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Critical review

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Abstract: Detailed bedrock mapping of the Paleoproterozoic Hoare Bay group in central Cumberland Peninsula, Nunavut revealed that the stratigraphy can be divided into three distinct sucessions. The lower succession comprises mostly pelitic and semipelitic schist, with metamorphosed ultramafic-mafic volcanic and plutonic rocks, quartzite, carbonate-silicate gneiss, and metamorphosed sulphide iron-formation. The middle succession consists of metamorphosed ultramafic-mafic volcanic and plutonic rocks below metamorphosed iron-formation. The upper succession is a sequence of semipelitic and psammitic schist with a unit of ultramafic-mafic volcanic and plutonic rocks. Tabular, composite bodies of leucomonzogranite to tonalite gneiss, monzodiorite to gabbro gneiss, and hornblendite intruded into the Hoare Bay group. A correlation of stratigraphy between map areas implies the eastern map area exposes the overturned limb of a nappe-style fold. There are two generations of subparallel outcrop-scale folds in both map areas; the earlier generation is associated with an axial-planar fabric. Metabasite mineral assemblages are part of the amphibolite facies and metapelitic rocks are in the muscovite+sillimanite metamorphic zone. Based on lithostratigraphy, the Hoare Bay group shares a number of similarities with the Karrat Group in West Greenland.

Résumé : La cartographie détaillée du substratum rocheux attribué au groupe de Hoare Bay du Paléoprotérozoïque, dans le centre de la péninsule Cumberland au Nunavut, a révélé que la stratigraphie peut être divisée en trois successions distinctes. La succession inférieure comprend principalement du schiste pélitique et semi-pélitique, avec des roches volcaniques et plutoniques ultramafiques à mafiques métamorphisées, du quartzite, du gneiss carbonaté-silicaté et une formation de fer à faciès sulfuré métamorphisée. La succession intermédiaire est constituée de roches volcaniques et plutoniques ultramafiques à mafiques métamorphisées surmontées d'une formation de fer métamorphisée. La succession supérieure est une séquence de schiste semi-pélitique et psammitique avec une unité de roches volcaniques et plutoniques ultramafiques à mafiques. Des massifs composites tabulaires de gneiss leucomonzogranitique à tonalitique, de gneiss monzodioritique à gabbroïque et de hornblendite recoupent le groupe de Hoare Bay. Une corrélation de la stratigraphie entre les régions cartographiques indique que la région orientale présente le flanc déversé d'un pli de type nappe. Il y a deux générations de plis presque parallèles à l'échelle de l'affleurement dans les deux régions cartographiques; une fabrique de plan axial est associée à la génération la plus ancienne. Les associations minérales des métabasites font partie du faciès des amphibolites et les roches métapélitiques se situent dans la zone métamorphique à muscovite+sillimanite. Selon la lithostratigraphie, le groupe de Hoare Bay présente un certain nombre de similitudes avec le Groupe de Karrat dans le Groenland occidental.

INTRODUCTION

The Hoare Bay group is a Paleoproterozoic supracrustal sequence exposed on Cumberland Peninsula, eastern Baffin Island. Several attempts have been made to correlate the Hoare Bay group with other supracrustal packages in northern Canada and West Greenland. When first studied, the Hoare Bay group was noted as having similarities to the metasedimentary rocks on Hall Peninsula to the south and was suggested to be the deep-water equivalent of the Piling Group to the northwest on central Baffin Island (Jackson and Taylor, 1972). Recent regional syntheses proposed incongruent basin-tectonic models: the Hoare Bay group may correlate with the Karrat, Anap nunâ (West Greenland), and Piling groups (St-Onge et al., 2009), or with a supracrustal sequence on Hall Peninsula (Jackson, 2000; Corrigan et al., 2009).

This report presents detailed rock descriptions for the Hoare Bay group and those rocks that intrude into it in addition to bedrock maps and stratigraphic columns for two regions on Cumberland Peninsula that were mapped in detail in 2011. Preliminary observations on the structural and metamorphic geology are included and a detailed analysis is forthcoming.

REGIONAL GEOLOGY

The geology of Cumberland Peninsula was studied first at a reconnaissance scale (Jackson, 1971, 1998; Jackson and Taylor, 1972; Fraser et al., 1978; Jackson and Morgan, 1978), and recently systematically mapped at 1:150 000 scale as part of the 2008–2013 Geo-mapping for Energy and Minerals (GEM) program (Fig. 1; Sanborn-Barrie et al., 2011a, b, c, 2013a, b; Sanborn-Barrie and Young, 2013a, b, c). These maps were developed in tandem with studies of geochemistry (Sanborn-Barrie and Young, 2011; Keim et al., 2011; Mackay, 2011; Whalen et al., 2012; Keim, 2012), metamorphism (Hamilton et al., 2012), and geochronology (Rayner et al., 2012; Berman et al., 2013). The peninsula is primarily underlain by Mesoarchean and Neoarchean tonalite to monzogranite gneiss that, in the south, is intruded by discrete Neoarchean granite plutons (most rocks on Cumberland Peninsula were metamorphosed to amphibolite facies or higher grade, so the prefix 'meta' is omitted in this report). Several strands of supracrustal rocks in the southern part of the peninsula were deposited and metamorphosed in the Archean. Supracrustal rocks that outcrop across a 160 km by 45 km region in the centre of the peninsula and as metre to kilometre thick lenses within the Archean gneiss units form the Hoare Bay group (Jackson, 1971, 1998; Jackson and Taylor, 1972), which was deposited in the Orosirian (2.05–1.80 Ga; M. Sanborn-Barrie, M. Young, N. Wodicka, J. Whalen, B. Hamilton, R. Keim, R. Berman, and J. Craven, unpub. paper, 2014). The Hoare Bay group is a clastic-dominated succession, the lower part of which consists of pelite, semipelite, psammite, quartzite, ultramafic-mafic volcanic and plutonic rocks, and carbonate rocks. The middle part of the group, the focus of study by Keim (2012), is composed of ultramafic-mafic volcanic rocks and their intrusive equivalents (Totnes Road formation) and overlain by a sequence dominated by iron-formation (Clephane Bay formation). Psammite, semipelite, and minor ultramafic-mafic volcanic and plutonic rock comprise the upper part of the Hoare Bay group. Archean rocks and the Hoare Bay group were intruded first by ca. 1.89 Ga granodiorite–charnockite–quartz diorite (Qikiqtarjuaq plutonic suite) and later by at least two generations of granitoid to syenite sills and dykes.

