are very similar and overlap, within error. The CA-TIMS U-Pb age for the miarolitic monzogranite of the Neyles Brook quarry $(418 \pm 1.6 \text{ Ma})$, however, does not overlap the other two, within error. The new U-Pb data and observations provided herein indicate that the mineralization at the Slip showing is latest Silurian to earliest Devonian (Pridoli to Lochkovian; Cohen et al., 2016). The similar TIMS U-Pb ages that have been determined on gabbro at Norris Arm and Rolling Pond, and for the miarolitic monzogranite at the Slip, indicate that much of the magmatism in the MPIS is constrained to between 425 and 418 Ma. It appears, therefore, that in light of the U-Pb chemical abrasion method used for the Slip, miarolitic monzogranite analysis, the younger 419 Ma TIMS U-Pb age (Dunning and Manser, 1993) for the Red Rocks monzogranite (see discussion in Dickson et al., 2007) may now be interpreted as more appropriate, in particular in light of the new biostratigraphic constraints on the Indian Islands Group (Boyce and Dickson, 2006). However, the SHRIMP age for the Red Rocks monzogranite (Dickson et al., 2007; 411 \pm 3 Ma) is much younger by a number of millions of years, and the LAM-ICPMS U-Pb ages for the diorite at the Corsair prospect and the Red Rocks monzogranite (O'Driscoll and Wilton, 2005) are too old. These observations indicate that in these Paleozoic intrusive rocks, traditional TIMS, and in particular CA-TIMS analysis is more consistent and accurate because of the low amounts of ²⁰⁷Pb in the analyzed zircon. The similarities in grain-size, texture, petrological characteristics and, the broadly contemporaneous intrusive relationships between monzogranite and gabbro-diorite at both the Slip showing and the Salmon River zones, suggest that the northeastern miarolitic monzogranite may represent the youngest identified phase of the MPIS.

All of the samples of gabbro-diorite analyzed are very similar in composition. The mafic rocks from each geographic area form distinct groups and trends on element vs. SiO₂ diagrams, indicating that although they are all petrogenetically similar, they each must represent distinct magma batches. The major distinction is that the gabbro-diorite is more primitive in the west near Norris Arm, with lower SiO₂ and elevated MgO, Cr and Ni, relative to those exposed at the Slip showing. Moreover, quartz-diorite at the Hurricane-Corsair zones is the most evolved of the mafic rocks investigated, and appears to have undergone titanomagnetite fractional crystallization and removal. These gabbro-diorites all represent transitional tholeiitic to calc-alkaline, modestly incompatible and rare-earth-element enriched, mafic to intermediate intrusive rocks that have Nb, P and TiO₂ troughs that increase in magnitude with increased fractionation. These rocks have compositions that appear to be transitional between arc-related mafic suites (Pearce, 2008) and low-TiO₂ continental tholeiites generated via continental extension (Gibson *et al.*, 1996). The mafic intrusive rocks collectively represent a number of batches of similar gabbro varying to diorite melts that were emplaced cyclically into a large-scale, likely laccolithic magma chamber.

The Slip showing represents late-stage, syngenetic, intrusion-related mineralization (Sillitoe and Thompson, 1998; Thompson *et al.*, 1999; Hart, 2007), having Au–As– Sb \pm Ag \pm Cu \pm Pb \pm Cd \pm Mo \pm Te metal associations. Mineralization is confined to miarolitic cavities in broadly north- to northwest-trending miarolitic monzogranitic dykes intruding the MPIS gabbro–diorite (Dickson, 1994; Dickson *et al.*, 2000; *this study*). The Hurricane–Corsair mineralized zones at the Salmon River appear to represent epigenetic, fracture-controlled veining and accompanying disseminated wall-rock alteration and Au–Ag–As–Sb mineralization. These zones may be genetically related to miarolitic monzogranite as at the Slip showing and, would therefore represent 'vein-style' mineralization developed structurally above a comparable magmatic fluid source.

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