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THE PALEOPROTEROZOIC METAVOLCANIC, METASEDIMENTARY AND IGNEOUS ROCKS OF THE AILLIK DOMAIN, MAKKOVIK PROVINCE, LABRADOR (NTS MAP AREA 13O/03)

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ABSTRACT

In the Makkovik area (NTS map area 13O/03), 1:50 000 scale mapping has further defined the lithological units that occur within the Aillik domain of the Makkovik Province, which hosts abundant syn- and post-deformational mafic dykes and post-deformational aplitic dykes. Regional bedrock mapping focused on characterizing the Aillik Group (previously called the Upper Aillik Group), a package of Paleoproterozoic volcano-sedimentary rocks that dominate the area. The Aillik Group is intruded by abundant, syn- and post-deformational Paleoproterozoic intrusive suites.

The Aillik Group comprises upper-greenschist to lower-amphibolite facies, felsic tuff, flow-banded to non-banded rhyolite, quartz-feldspar-porphyritic granite, volcaniclastic breccia/conglomerate, tuffaceous sandstone, thin-bedded to laminated metasandstone and siltstone, and lesser components of metabasalt (with locally preserved pillow selvages), mafic tuff and porphyritic granites. The degree of deformation and grade of metamorphism vary throughout the map area. Paleoproterozoic intrusive suites include the syntectonic Makkovikian (ca. 1840-1800 Ma) plutonic rocks of the Long Island Quartz Monzonite and the Kennedy Mountain Intrusive Suite, the posttectonic Makkovikian (ca. 1800-1720 Ma) plutonic rocks of the Strawberry Intrusive suite, and the Labradorian (ca. 1670-1630 Ma) plutonic rocks of the Monkey Hill and Adlavik intrusive suites.

The study area lies within the Central Mineral Belt of Labrador, an area known to host an abundance of base-metal and uraniferous showings. Previous studies in the area have illustrated the strong economic potential of the Aillik domain, and this study has identified several previously unreported mineral occurrences.

INTRODUCTION

The 2006 field season marked the first year of a multi-year, 1:50 000-scale, bedrock mapping project with the goal of mapping and interpreting the geology of the Aillik domain of the Makkovik Province. The Aillik domain, which is one of three domains that divide the Makkovik Province, is dominated by Paleoproterozoic metasedimentary and metavolcanic supracrustal sequences (Aillik Group) and by intrusive suites (Kerr *et al.*, 1996). The outcome of this project will be a detailed, comprehensive, GIS-integrated geological map and associated database, which will also be a valuable tool for mineral exploration and for land-use planning. The 2006 field season covered all of the Makkovik map area (NTS map sheet 13O/03; *see* Figure 1), which is contained entirely within the Central Mineral Belt of Labrador (Ryan, 1984), an area known for its abundant and varied base-metal and uraniferous occurrences. Regional bedrock mapping focused on characterizing the Aillik Group, previously known as the Upper Aillik Group and renamed to distinguish it from an older, distinct package of

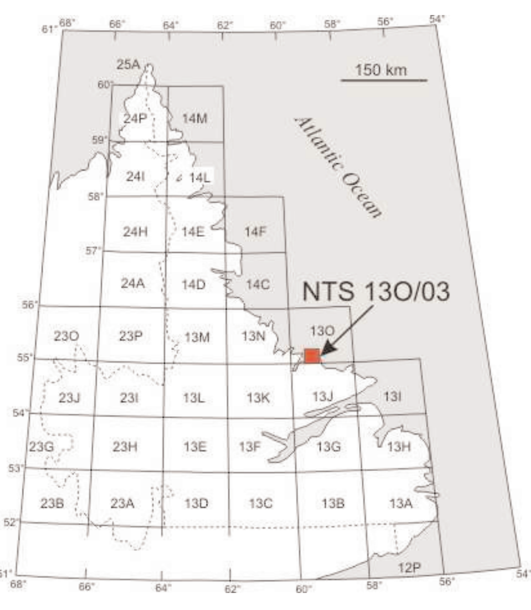


Figure 1. *Index map of Labrador showing the location of the NTS 13O/03 Makkovik study area.*

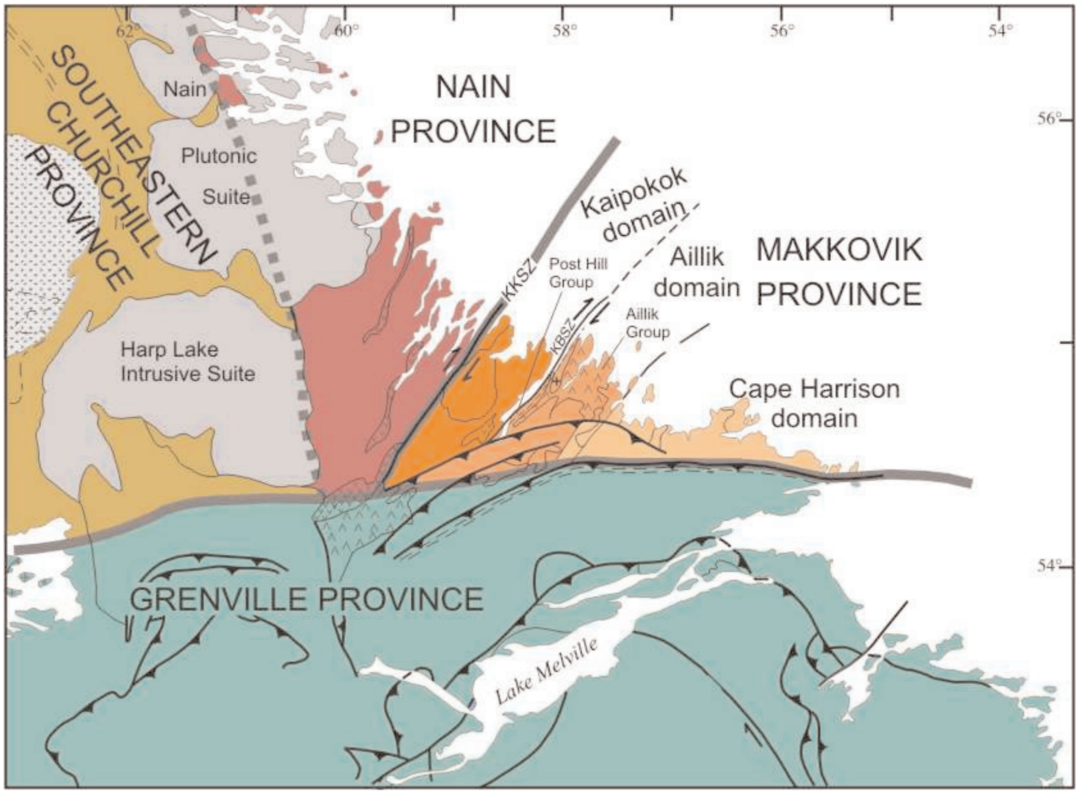


Figure 2. *A simplified tectonic framework of south-central Labrador; the map highlights the three domains of the Makkovik Province: the Kaipokok, Aillik and Cape Harrison domains (simplified after Wardle* et al.*, 1997). KBSZ - Kaipokok Bay Shear Zone; KKSZ - Kanairiktok Shear Zone.*

rocks, previously known as the Lower Aillik Group and renamed the Post Hill Group (*see* Ketchum *et al.*, 2002). The Aillik Group is a Paleoproterozoic, metavolcanic and metasedimentary package of rocks that are intruded by abundant syn- and post-deformational intrusive suites. The Aillik domain also contains abundant pre- and post-deformational mafic dykes that intrude the entire map area. This preliminary report is based on data from the 2006 field-mapping season.

PREVIOUS WORK

Most of the early geological studies in the area were carried out by the Geological Survey of Canada, and were reconnaissance geological mapping surveys (Kranck, 1939, 1953; Christie *et al.*, 1953; Douglas, 1953). Since the discovery of uranium and molybdenite mineralization in the region in 1954, many studies have focused on the mineral potential of the area (*e.g.*, Beavan, 1958; Gandhi *et al.*, 1969; Gandhi, 1978; MacDougall, 1988; MacKenzie, 1991; Wilton, 1996). The Newfoundland and Labrador Department of Natural Resources completed a 1:100 000-scale mapping survey of the region that resulted in several published reports and articles (Bailey, 1981; Gower *et al.*, 1982; Gower and Ryan, 1987). The Aillik Group in the Big Island–Rangers Bight area was the focus of a detailed study (Sinclair, 1999; Sinclair *et al.*, 2002). The timing and geochemistry of the Paleoproterozoic intrusive suites have also been the focus of several studies (Kerr, 1989, 1994; Kerr *et al.*, 1992). Other research has focused on the structural evolution of the Aillik Group (Clark, 1979), and on the timing and tectonic evolution of the Makkovik Province (Ketchum *et al.*, 1997, 2001, 2002; Culshaw *et al.*, 2000). The mafic dykes that occur throughout the area have also been examined (King, 1963; King and MacMillan, 1975; Malpas *et al.*, 1986; Tappe *et al.*, 2006). The major findings of these relevant studies are summarized below.