The most pronounced map-scale structures are thick-skinned thrust faults and east-trending, approximately isoclinal folds (Fig. 1). The thrust faults juxtapose Archean gneiss with Hoare Bay group rocks and some of these faults are folded. East-trending mylonitic shear zones occur mainly in the centre of Cumberland Peninsula, at and near the contacts between Archean orthogneiss and Hoare Bay group rocks. Upright, open folds were the last major structures to form. Most structures on Cumberland Peninsula formed during what is considered the main tectonometamorphic event at ca. 1.86 Ga, but this was preceded by one or more phase of deformation during the Archean; two additional periods of deformation occurred during the Paleoproterozoic.

The majority of Cumberland Peninsula has upper-amphibolite-facies mineral assemblages with local domains of granulite-facies and middle-amphibolite-facies assemblages. Neoarchean monazites provide evidence for Neoarchean metamorphism of Archean supracrustal rocks. Granulite-facies contact aureoles developed adjacent to Qikiqtarjuaq suite intrusions, and this was followed by the main regional upper-amphibolite-facies tectonometamorphic event at ca. 1.86 Ga. Across the centre of the peninsula, there is a northeast-trending domain of lower grade, middle-amphibolite-facies supracrustal rocks called the Touak-Sunneshine metamorphic low (Hamilton et al., 2012). This metamorphic low developed contemporaneously with the intrusion of the Qikiqtarjuaq plutonic suite, suggesting that this metamorphism is regional contact metamorphism (Hamilton et al., 2013).

Younging direction of the Hoare Bay group

The relative age of the Totnes Road and Clephane Bay formations were established regionally on Cumberland Peninsula based on field relations. Graded bedding in clastic sedimentary rocks occurs sparsely and mostly in the Touak-Sunneshine metamorphic low. Ten kilometres west of Clephane Bay (Fig. 1), the Totnes Road formation underlies the Clephane Bay formation and both underlie psammitic-semipelitic schist with graded bedding (Fig. 2), indicating the strata are upward facing. Reverse metamorphic grading in andalusite-bearing semipelitic schist underlying the Totnes Road formation at Mermaid Fiord also suggest the Clephane Bay formation is younger than the Totnes Road formation (Keim et al., 2011).

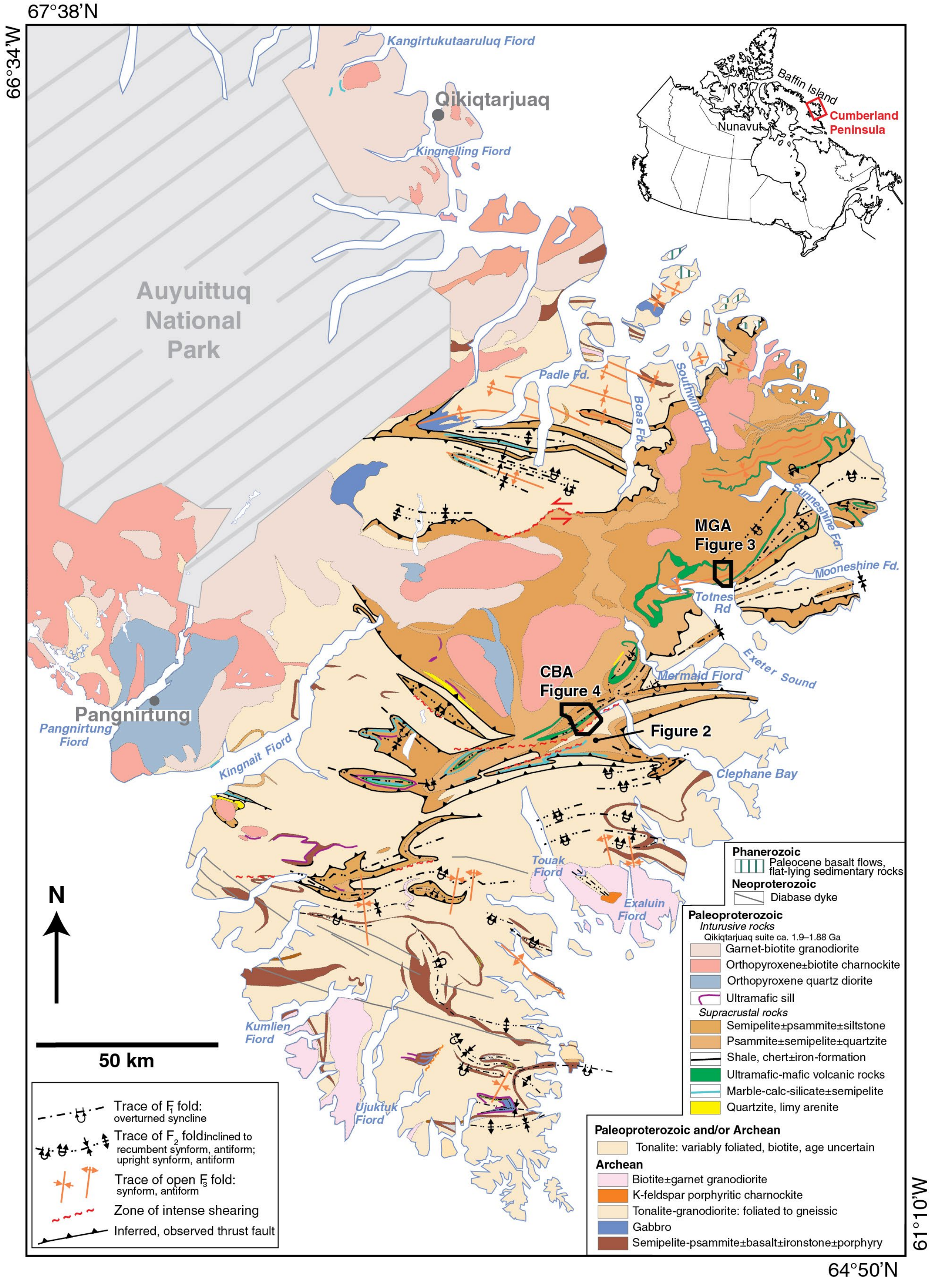


Figure 1. Simplified bedrock geology of Cumberland Peninsula (*modified from* Sanborn-Barrie and Young, 2013a). The locations of Figure 2, the Mischief Glacier map area (MGA; Fig. 3), and the Clephane Bay map area (CBA; Fig. 4) are shown in black.

MAP AREAS AND METHODS

Two areas of central-eastern Cumberland Peninsula, the Mischief Glacier and the Clephane Bay map areas (Fig. 1), were mapped at 1:5000 and 1:10 000 scale, respectively. Both areas have good and continuous exposure of Hoare Bay group rocks in the Touak-Sunneshine metamorphic low, facilitating a study of the stratigraphy as well as Orosirian structures and metamorphism. The Mischief Glacier map area (Fig. 3) is a 4 km by 5 km area within a glacier-carved valley near a bay called Totnes Road. The Clephane Bay map area (Fig. 4) is 8 km by 7 km and consists of a south-facing mountainside and an east-west oriented valley.

Mapping and sample collection were conducted during the summer of 2011. Orthogneiss samples were etched with hydrofluoric acid then stained using sodium cobaltinitrite in order to discriminate between plagioclase and white potassium feldspar. Metamorphic rocks were named in accordance with the recommendations of the International Union of Geological Sciences (Fettes and Desmons, 2007). Igneous and sedimentary protolith names follow common conventions (e.g. Boggs, 1995; Le Maitre, 2002). Iron-rich rocks are referred to as iron-formation and prefixed according to the main iron-bearing minerals: silicate, sulphide, oxide, or carbonate following the recommendations of Trendall (1983). Map units have the name of the most abundant rock type and in some cases, a shortened name is used for brevity.

Figure 2. An outcrop of psammitic and semipelitic schist showing fining-upward beds. The arrow indicates the younging direction. This photograph was taken 1.5 km south of the Clephane Bay map area (Fig. 1); black and white scale is in centimetres. Photograph by B. Hamilton. 2014-060

HOARE BAY GROUP

Supracrustal rocks of the Hoare Bay group underlie the majority of both map areas (Fig. 3, 4) with 10 lithological units recognized in the Mischief Glacier map area and 13 in the Clephane Bay map area. Sufficient lithostratigraphic similarities exist between the Mischief Glacier and Clephane Bay map areas to allow correlation between the two areas (Fig. 5). These stratigraphic units allow the Hoare Bay group to be divided into a lower, middle, and upper successions (Fig. 5). The defining features of each unit are described below. A complete characterization of the rocks in each unit is available from the author by request.

Lower Hoare Bay group

Pelitic schist

Both map areas expose pelitic and semipelitic schist interlayered with lesser quartzite and psammitic schist. Pelitic schist–dominated lithologies occur at several stratigraphic levels below the Totnes Road formation (Fig. 5) and are not subdivided because they cannot be lithologically differentiated. Two stratigraphic packages of pelitic schist in the Mischief Glacier map area have a combined structural thickness of 550–1500 m. Four separate stratigraphic horizons in the Clephane Bay map area have a total thickness of 300–750 m.

Rocks of this unit are layered on a millimetre- to decimetre-scale, and include pelitic muscovite-plagioclase-biotite-quartz schist, semipelitic to psammitic biotite-plagioclase-quartz schist, and biotite±muscovite-bearing quartzite. Pelitic and semipelitic schist typically contain staurolite (2–8 mm), plagioclase (0.5–1.2 mm), andalusite (3–80 mm), garnet (3–10 mm), and magnetite (2 mm) porphyroblasts (Fig. 6a). Fibrolitic sillimanite is common in both map areas, but often only visible in thin section. Abundant magnetite-bearing pelitic schist in the northern part of the Mischief Glacier map area is likely the reason for a distinctive lineament on aeromagnetic survey maps (Coyle, 2009a, b). This unit contains 15 cm to 1 m thick, extremely elongate lenses (aspect ratio greater than five to one) of hornblende-plagioclase-quartz±garnet±epidote gneiss, interpreted to be metamorphosed calcareous sediment and concretions (Scott et al., 2002). The pelitic schist unit contains ultramafic rocks, described in the following section.