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 Mesoproterozoic Grenville Province (Figure 2). The province is divided into 3 domains (from northwest to southeast), namely, the Kaipokok, the Aillik and the Cape Harrison domains (Kerr *et al.*, 1996). The Kaipokok domain consists of

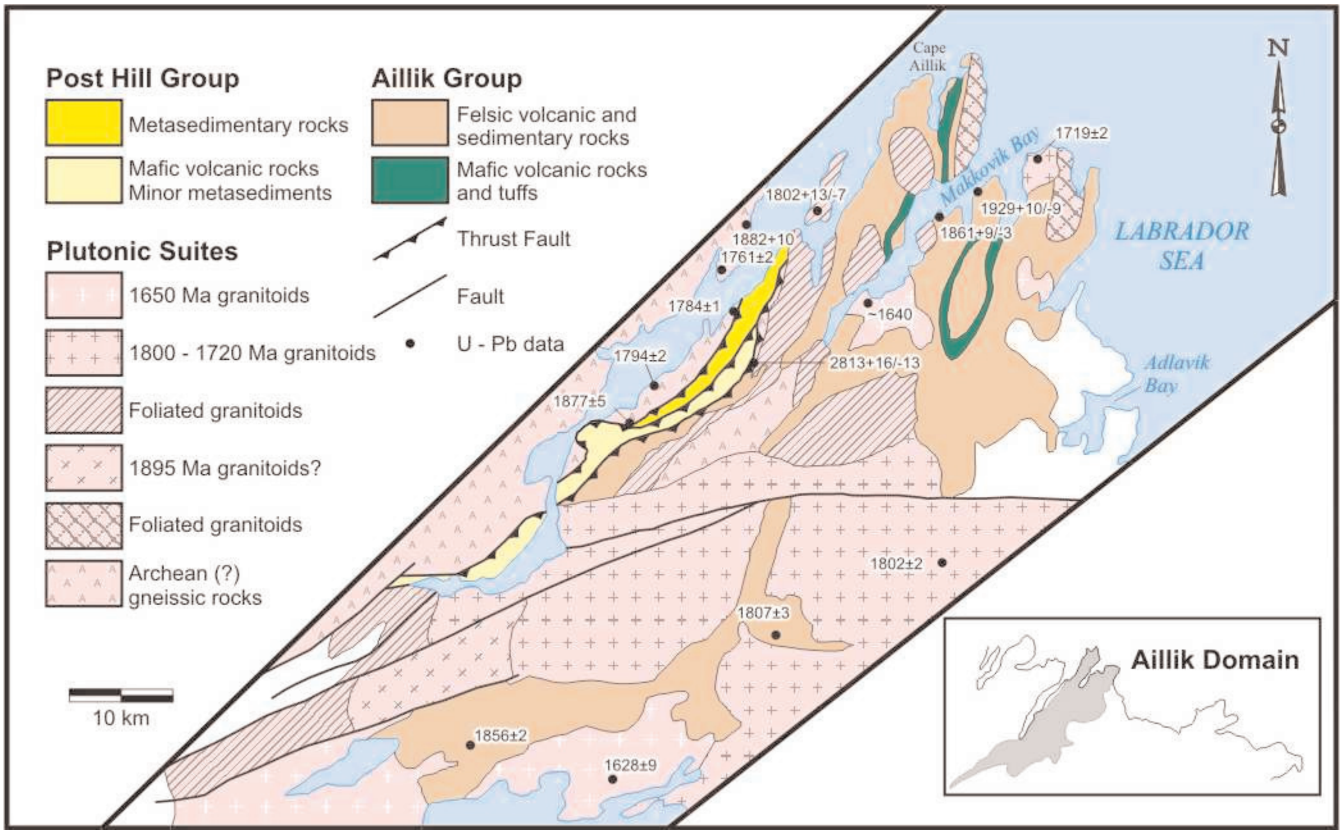


Figure 3. *A simplified geological map of the Aillik domain, Makkovik Province (modified after Kerr, 1996). Locations of U–Pb zircon dates are plotted; data is from Schärer* et al. *(1988); Kerr* et al. *(1992), Ketchum* et al. *(1997, 2002) and Sinclair* et al. *(2002).*

reworked Archean gneiss of the Nain Province, the overlying Paleoproterozoic metavolcanic and metasedimentary supracrustal sequence of the Moran Lake and the Post Hill groups, and Paleoproterozoic granitoid intrusions (Kerr *et al.*, 1996; Ketchum *et al.,* 2001); it is interpreted as 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 comprise the Kaipokok Bay shear zone (*cf.,* Kaipokok Bay structural zone of Kerr *et al.*, 1996; Ketchum *et al.*, 1997; Culshaw *et al.*, 2000). The Aillik domain is dominated by Paleoproterozoic metasedimentary and metavolcanic supracrustal sequences (Aillik Group) and by Paleoproterozoic intrusive suites (Kerr *et al.*, 1996). The Cape Harrison domain is dominated by the syn- and posttectonic Paleoproterozoic intrusive suites, a package of reworked orthogneiss (Cape Harrison Metamorphic Suite), and rare enclaves of supracrustal rocks (Gower and Ryan, 1986). The boundary between the Aillik domain and the Cape Harrison domain is obscured by the abundant plutonic intrusions and may be transitional at deeper crustal levels. The Aillik and Cape Harrison domains are interpreted as being part of composite arc/rifted-arc terrane that formed prior to, and after, the start of their accretion to the Nain cratonic margin (Ryan, 1984; Culshaw *et al.*, 1998; Kerr *et al.*, 1996). The accretion of this juvenile 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; Culshaw *et al.*, 2000). Syn- to post-orogenic granitic plutons occur throughout the Makkovik Province.

The Aillik domain comprises largely the Paleoproterozoic Aillik Group, a supracrustal assemblage consisting of metavolcanic and metasedimentary rocks (Figure 3) that is intruded by granitoid plutons, ranging in age from ca. 1800 to 1630 Ma (Kerr, 1994). The Aillik Group structurally overlies the Paleoproterozoic Post Hill Group, a highly strained, amphibolite-facies, supracrustal sequence, which, in turn, structurally overlies Archean gneiss that forms the basement to the lowest members of the Post Hill Group (Culshaw *et al.*, 1998, 2000; Ketchum *et al.*, 2001).

The Post Hill Group is composed of deformed and metamorphosed siliciclastic and mafic volcanic rocks (Marten, 1977; Gower *et al.*, 1982). Two of the lower quartzite units contain only Archean detrital zircons and are interpreted as being deposited on the Nain craton after the 2235 Ma rifting and initiation of a passive margin (Ketchum *et al.*, 2001). The overlying mafic volcanic rocks, termed the Post Hill amphibolite, contain thin horizons of intermediate tuff, one of which has a U–Pb zircon date of at 2178 ± 4 Ma (Ketchum *et al.,* 2001). A stratigraphically higher package of psammitic and semipelitic metasedimentary rocks were deposited after 2013 Ma, based on the youngest detrital zircon age (Ketchum *et al.*, 2001). This range in age indicates that deposition of the Post Hill Group occurred over a >165 m.y. period, prior to the onset of the Makkovikian orogeny.

Historically, the Aillik Group has been divided into two sequences: a lower (earlier) sequence of dominantly sandstone, siltstone, conglomerate, tuffaceous sandstone, and minor felsic volcanic rocks; and, a higher (later) sequence of dominantly felsic tuff, flow-banded rhyolite, volcanic breccia, lapilli tuff, syn-volcanic porphyritic granite and minor volcaniclastic sedimentary rocks (Gower and Ryan, 1987, and references therein). The early part of the sequence was separated from the later sequence by a mafic volcanic unit/tuffaceous unit (Gower and Ryan, 1987). In light of recent mapping as part of this project, it is apparent that the interpretation of the stratigraphy of the Aillik Group is complicated by the fact that lithological units are not laterally continuous and the structure is locally complex resulting in repetition of the stratigraphy (Figure 4). Based on these stratigraphic complexities and field observations, it is unlikely that the Aillik Group can be so easily divisible into an early and late sequence.

U–Pb zircon ages for felsic volcanic units within the Aillik Group include an age of 1856 ± 2 Ma from an ash-flow tuff at Michelin Ridge, an age of 1861 +9/-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). The significance of the ca. 1807 Ma age has been questioned because this younger 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, it is likely that the dated porphyry is related to the younger magmatic event (Sinclair *et al.*, 2002). Sinclair *et al.* (2002) report a U–Pb zircon age of 1929 +10/-9 Ma for the Measles Point Granite a deformed porphyritic granite along the southeast coast of Makkovik Bay (Figure 3); however, the significance of this age is unclear because the Measles Point Granite is interpreted as a sill-like, hypabyssal, foliated granite that is lithogeochemically similar, and spatially associated, with the felsic volcanic rocks of the Aillik Group reported to be approximately 70 Ma younger. The completion of additional geochronological work, as part of this project, should resolve this issue.

The Aillik domain is intruded by several Paleoproterozoic magmatic suites that are largely divisible into three broad groupings with ages of ca. 1800 Ma, ca. 1720 Ma and ca. 1650 Ma (Kerr *et al.*, 1992; Kerr, 1994). The dominantly foliated, ca. 1800 Ma intrusions are called the syntectonic Makkovikian plutonic rocks because the plutons are interpreted as being concomitant with the Makkovikian orogeny, which deformed the host rocks (Gower and Ryan, 1986). The non-foliated, ca. 1720 Ma intrusions are called the posttectonic Makkovikian plutonic rocks; whereas, the non-foliated ca. 1650 Ma intrusions are called the Labradorian plutonic rocks because they broadly correspond in age with the Labradorian orogeny of the Grenville Province (Kerr *et al.*, 1992).

The principal structural elements in the Aillik Group are large, upward-facing, gently plunging folds with axial-planar fabrics, concomitant with upper-greenschist to lower-amphibolite metamorphism (Clark, 1979; Gower *et al.*, 1982). In addition, a <1-km-thick, steeply southeast-dipping structure, the Big Island shear zone (Ketchum *et al.*, 2002; cf., the Ranger Bight slide of Clark, 1979; the "straight zone" of Culshaw *et al.*, 2000) extends from south of Cape Makkovik through to Big Island. These elements are interpreted as a regional D_3 event and to have resulted from sinistral transpression during the westward thrusting of the Aillik Group. The Big Island shear zone is interpreted to separate a region of northwest-verging folds and thrusts in the Aillik Bay area, to the northwest, and contemporaneous upright folds to the southeast (Culshaw *et al.*, 2000). Following amphibolite-facies sinistral transpression, this shear zone is interpreted as being reactivated with a subsequent greenschist-facies, sinistral transpression (Ketchum *et al.*, 2002). The timing of thrusting and strike-slip deformation in the area is poorly constrained. D_3 deformation postdates ca. 1860 Ma, the upper age constraint on the Aillik Group, and predates ca. 1802 Ma, the age of foliated Long Island Quartz Monzonite that cuts the Aillik Group. This deformation event is unique to the Aillik Group and may reflect the northwestward transport of the Aillik Group. This interpretation is supported by the absence of a distinctive suite of abundant metadiabase dykes from the underlying Archean rocks (Culshaw *et al.*, 2000).

GEOLOGY OF THE MAKKOVIK AREA

ARCHEAN ORTHOGNEISS

(Units 1 and 2)

Within the map area, there are two units that are interpreted as reworked Archean gneisses. The units are restricted in aerial extent and occur on the eastern coast of

Kaipokok Bay (Figure 4). The units are, a) a locally migmatitic, grey, quartzofeldspathic orthogneiss (Unit 1), and b) an augen granodioritic orthogneiss (Unit 2).

The quartzofeldspathic orthogneiss is highly strained, strongly foliated, and locally migmatized (Plate 1a); compositional bands within the gneiss are 1 to 5 cm thick. This unit typically contains ca. 5 cm wide amphibole-rich layers, and quartz-rich pods. Within the migmatitic layers, the leucosome can constitute up to 25 percent of the rock unit. This unit contains folded, boudinaged amphibolite dykes that are typically 30 to 50 cm wide. The quartz-feldspar orthogneiss occurs in a thin belt (~300 m wide), separating the Long Island Quartz Monzonite from the Post Hill Group.

The augen granodioritic orthogneiss is a strongly foliated, locally lineated, fine- to medium-grained, locally migmatitic gneiss (Plate 1b). The augen are potassium feldspar, define the lineation and range from 1 to 5 cm in length. In locally migmatitic layers, centimetre-wide leucosomes can be up to 5 percent of the outcrop and the leucosome both parallels and crosscuts the foliation. The augen granodiorite intrudes the banded quartzofeldspathic orthogneiss and both units are cut by aplite, diabase and net-veined gabbro dykes.

POST HILL GROUP

Units 3 and 4

In the map area, the Post Hill Group is preserved within the locally mylonitic, Kaipokok Bay shear zone that delineates the contact between the Aillik domain to the southeast and the Kaipokok domain to the northwest. The nature of this contact between the Post Hill Group of the Kaipokok domain and Aillik Group of the Aillik domain is obscured in the map area by the Long Island Quartz Monzonite intrusion. In the map area, the Post Hill Group has limited exposure and is restricted to the southwest corner of the map area. Units of the Post Hill Group preserved in the area include a strongly banded, psammitic to pelitic schist (Unit 3) and highly strained fine-grained amphibolite (Unit 4).

The strongly banded, psammitic to pelitic schist is foliated, compositionally layered, locally crenulated and highly deformed (Plate 2a). The protolith of this unit is interpreted as thin-bedded sandstone and siltstone that were folded and metamorphosed in the amphibolite facies to psammitic and garnet–sillimanite–biotite–muscovite schist; extensive 5- to 10-cm-wide, granitic leucosome form up to 5 percent of the unit. Deformation within the unit ranges from protomylonitic, in zones of higher strain proximal to shear zones, to large open (F_2 or later) folds in areas of lower strain.

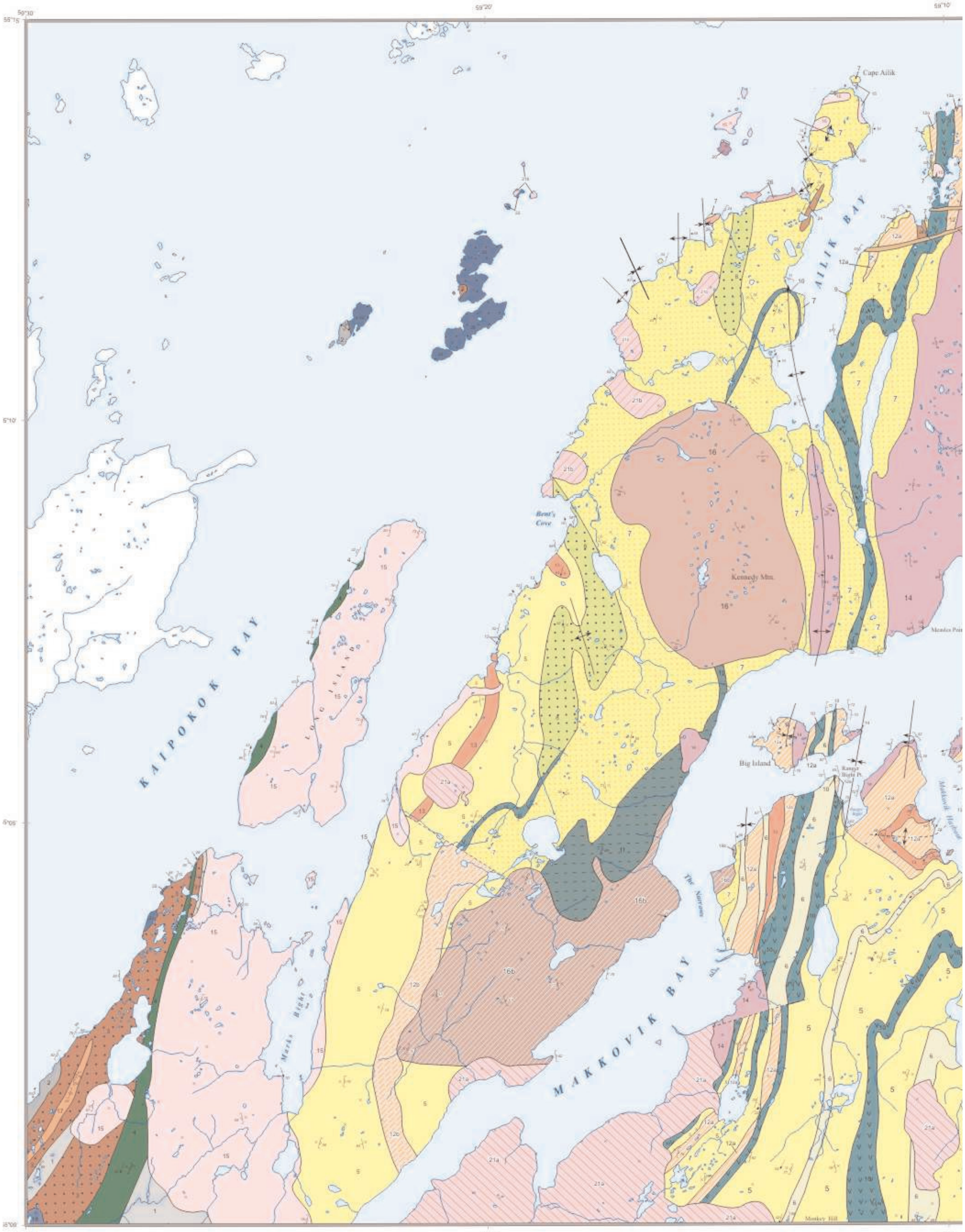
The amphibolite unit is foliated, cleaved, flattened, recrystallized and locally the foliation is boudinaged (Plate 2b). This unit is interpreted to represent a highly deformed mafic metavolcanic unit that is interlayered with psammitic to pelitic schist at the metre scale. The fine-grained amphibolite is altered to epidote, locally boudinaged and contains flattened to boudinaged epidote–quartz–feldspar pods ranging from 2 to 25 cm in width. Rusty-weathering, pyrite-rich horizons occur throughout the unit.