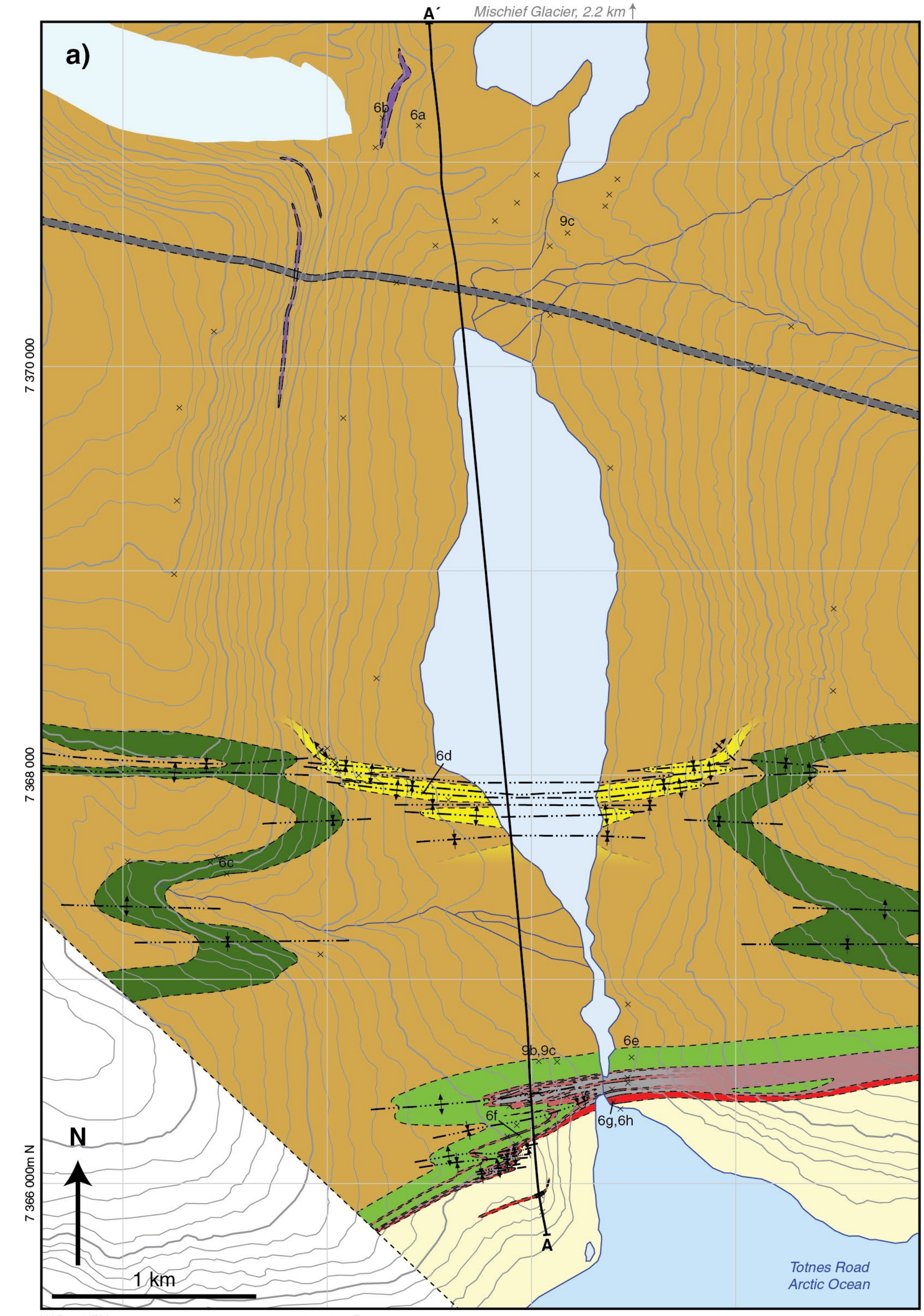


Figure 3. Mischief Glacier map area **a)** bedrock geology map.

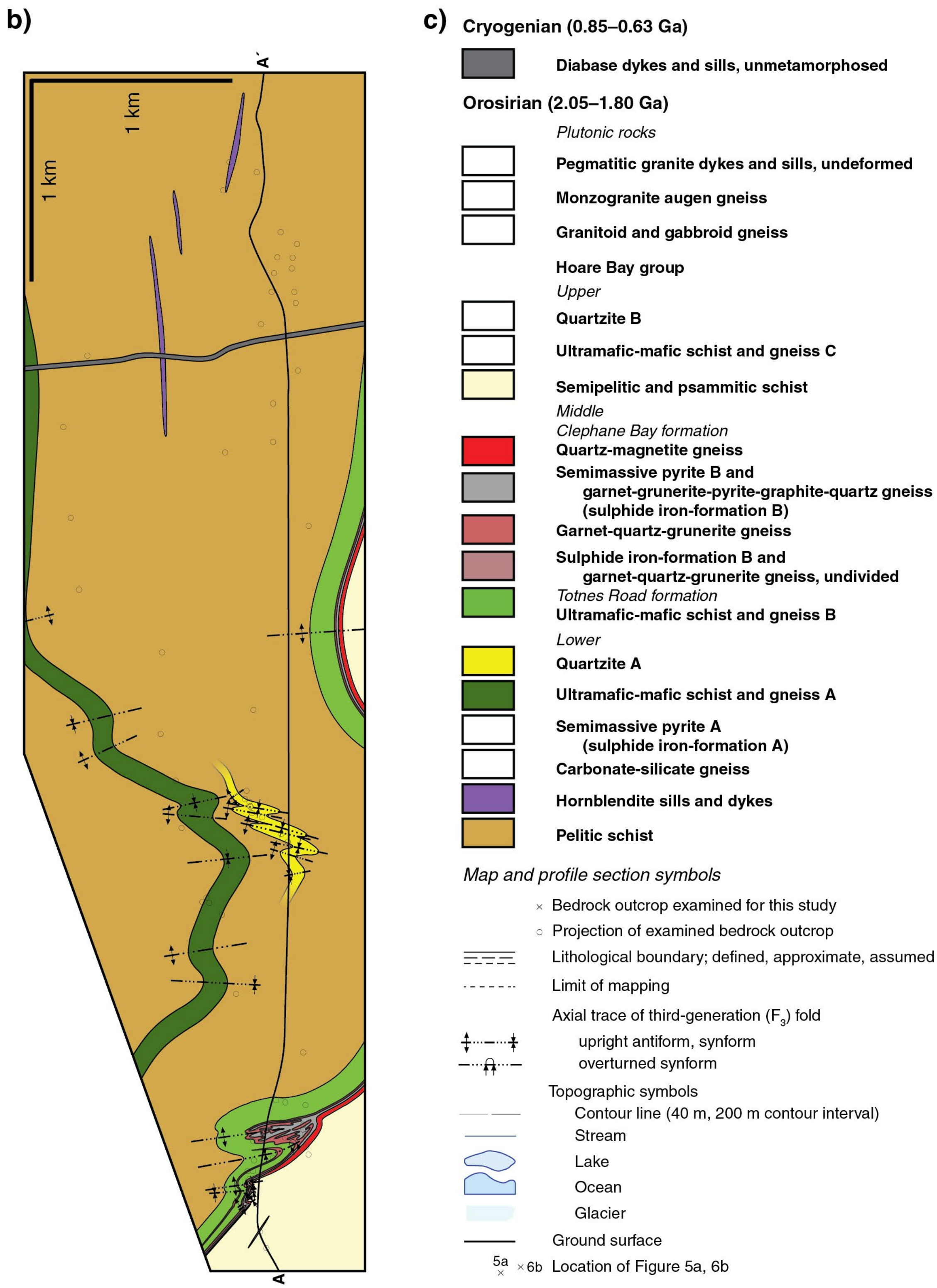


Figure 3. Mischief Glacier map area **b)** profile section (plane of section oriented 355/80), and **c)** legend.

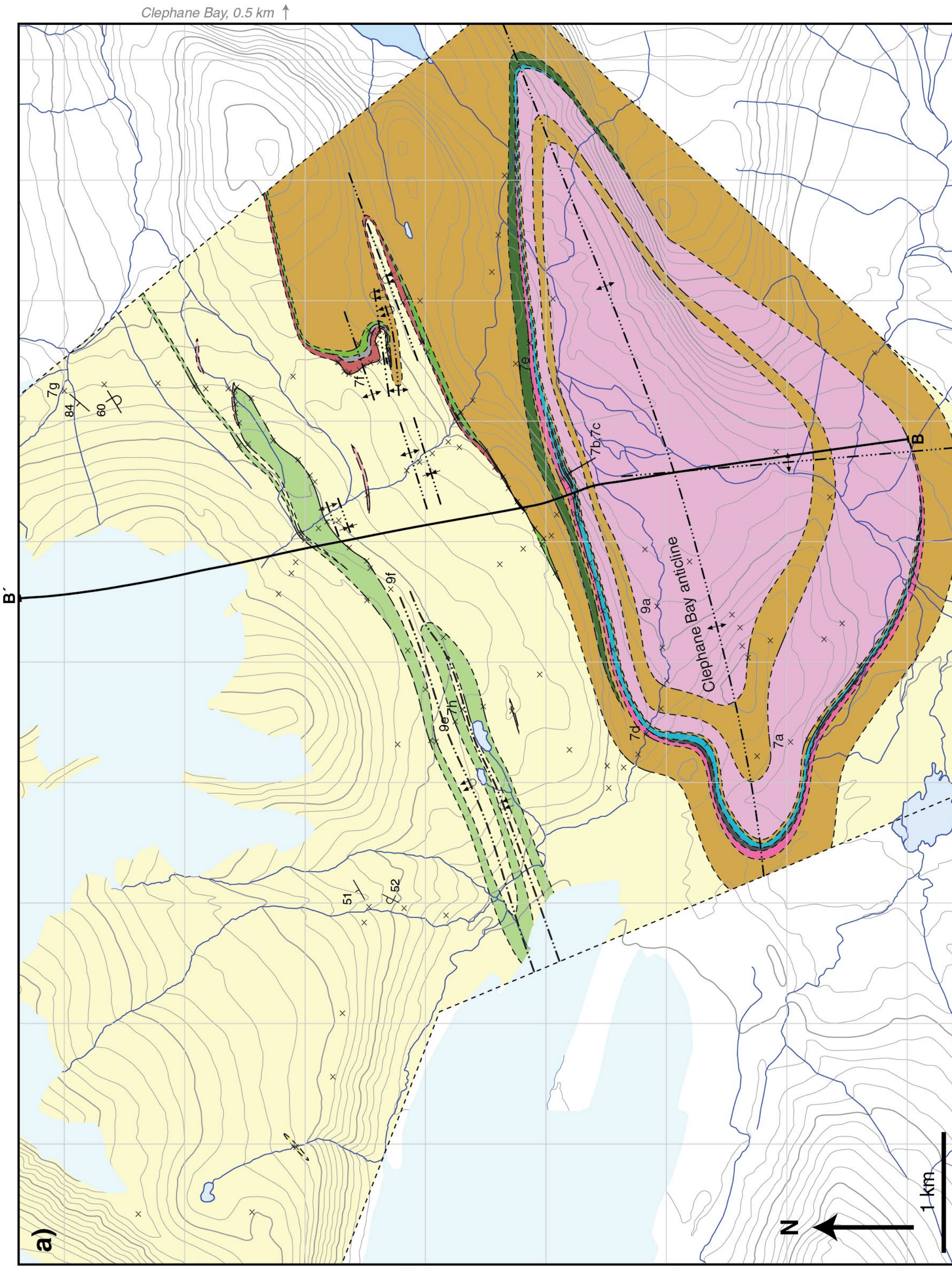
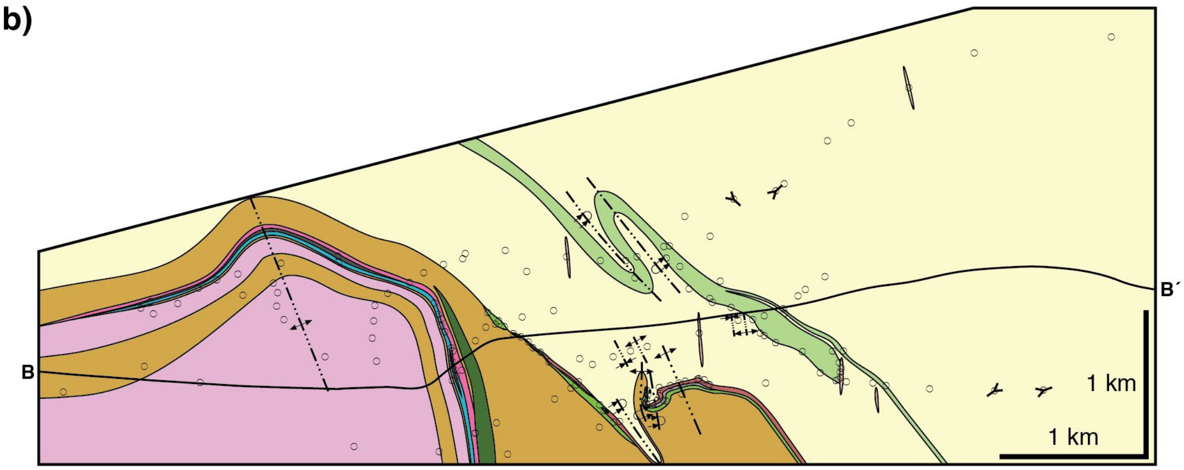


Figure 4. Clephane Bay map area **a)** bedrock geology map.

b)



c)

Cryogenian (0.85–0.63 Ga)