AILLIK GROUP

The Aillik Group comprises upper-greenschist to lower-amphibolite facies, felsic tuff, flow-banded to non-banded rhyolite, quartz–feldspar–porphyritic granite, volcaniclastic breccia and conglomerate, tuffaceous sandstone, thin-bedded to laminated metasandstone–siltstone, and lesser components of metabasalt containing locally preserved pillow selvages and mafic tuff (Figure 4). The degree of deformation and grade of metamorphism are variable throughout the map area. For instance, south of Cape Aillik, the area comprises a dominantly metasedimentary package of thin-bedded sandstone and lesser conglomerate, marble and rhyolite that has been metamorphosed in the upper-greenschist facies. This dominantly metasedimentary package commonly displays primary sedimentary features such as ripple marks and crossbedding. In contrast, in the Rangers Bight area, the area comprises dominantly a metavolcanic package of dominated by felsic tuff, basalt, rhyolite and lesser interbedded conglomerate and sandstones. This package of rocks has been metamorphosed in the amphibolite facies, is highly strained and primary sedimentary structures have been almost entirely eradicated.

Tuffaceous Sandstone (Unit 5)

Tuffite (dominantly tuffaceous sandstone) occurs throughout the map area but is mainly found in the area between Makkovik Harbour and Round Pond (Unit 5). Unit 5 is a dominantly non- to weakly-bedded sequence of tuffaceous to volcaniclastic sandstone and includes minor metre-scale rhyolite flows, all of which have been metamorphosed in the upper-greenschist to lower-amphibolite facies. The tuffaceous sandstone is fine grained, light to pinkish grey, moderately to strongly foliated, recrystallized, sugary textured and is often silicified; this alteration being associated with rusty horizons rich in sulphides. In areas where the bedding is preserved, it is generally thin (2 to10 cm thick), and is locally interbedded with minor arenaceous sandstone. Locally, there are metre-scale horizons that are rich in lithic and crystal fragments, 1 to 2 cm long. Disseminated magnetite and biotite occur throughout this unit.


Cape Aillik
AILLIK BAY
KAIPOKOK BAY
LONG ISLAND
Bent's Cove
Kennedy Mtn.
Big Island
The Narrows
MAKKOVIK BAY
Marks Bight
Monkey Hill

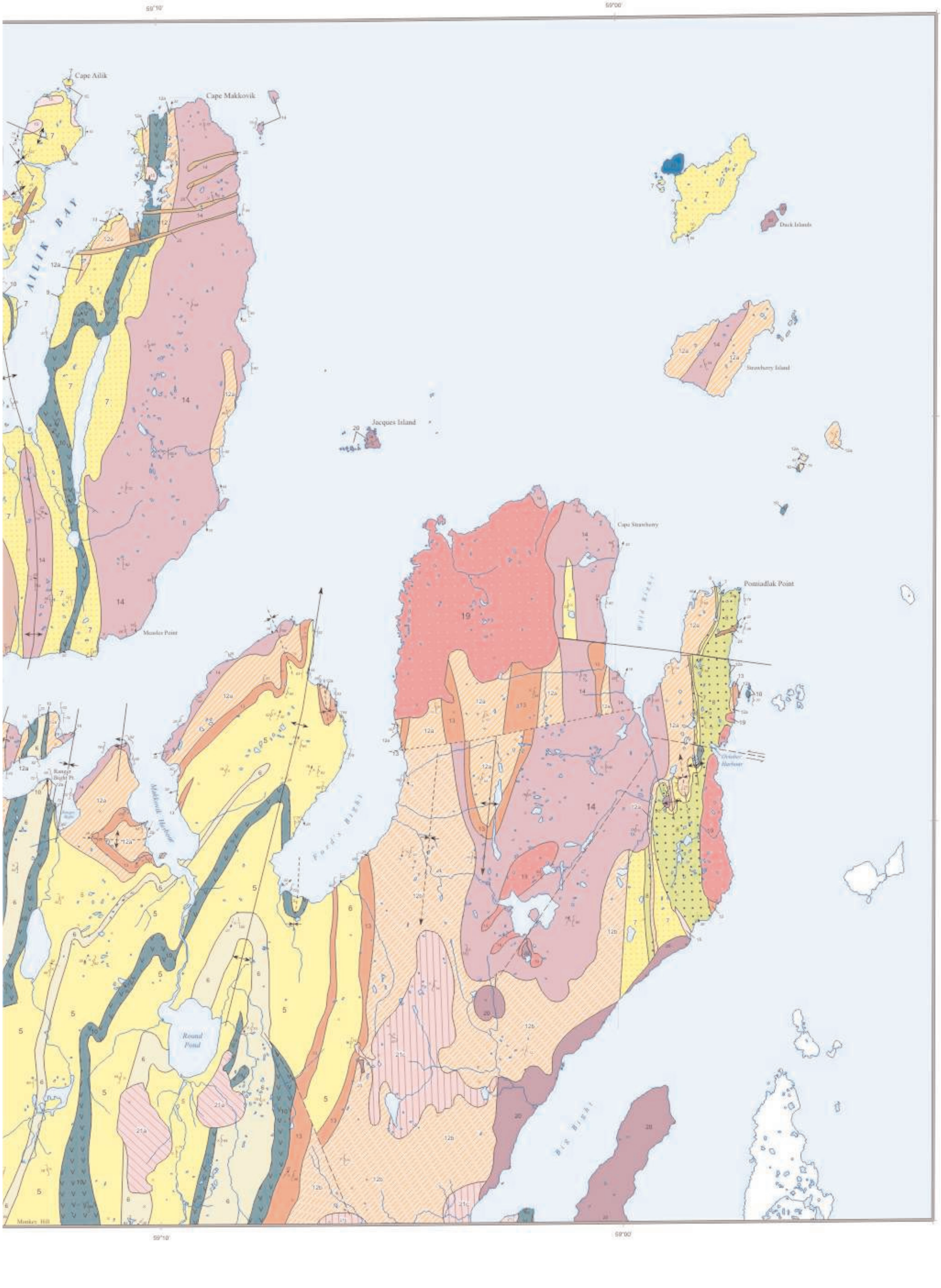


Figure 4. *A preliminary geological map of the Makkovik area (NTS 13O/03).*

Figure 4. *Legend for map on pages 30 and 31.*

Plate 1. *Representative photographs of the Archean orthogneiss in the Makkovik area; A) compositionally banded, quartzofeldspathic orthogneiss contains amphibolite layers, quartz-rich pods and abundant leucosome (Unit 1); B) strongly foliated, augen granodioritic orthogneiss (Unit 2).*

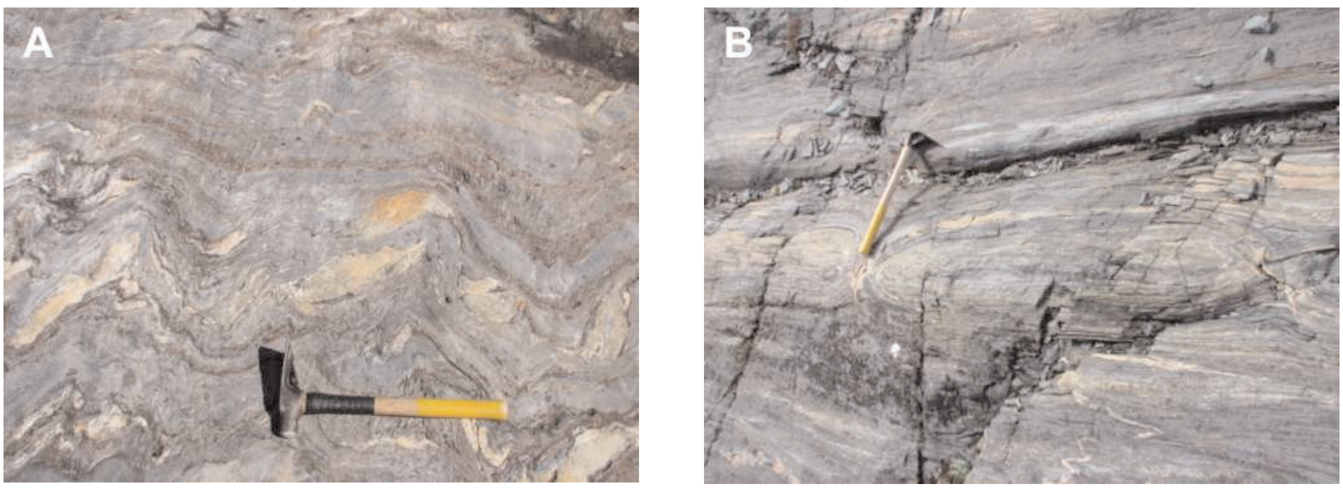


Plate 2. *Representative photographs of the Post Hill Group in the Makkovik area; A) folded, compositionally banded, psammitic and pelitic schist containing disseminated leucosome (Unit 3); B) boudinaged, foliated and recrystallized amphibolite interlayered with quartz-rich horizons (Unit 4).*