Diabase dykes and sills, unmetamorphosed

Orosirian (2.05–1.80 Ga)

Plutonic rocks

Pegmatitic granite dykes and sills, undeformed

Monzogranite augen gneiss

Granitoid and gabbroid gneiss

Hoare Bay group

Upper

Quartzite B

Ultramafic-mafic schist and gneiss C

Semipelitic and psammitic schist

Middle

Clephane Bay formation

Quartz-magnetite gneiss

Semimassive pyrite B and garnet-grunerite-pyrite-graphite-quartz gneiss (sulphide iron-formation B)

Garnet-quartz-grunerite gneiss

Sulphide iron-formation B and garnet-quartz-grunerite gneiss, undivided

Totnes Road formation

Ultramafic-mafic schist and gneiss B

Lower

Quartzite A

Ultramafic-mafic schist and gneiss A

Semimassive pyrite A (sulphide iron-formation A)

Carbonate-silicate gneiss

Hornblendite sills and dykes

Pelitic schist

Map and profile section symbols

× Bedrock outcrop examined for this study

○ Projection of examined bedrock outcrop

Lithological boundary; defined, approximate, assumed

Limit of mapping

30 40 Bedding, tops known, upright, overturned

Graded bedding fining-upward direction

Axial trace of second-generation (F_2) fold

overturned antiform, synform

Axial trace of third-generation (F_3) fold

upright antiform, synform

overturned antiform, synform

Axial trace of fourth-generation (F_4) fold

upright antiform

Topographic symbols

Contour line (40 m, 200 m contour interval)

Stream

Lake

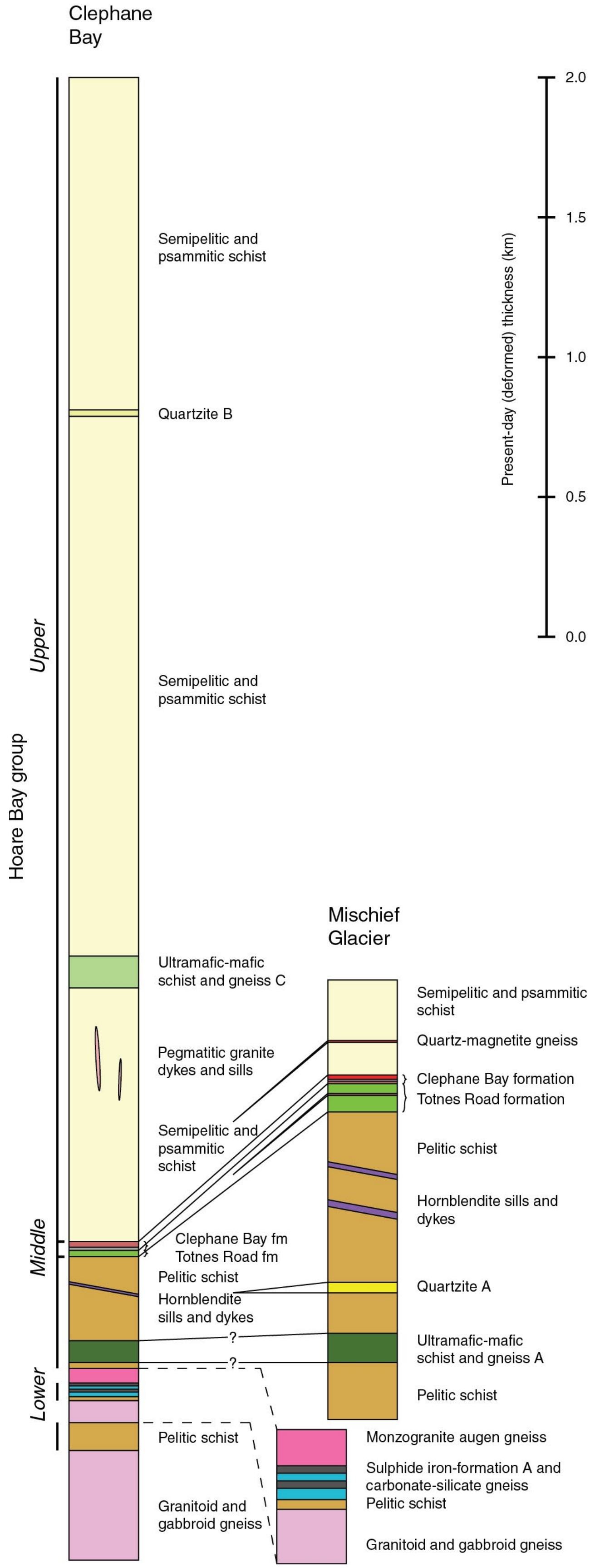
Ocean

Glacier

Ground surface

5a × 6b Location of Figure 5a, 6b

Figure 4. Clephane Bay map area **b)** profile section (plane of section oriented 351/75), and **c)** legend.



Hornblendite sills and dykes

Granofelsic hornblendite and biotite-ilmenite-hornblende granofels occur within the pelitic schist units in both map areas. They are slightly to moderately elongate, lenticular bodies that have sharp contacts with pelitic schist. Most lenses are 30 cm to 4 m wide with a lateral continuity of up to tens of metres, and three larger bodies in the Mischief Glacier map area are each about 30 m thick and hundreds of metres long (Fig. 3). In the Mischief Glacier map area hornblendite lenses are distributed throughout the pelitic schist unit; in contrast, hornblendite is found in only two localities in the Clephane Bay map area.

One hornblendite lens in the Mischief Glacier map area cuts the compositional layering of the host rock (Fig. 6b), implying an intrusive origin as a dyke. In contrast, most lenses parallel the layering in the host rock, and are thought to be either sills or transposed dykes. Xenoliths of psammitic schist, pelitic schist, and carbonate-silicate gneiss occur rarely. Due to lithological and geochemical similarities, rocks of this unit sampled elsewhere on Cumberland Peninsula are thought to be feeder dykes and sills to at least one of the three units containing ultramafic-mafic volcanic rocks (Mackay, 2011; Keim, 2012; Whalen et al., 2012).

Carbonate-silicate gneiss

The carbonate-silicate gneiss unit outcrops poorly, is 10–15 m thick, and is found only in the Clephane Bay map area (Fig. 4). The carbonate-silicate to impure marble gneiss (Fig. 7a), with minor layers of light grey chert, has centimetre- to decimetre-scale layering. Individual layers have variable composition including dolomite>>phlogopite±tremolite±apatite, tremolite>>phlogopite, diopside±plagioclase, plagioclase>apatite±diopside, or diopside+tremolite.

Semimassive pyrite A (sulphide iron-formation A)

In the Clephane Bay map area, a unit of recessively weathering, gossanous rocks rich in pyrite and lesser graphite is thought to be mainly sulphide iron-formation. The unit thickness varies from less than 1 m to 15 m. It is stratigraphically above the carbonate-silicate gneiss unit everywhere except at one locality where carbonate-silicate gneiss is both above and below semimassive pyrite (Fig. 4). Here, fine-grained plagioclase-hornblende schist (amphibolite)

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Figure 5. Pseudostratigraphic columns of the Clephane Bay and Mischief Glacier map areas with correlations.

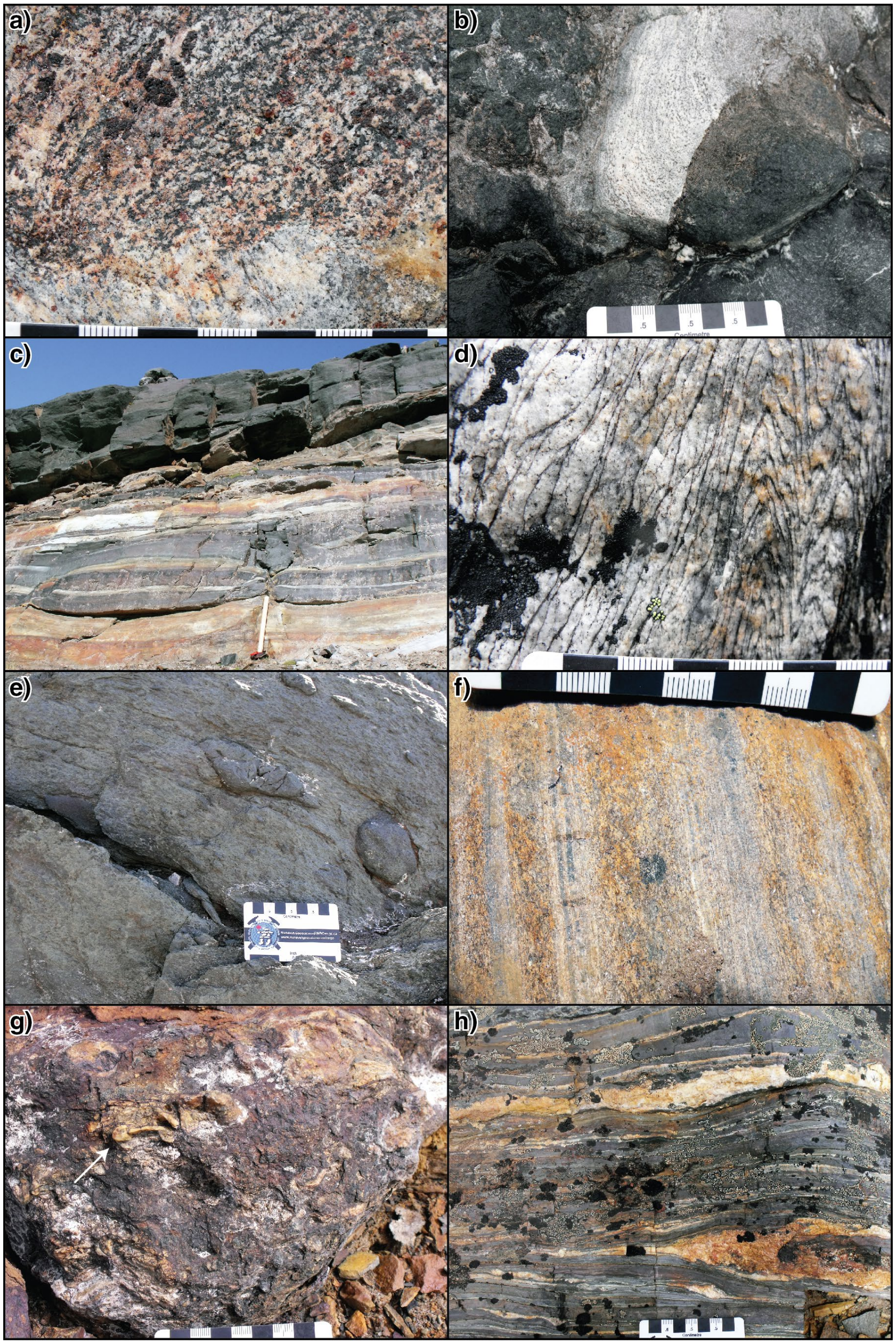

Figure 6. Outcrop photographs of lithologies in the Mischief Glacier map area. **a)** Garnet-staurolite-muscovite-plagioclase-biotite-quartz schist and a quartz vein in the pelitic schist unit; 2014-041. **b)** A hornblendite sill, of the ultramafic sills and dykes unit, crosscuts the layering of a hornblende-plagioclase-quartz gneiss lens; 2014-048. **c)** Dusky yellowish-green and massive ultramafic ilmenite-chlorite-hornblende schist, typical of ultramafic-mafic schist and gneiss A, structurally overlies the lighter coloured quartz-bearing components of the unit including hornblende-plagioclase-chlorite-quartz gneiss and hornblende-quartz-plagioclase gneiss; hammer handle is 59 cm; 2014-050. **d)** Tight folds (F_3) outlined by biotite-rich layers in biotite-muscovite-bearing quartzite; 2014-061. **e)** Bedding and schistosity plane of hornblende schist in the Totnes Road formation with flat and variably elongate lapilli and bombs; 2014-046. **f)** Biotite-garnet-quartz-grunerite gneiss; 2014-058. **g)** Typical gossanous and bulbous outcrop of sulphide iron-formation B with durchbewegung structure. One chert clast is isoclinally folded (arrow); 2014-051. **h)** Hematite-quartz-magnetite gneiss with monomineralic quartz layers (quartz veins and possibly chert) in the quartz-magnetite gneiss unit; 2014-045. All photographs by B. Hamilton. All black and white scales are in centimetres.