Conglomerate (Units 6, 8 and 9)

In the map area, the conglomeratic rocks are divided into three units (Units 6, 8 and 9). Unit 6 is a conglomerate to tuffaceous conglomerate that is interbedded with 2- to 10-m-thick beds of tuffaceous sandstone (Plate 3a). The clasts within the conglomerate are poorly sorted, subrounded, flattened and range from 1 to 15 cm in diameter. The clasts are dominantly tuffaceous sandstone and include minor metasandstone, non-foliated granite, amphibolite, rhyolite, marble and mafic tuff. This unit is matrix dominated and the matrix has a composition similar to felsic tuff. The association of the conglomerate with the tuffaceous sandstone indicates that the conglomerate may be a stratigraphic equivalent of the tuffaceous sandstone (Unit 5). The foliation in the unit is variably intense, and, in the Big Island–Ranger Bight area, the rocks are strongly deformed and the foliation is defined by the alignment of clasts and of biotite in the matrix.

Unit 8 is a light- to medium-grey, foliated, matrix-supported, polymictic conglomerate. The clasts are poorly sorted, subrounded to rounded, and typically range from 2 to 20 cm in long diameter, but locally are up to 45 cm in diameter, and rarely, as at Pomiadluk Point, some approach 75 cm. Clasts are dominantly pink to grey sandstone, foliated and non-foliated granite, felsic tuff, and minor rhyolite, plagioclase–porphyritic amphibolite, mafic tuff, and marble (Plate 3b). The granitic clasts tend to be rounded, whereas the sedimentary clasts tend to be subrounded. The matrix varies from fine to coarse grained and is dominantly sandstone, although, there are thin, typically 5- to10-cm-thick beds that

Plate 3. *Representative photographs of certain rock types in the Aillik Group; A) interbedded tuffaceous conglomerate to volcaniclastic breccia and laminated tuffaceous sandstone (Unit 6); B) polymictic conglomerate with subrounded clasts of foliated granite, sandstone, felsic and mafic tuff (Unit 8); C) crossbedding preserved in the thin-bedded metasandstone and metasiltstone (Unit 7); D) coarse-grained, orange-white calcite nodule intergrown with titanite, garnet and diopside hosted in the altered felsic tuff (Unit 12a); fine-grained, chlorite facies, pillowed metabasalt (Unit 11); pillows are 30 to 50 cm wide; F) centimetre-scale compositional banding in a fine-grained felsic tuff (Unit 12a).*

contain a calcite-rich matrix that is partially dissolved. Locally, beds display a diffuse, normal grading that is generally preserved near the tops of the unit. In addition, millimetre-scale reaction rims surrounding the clasts occur rarely; locally, this unit grades into a volcaniclastic conglomerate.

Unit 8 is variably strained, with attenuated clasts and matrix minerals defining the foliation and lineation. In the Bent's Cove area, this conglomerate is preserved in the steep limb of an overturned syncline and structurally overlies the thinly bedded metasandstone (Unit 7) and underlies the tuffaceous sandstone (Unit 6). At Pomiadluk Point, there are two conglomerate horizons with one overlain by a felsic tuff (Unit 12a) and underlain by tuffaceous sandstone (Unit 6). The second conglomerate is overlain by the same tuffaceous sandstone and underlain by metabasalt (Unit 10) indicating that Unit 8 comprises more than one conglomerate horizon.

Unit 9 is another conglomeratic sequence. At the current scale of mapping, Unit 9 can only be shown as a separate unit along the eastern coast of Aillik Bay. It is a matrix-supported, dominantly monolithic conglomerate to volcanic breccia. Clasts are angular to subrounded, ranging from 2 to 20 cm in diameter, but locally they are up to 60 cm in length. The clasts are mainly (95 percent) light-grey sandstone and the remainder of the clasts are amphibolite, rhyolite, felsic tuff and foliated granite. The matrix is sandstone to tuffaceous sandstone and locally is calcareous and partially dissolved. Where a contact is exposed, this unit is structurally overlain by the thin-bedded metasandstone (Unit 7).

Metasandstone–Metasiltstone (Unit 7)

Unit 7 comprises a thin-bedded to laminated, grey, green and pink, metamorphosed, arenaceous sandstone interbedded with lesser siltstone. The sandstone beds are 2 to 10 cm thick, fine to medium grained, typically thin bedded, recrystallized, dominantly quartz arenite and lesser lithic arenite. The interbedded siltstones are dark brown to dark grey, fine to medium grained, and composed of biotite, muscovite, quartz and feldspar. Unit 7 commonly preserves primary crossbedding, ripple marks and mudcracks, making this unit a good source for way-up indicators (Plate 3c); rarely, load casts and graded bedding are also found. The foliation in this unit is bedding parallel and is largely defined by the alignment of biotite and muscovite. Along the coastline east of Kaipokok Bay, the thin-bedded sandstone–siltstone unit is underlain by the polymictic conglomerate (Unit 8), although the contact is locally gradational and/or interfingered, and rhyolite structurally overlies the sandstone–siltstone unit.

Variations within Unit 7 include beds that are calc-silicate-rich, and marble horizons. The calc-silicate beds are typically less than 10 cm thick, grey-green and rarely orange, planar bedded, and composed of carbonate, muscovite, biotite, quartz and feldspar. Some beds of marble also occur with the unit; these marble beds are up to 10 m thick but typically are interbedded with 5- to 10-cm-thick beds of sandstone. The marble beds accommodate internal strain, and often preserve isoclinal folding. Nodules of orange calcite, titanite and epidote, which occur locally in Unit 7, most notably along the east side of Kaipokok Bay (Plate 3d), are elongate, 5 to 10 cm in diameter, and form up to 3 percent of the exposed rock.

Metabasalt (Units 10 and 11)

Metabasalt occurs as thin belts throughout the map area. Two units are distinguished, 1) a fine- to medium-grained, strongly deformed, dominant metabasalt (amphibolite) unit containing minor mafic tuff (Unit 10), and 2) a less abundant, moderately deformed, pillowed metabasalt (Unit 11).

In outcrop, the metabasalt of Unit 10 is foliated to highly strained, fine to medium grained, typically of amphibolite grade and contains a well-developed tectonic fabric defined by the alignment of amphibole and biotite. Locally, this unit displays epidote alteration, schistosity, relict vesicular texture and minor quartz–chlorite–epidote veining that may mark relict pillow selvages. Some horizons contain flattened nodules, 2 to 10 cm in length, containing aggregates of calcite, feldspar and epidote. Disseminated pyrite occurs throughout this unit and sulphide-mineralized nodules occur in the metabasalt to the east of Pomiadluk Point. Unit 10 also contains mafic tuff horizons that are medium to light grey, occur as discontinuous horizons that vary from 2 to 15 m in thickness. The mafic tuff locally contains 1- to 4-cm-long aligned biotite and/or hornblende that define the foliation. Thin, 2- to 5-m-wide outliers of mafic tuff, east of Ford's Bight, are cut by mineralized, 5- to 20-cm-wide quartz veins that contain chalcopyrite, molybdenite and pyrite.

Pillowed metabasalt (Unit 11) occurs to the southwest of the Kennedy Mountain Intrusive Suite. This unit is dark grey to greenish black, fine grained, preserves upper chlorite to lower amphibolite-facies metamorphism, contains a weakly developed foliation and is locally schistose. Relict pillows are preserved within this unit, and in areas of low strain, they are only weakly deformed (Plate 3e), with long axes varying in length from 15 to 50 cm. In well-exposed areas, thick homogenous layers of basalt are up to 20 m thick and likely reflect primary basaltic flows. The pillows

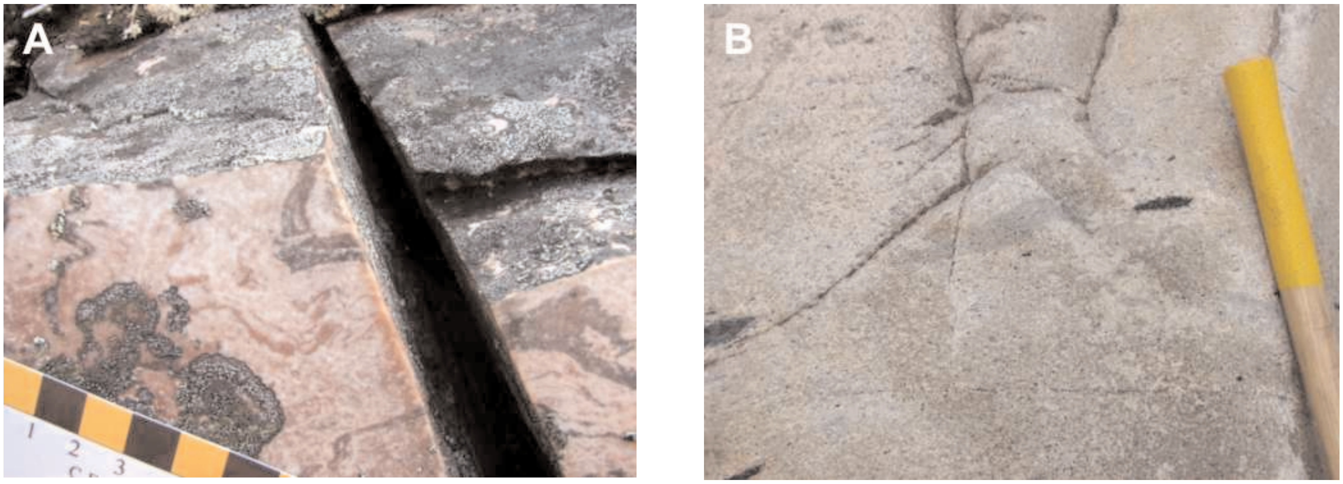


Plate 4. *Representative photographs of; A) fine-grained, recrystallized, pink, flow-banded rhyolite of the Aillik Group (Unit 13); B) quartz-porphyritic granite containing flattened cigar-shaped fragments of mafic pods of biotite, magnetite and amphibole (Unit 14).*

are cut by thin (millimetre-scale) calcite–quartz–epidote veins.

The preservation of pillows and vesicular textures in both the metabasalt and mafic tuff supports previous interpretations (Gower *et al.*, 1982) that the Aillik Group was deposited in both subaqueous to subaerial environments. Although, the mafic volcanic rocks form a viable marker horizon, their location within the stratigraphic column is complex and varies from location to location. In the highly strained Big Island and Rangers Bight areas, the metabasalt is typically overlain by felsic tuff (Unit 12a) and underlain by polymictic conglomerate. In contrast, around Aillik Bay, this unit occurs within the thin-bedded quartz arenite (Unit 7) and, near Pomiadluk Point, the metabasalt is underlain by felsic tuff (Unit 12a). The metabasalt and associated mafic tuff occur east of Round Pond where they are underlain by polymictic conglomerate and overlain by rhyolite. The pillow basalt, south of the Kennedy Mountain intrusion, underlies the thin-bedded quartz arenite (Unit 7). These relationships highlight the complex and variable stratigraphy within the Aillik Group and suggest that the previous interpretations of a division between the early and late sequences may be too simplistic.

Felsic Tuff (Units 12a and b)

In the map area, the felsic tuffs are divided into two units, a lithologically dominant, banded felsic tuff with minor lapilli tuff, tuffaceous sandstone and rhyolite (Unit 12a), and a less abundant, highly altered unit of apparent felsic tuff, containing minor apparent lapilli tuff and tuff breccia (Unit 12b). The banded felsic tuff (Unit 12a) includes both crystal and lithic varieties. This unit is pinkish-grey to white in outcrop, foliated, compositionally banded, locally displays graded bedding and has a fine- to medium-grained matrix (Plate 3f). The lithic tuffs contain clasts of cognate material that typically range from 1 mm to 5 cm in length and are attenuated, defining a lineation. The crystal tuffs have a fine- to coarse-grained matrix, within which rare phenoclasts of quartz and feldspars are preserved and disseminated garnet, biotite, pyrite and magnetite occur throughout. This unit occurs at different stratigraphic levels throughout the map area. In the Big Island to Ranger Bight area, it structurally overlies a metabasalt unit, and underlies porphyritic granite. At Ford's Bight, felsic tuff overlies porphyritic granite and underlies rhyolite, exhibiting the lateral variability of the felsic volcanic units within the map area.

The highly altered felsic tuff (Unit 12b) occurs mainly in the area between the eastern edge of Ford's Bight and the western edge of Big Bight. The tuff is cream to light grey, fine grained, foliated, and recrystallized. The alteration is predominately a pervasive feldspar alteration that has obliterated the primary textures, making the classification of the protolith difficult. This unit is characterized by weak compositional banding, strong axial-planar foliation, its fine grain size, the locally preserved quartz or feldspar phenoclasts and isolated rusty horizons rich in disseminated sulphides.

Rhyolite (Unit 13)

Unit 13 is a porphyritic to equigranular rhyolite that occurs throughout the map area where it is commonly associated with felsic tuff. The rhyolite is pinkish to medium grey to cream, recrystallized, massive, and fine to medium grained. The rhyolite occurs as flows that are 5 to 10 m thick, and locally preserve flow bands (Plate 4a) that are generally discontinuous, 1 to 2 mm thick and 5 to 20 cm long, and are resistant to weathering and are darker, reflecting a concentration of magnetite and biotite. Autobrecciation is locally preserved at the base of some of the rhyolite flows. Porphyritic rhyolite often occurs as horizons within non-porphyritic rhyolite, although it is also found as isolated flows. The phenocrysts are feldspar and/or quartz, are typically 5 to 15 percent of the rock, and range in size from 1 to 5 mm. This unit is commonly cut by centimetre-wide mineralized quartz veins.

Depositional Environment of the Aillik Group

Previous work has suggested that the Aillik Group depositional environment is a transition from a shallow-marine environment, represented by bedded sandstone–siltstone and conglomerate units, to a marginal marine or subaqueous environment represented by felsic tuffs and epiclastic sediments composed of reworked felsic volcanic material (Gower *et al.*, 1982). This interpretation is supported by data from the current field observations, which include: a) preservation of abundant ripple marks, crossbedding and mudcracks within the thin-bedded sandstone–siltstone units; b) preservation of pillow basalt and of vesicular textures in both the metabasalt and mafic tuff; c) the presence of polymictic conglomerate; and d) the abundant reworked felsic volcanic material within the sedimentary sequences.

Preliminary Interpretation of the Structural Evolution of the Aillik Group

Regional mapping has illustrated that the deformation in the Aillik Group is more complex than previously interpreted (Gower *et al.*, 1982) and that much of the Aillik Group is folded by regional-scale, closed to tight, moderately plunging, generally north-northeast striking open to overturned folds that were subsequently refolded. This fold pattern is highlighted in the higher strained area from Makkovik Harbour to Ford's Bight, where initial structural interpretation suggests that the area is dominated by northeast-verging, and moderately plunging, tightly refolded, regional-scale isoclinal folds. There is some variability in the fold style throughout the map area. In the lower strained area from Aillik Bay to Kaipokok Bay, the fold style is dominated by open to closed, upright folds. Fold interference patterns occur at the map scale (Figure 4), highlighting the multiple generations of folding. Based on fold interference patterns, the Aillik Group has been deformed by at least three phases of folding.

INTRUSIVE ROCKS
PRE-MAKKOVIKIAN PLUTONIC ROCKS

Porphyritic Granite (Unit 14)

Foliated, porphyritic granite (Unit 14) occur throughout the map area. This unit is a pinkish to medium grey, variably foliated, locally lineated, recrystallized, fine- to medium-grained, porphyritic granite (Plate 4b). The quartz and feldspar phenocrysts are typically 1 to 5 mm in length and euhedral to subhedral. Ellipsoidal mafic pods of biotite, magnetite and amphibole occur throughout the granite and are typically 2 to 8 cm long, 1 to 4 cm wide, and account for less than 2 percent of the rock; accessory magnetite and biotite are common. Locally, the porphyritic granite contains altered feldspar and rusty, discontinuous sulphide horizons that are rich in pyrite. The foliation is variably developed in the porphyritic granite, is parallel to the regional foliation, and is defined by the alignment of biotite, phenocrysts and the mafic pods.

The granite is preserved in regional-scale synclines and anticlines, suggesting that it occurs as sheets or sill-like bodies within the felsic volcanic sequences. Near the margins of the granite, rare xenoliths of strongly foliated metabasalt and felsic tuff are preserved and are interpreted to be derived from the Aillik Group. Based on these field relationships, this unit is inferred to have been emplaced as a high-level granite intrusion; however, the contacts with the Aillik Group are highly deformed and sheared, often paralleling the regional foliation and intrusive contacts are rarely preserved. This interpretation is compatible with the observations of Sinclair *et al.* (2002), who noted that, the similar major- and trace-element chemistry and similar structural history of the Measles Point Granite and the felsic volcanic rocks of the Aillik Group, coupled with the granite's fine grain size and emplacement as sill-like bodies, are consistent with the granite originating as a hypabyssal intrusion. These observations are in conflict with the U–Pb zircon age of 1929 +10/-9 Ma for the Measles Point Granite (Sinclair *et al.*, 2002), which is included within this unit. The ~70 m.y. age difference between the dated porphyritic granite and the younger, ca. 1861 Ma rhyolite of the Aillik Group, does not support a co-magmatic relationship. This seemingly contradictory data can be explained several ways; however, without further data, discriminating between these hypotheses is not possible. First, the U–Pb zircon date of ca. 1929 Ma is an intercept age with the least discordant fraction having 10% discordance, and therefore this date is not very robust.

It is possible that the zircon may be inherited, or a product of mixing of different zircon ages producing an erroneous date. Second, there may be several generations of deformed, porphyritic granite; the Measles Point Granite dated by Sinclair *et al.* (2002) may be basement to the Aillik Group, but may not be coeval with other porphyritic granites in the area, that preserve xenoliths of the Aillik Group. Third, the age of ca. 1861 Ma (*see* above) may not reflect the timing of the deposition of the entire Aillik Group. This age was derived from seven zircon fractions from a rhyolite, which has been interpreted as a flow, that yielded 1 to 2% discordant dates that all fell within the +9 Ma error of this date (Schärer *et al.*, 1988), making it a reasonable maximum age of crystallization for this rhyolite. It is possible, although unlikely, based on field observations and geochemistry, that the Aillik Group is diachronous, representing an older (ca. 1930 Ma) and a younger (ca. 1860 Ma) sequence. To resolve the interpretation of the age date from the foliated porphyritic granite and its relationship to the Aillik Group, additional geochronological studies are required, and this will be undertaken as part of this project.

SYNTECTONIC MAKKOVIKIAN PLUTONIC ROCKS, ca. 1840-1800 Ma

Units 15 to 17

In the map area, syntectonic Makkovikian plutons that intruded the Aillik Group consist primarily of the Long Island Quartz Monzonite (Unit 15) and the Kennedy Mountain Intrusive Suite (Unit 16). Biotite-muscovite leucogranites (Unit 17) also occur as syn-tectonic plutonic rocks; however, their map distribution is very minor and limited to the extreme southeast corner of the map sheet. As such they do not warrant a detailed description for the purposes of this manuscript. All of the geochronological constraints for the magmatic suites in the map area are from Kerr *et al.* (1992).

The Long Island Quartz Monzonite (Unit 15) occurs in the area surrounding and to the south of Marks Bight, and on Long Island. The definition and regional extent of the unit remain largely unchanged from those of Gower *et al.* (1982) and Kerr (1994). The Long Island Quartz Monzonite is weakly to moderately foliated, locally plagioclase–porphyritic, leucocratic to melanocratic, and varies in composition from granodiorite, monzodiorite to quartz monzonite. Unit 15 is medium grained, containing plagioclase phenocrysts that are typically 1 to 5 mm in length. Accessory biotite, hornblende and magnetite occur throughout the suite. The variably developed foliation is defined by alignment of biotite and hornblende with the strongest foliation occurring along the margins of the intrusion. Flattened mafic enclaves occur locally within the unit. These enclaves are typically 2 to 30 cm wide and 3 to 40 cm long, can vary in abundance by up to 10 percent of the exposure, and contain quartz, feldspar, biotite and magnetite (Plate 5a). A U–Pb zircon age of 1802 +13/-7 Ma was reported for the Long Island Quartz Monzonite (Kerr *et al.*, 1992).

The Kennedy Mountain Intrusive Suite (Unit 16) occurs as stocks and sheets between Kaipokok Bay and Makkovik Bay. There are two main divisions of the unit, *viz.*, a pluton (Unit 16a) surrounding "Kennedy Mountain", an informal name for the hill northwest of Makkovik Harbour and underlain by this granite, and several smaller intrusions, west of the narrows in Makkovik Bay (Unit 16b). The granite in the suite is coarse to medium grained, weakly to moderately foliated, and locally contains potassium feldspar augen, and varies in composition from monzogranite to quartz monzonite (Plate 5b). Accessory biotite and magnetite occur throughout the intrusions along with local occurrences of fluorite and pyrite. Along the margins of the intrusion, xenoliths of the country rock (Aillik Group) are found. The foliation is variably developed, being defined by the alignment of mafic minerals and feldspar augen, and is more pronounced along the margins of the intrusion. A U–Pb zircon age of 1800 ± 4 Ma for the granite at Kennedy Mountain was reported by Sinclair *et al.* (2002) from unpublished work of J.W.F. Ketchum.

POSTTECTONIC MAKKOVIKIAN PLUTONIC ROCKS, ca. 1800 to 1720 Ma

Units 18 and 19

Posttectonic Makkovikian intrusions that occur in the area are assigned mainly to the Strawberry Intrusive Suite (Unit 19), with a very minor occurrence of tremolite-actinolite gabbro (Unit 18). Due to the very limited exposure of unit 18, it will not be described in detail herein. Unit 19 occurs at Cape Strawberry, as well as on the west coast of October Harbour. The suite comprises coarse- to medium-grained, pink- to orange-weathering, porphyritic, biotite monzogranite to alkali-feldspar granite (Plate 9c). Phenocrysts of plagioclase and alkali feldspar are typically 1 to 3 cm long, forming up to 15 percent of the unit and are most abundant in the coarser grained granitoid rocks. Along the margins of the intrusions, the contact with host rocks varies from a sharp to more complex where xenoliths (1 to 2 m long) of felsic volcanic rocks of the Aillik Group, form approximately 5 percent of the rock. Accessory biotite and magnetite occur throughout the intrusion. A slightly discordant U–Pb zircon age of 1719 ± 3 Ma was calculated for a sample of this suite from Cape Strawberry (Kerr *et al.*, 1992).

Plate 5. *Representative photographs of the Paleoproterozoic suites in the Makkovik area; A) moderately foliated, biotite quartz monzonite of the Long Island Quartz Monzonite containing flattened mafic enclaves composed of quartz, feldspar, biotite and magnetite (Unit 15); B) moderately foliated, magnetite–biotite monzogranite of the Kennedy Mountain Intrusive Suite (Unit 16a); C) coarse-grained, undeformed plagioclase–porphyritic biotite–magnetite monzogranite of the Strawberry Intrusive Suite (Unit 19); D) fine-grained, undeformed, leucocratic, biotite monzogranite of the Monkey Hill Intrusive Suite (Unit 21).*

LABRADORIAN PLUTONIC ROCKS, ca. 1670 to 1630 Ma

Units 20 and 21

Labradorian-aged intrusions in the map area include the Monkey Hill Intrusive Suite (Unit 21) and the Adlavik Intrusive Suite (Unit 20). Minor intrusions of leucogabbro (Unit 22) and monzodiorite to ferrosyenite (Unit 23) also occur in the map area but are restricted in occurrence to scattered small islands, and therefore are not described in detail herein. The Monkey Hill Intrusive Suite occurs at Monkey Hill and to the west of Makkovik Bay. The suite is fine to medium grained, leucocratic, locally plagioclase porphyritic, and varies from biotite quartz monzonite, granodiorite to monzogranite (Plate 5d). Locally developed plagioclase phenocrysts are typically 1 to 2 cm long. Accessory biotite, hornblende, secondary chlorite and magnetite occur throughout the suite. The unit is relatively homogenous except near contacts that are often characterized by abundant xenoliths of country rock. This suite intrudes the Aillik Group and the foliated Kennedy Mountain Intrusive Suite. A discordant U–Pb zircon age of ca. 1641 Ma is interpreted as a lower age limit for the unit (Kerr *et al.*, 1992).

In the map area, the Adlavik Intrusive Suite (Unit 21) forms small satellite intrusions on islands, such as Jacques Island and Duck's Island, and along the coast and inland from Big Bight. The suite is undeformed, locally porphyritic, coarse- to medium-grained, and varies from leucogabbro, gabbro, and melanogabbro to rare monzodiorite. The main mineral phases within the suite are plagioclase, pyroxene

Plate 6. *Representative photographs of the various dykes and sills that have intruded the Aillik domain; A) feldspar-phyric amphibolite dykes; B) compositionally zoned, lamprophyre dyke that has intruded a foliated granodiorite of the Long Island Quartz Monzonite; C) an aplite dyke that has cut a fine-grained diabase dyke and an older, folded amphibolite dyke; the host rock is a felsic tuff; D) diatreme at Ford's Bight containing rounded to angular fragments of felsic tuff, sandstone, mafic tuff, metabasalt and gabbro in a brown matrix rich in iron minerals and carbonate.*

and biotite. The Adlavik Intrusive Suite has intruded the metavolcanic rocks of the Aillik Group and has been intruded by leucogranite veins that are correlated with the Monkey Hill Intrusive Suite (Kerr *et al.*, 1992). A sample of this suite, from outside the map area near Adlavik Bay, yielded a concordant U–Pb zircon age of 1649 ± 1 Ma (Kerr *et al.*, 1992).

DYKES AND SILLS

Granite pegmatite dykes (Unit 26) occur throughout the map area and are most abundant near the stocks and sheets of the major suites. Within the map area, syn- to post-deformational mafic dykes are abundant. There are at least two suites of metamorphosed, recrystallized, and folded and boudinaged, amphibolite dykes. One suite is characterized by recrystallized feldspar phenocrysts (Unit 24, Plate 6a), whereas the other suite is a fine-grained garnet amphibolite. These dykes range in width from 30 cm to greater than 12 m. Only rarely are the contact relationships of the deformed dykes preserved, with the porphyritic dykes crosscutting the finer grained amphibolite dykes.

Undeformed mafic dykes include, a) fine-grained, diabase dykes containing chilled margins, b) medium-grained, metre-wide lamprophyre dykes (Plate 6b), c) net-veined, medium-grained, gabbroic dykes, and, d) brown-weathering, plagioclase-megacrystic diabase dykes (Unit 25). The map area also contains fine-grained, 2- to 10-m-wide aplite dykes that are post-Makkovikian but predate most of the undeformed mafic dykes (Plate 6c). In addition, at Ford's Bight there are 0.5- to 2-m-wide breccia-filled, lamprophyre (diatreme) dykes (*cf.,* flat-lying breccia 'bed' of King and McMillan, 1975; Ford's Bight diatreme of Wilton *et al.*,

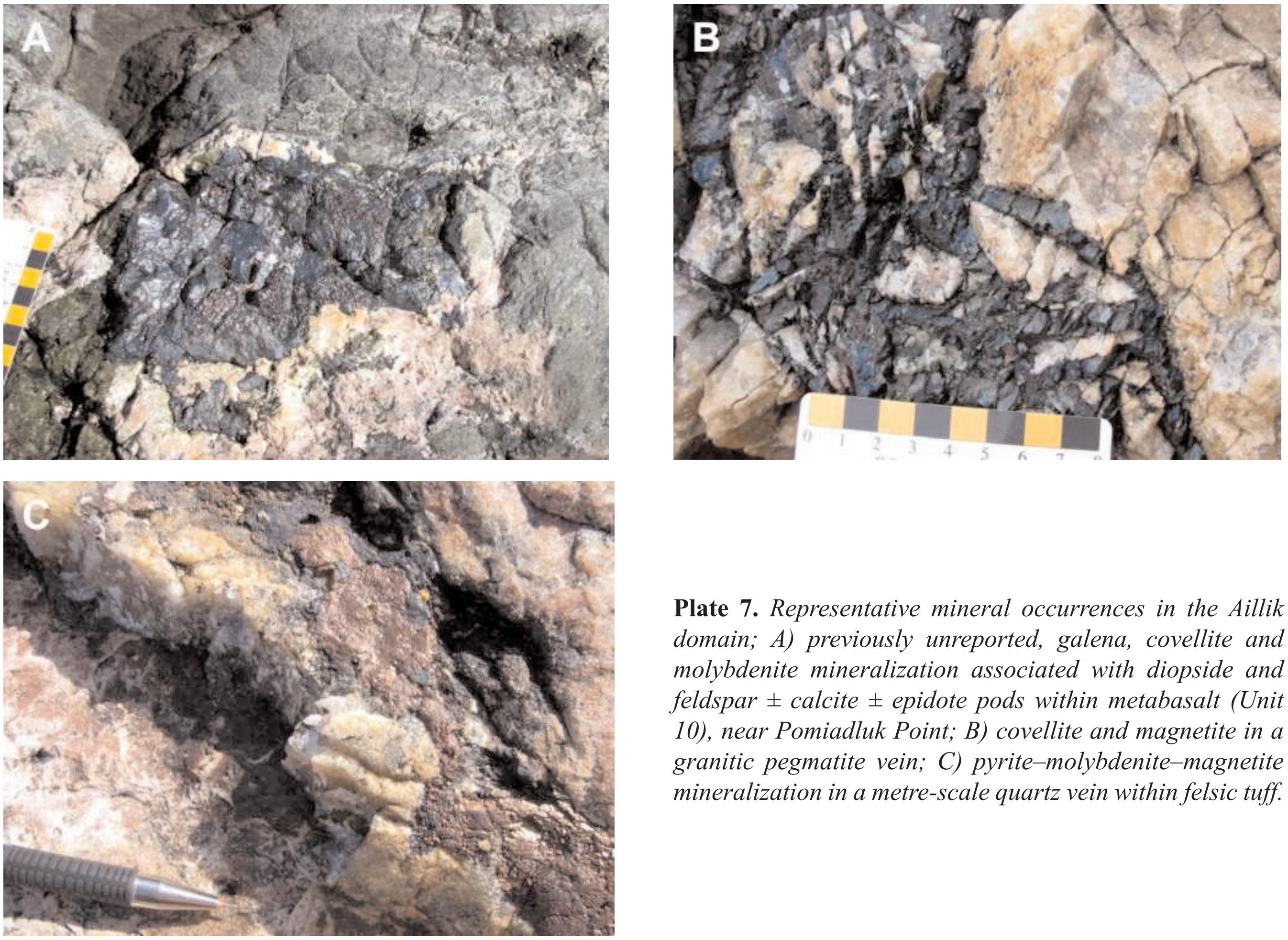


Plate 7. *Representative mineral occurrences in the Aillik domain; A) previously unreported, galena, covellite and molybdenite mineralization associated with diopside and feldspar ± calcite ± epidote pods within metabasalt (Unit 10), near Pomiadluk Point; B) covellite and magnetite in a granitic pegmatite vein; C) pyrite–molybdenite–magnetite mineralization in a metre-scale quartz vein within felsic tuff.*

2002). Based on their undeformed nature and on rock types of the xenoliths contained within, these dykes are the youngest intrusions in the map area (Plate 6d). Microfossils in the breccia were interpreted as being between <197 Ma and >145 Ma in age (King and McMillan, 1975), which is consistent with an approximate age of 142 Ma reported by Tappe *et al.* (2006).

MINERALIZATION

The Aillik Group hosts a multitude of promising mineral occurrences, dominated by uranium and molybdenite showings, as well as galena, pyrite, magnetite, copper minerals and covelite occurrences. Since the discovery of uranium and molybdenite mineralization in the mid-1950s, several studies have focused on the mineral exploration and potential of the area (*e.g.*, Beavan, 1958; Gandhi *et al.*, 1969; Gandhi, 1978; MacDougall, 1988; MacKenzie, 1991; Wilton, 1996).

Samples from many of the occurrences were collected for assay as part of this regional mapping study and the results will be published when the analyses are completed. Uranium and molybdenite mineralization are found throughout the area and occurrences are concentrated in the Aillik–Makkovik Belt and in the Round Pond area. The Aillik–Makkovik Belt extends from Cape Makkovik to the Cross Lake–Island Lake area (south of the current map area), a distance of about 30 km. This belt is characterized by uranium and molybdenite mineralization associated with lower grade uranium mineralization (Gower *et al.*, 1982). The uranium/molybdenite mineral occurrences in the area are considered to be mainly epigenetic within the Aillik Group (Wilton, 1996). The Round Pond area is characterized by widespread and varied Mo–base-metals–U–F-mineralization interpreted as having an epigenic origin within the Aillik Group, and a magmatic-hydrothermal origin related to the intrusion of high-level magmatic rocks of the Monkey Hill Intrusive Suite (MacDougall, 1988).

Mineralization is not restricted to these zones and a variety of mineral occurrences occur throughout the map area. The dominant styles include, a) sulphide-rich (galena, covellite, molybdenite) diopside–feldspar ± calcite ± epidote pods within the metabasalt unit (Plate 7a), b) discontinuous rusty, sulphide- and uranium-rich horizons that occur throughout the Aillik Group and the Pre-Makkovikian quartz–feldspar–porphyritic granite(s), c) pegmatitic granite dykes that contain tourmaline, covellite, and magnetite-rich zones (Plate 7b), and d) quartz veins containing either disseminated molybdenite, galena, titanite, pyrite, and tourmaline or fracture coatings of fine-grained molybdenite and galena (Plate 7c). Many mineral occurrences have previously been documented in the area; however, several new showings were identified during field mapping including, a) sulphide mineralized nodules with the metabasalt unit to the east of Pomiadluk Point, b) mineralized quartz veins (as described above) throughout the area, and c) covellite–molybdenite–mineralized granite pegmatite veins on the eastern coast of Kaipokok Bay. The abundant mineral occurrences in the Makkovik area illustrate its significant economic potential.

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