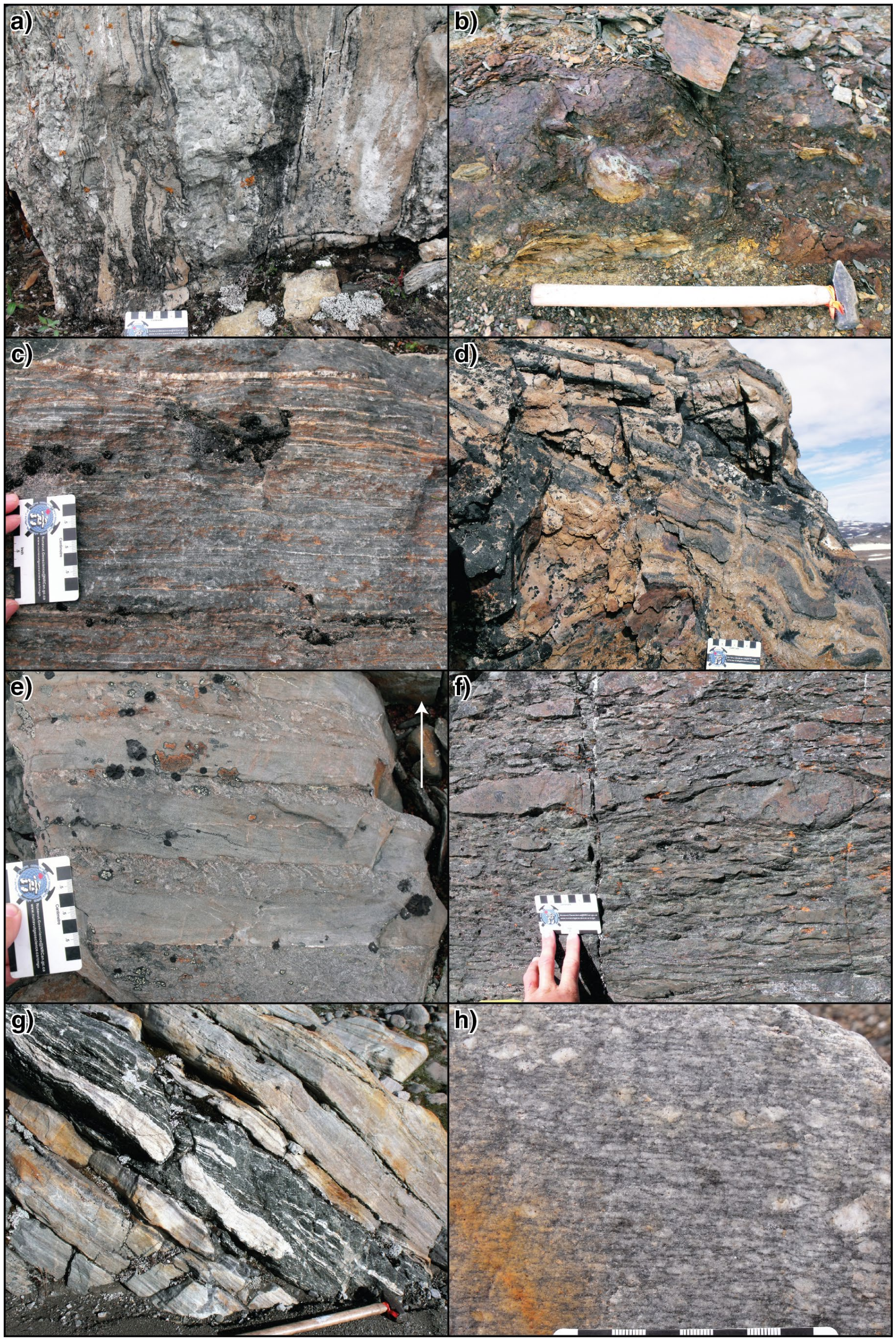

Figure 7. Outcrop photographs of lithologies in the Clephane Bay map area. **a)** Phlogopite-tremolite-dolomite±diopside carbonate-silicate gneiss; 2014-056. **b)** Durchbewegung structure in a gossanous outcrop of sulphide iron-formation A; hammer handle is 59 cm; 2014-043. **c)** Plagioclase-hornblende±biotite gneiss of ultramafic-mafic schist and gneiss A; 2014-047. **d)** Garnet-quartz-grunerite and monomineralic magnetite layers in the garnet-quartz-grunerite gneiss unit; 2014-064. **e)** An outcrop of the semipelitic and psammitic schist unit with rarely observed fining-upward beds. The arrow indicates the younging direction. The range of composition in this outcrop, from psammitic biotite-plagioclase-quartz schist at the bottom of each bedset to semipelitic plagioclase-muscovite-andalusite-biotite-quartz schist at the top, is typical of the semipelitic and psammitic schist unit as a whole; 2014-059. **f)** Flattened lapilli and bombs in ultramafic-mafic schist and gneiss C; 2014-057. **g)** Leucogranodiorite gneiss is cut by ultramafic-mafic hornblende gneiss in several places in the photograph. Both are part of the granitoid and gabbroid gneiss unit; hammer head is 13 cm; 2014-063. **h)** Monzogranite microcline augen gneiss; 2014-049. All photographs by B. Hamilton. All black and white scales are in centimetres.

and gossanous chert lie between the semimassive pyrite and carbonate-silicate gneiss. The repetition of the carbonate-silicate gneiss may be either structural or stratigraphic.

Most of the rocks of this distinctive unit are composed of 20–40% subrounded fragments (millimetres to centimetres) set in a matrix of fine-grained granofelsic pyrite with minor graphite (Fig. 7b). Fragments are mainly quartz-plagioclase-biotite-graphite schist, with or without pyrite, grunerite, magnetite, and rarely garnet, with mineral proportions varying widely. Late fractures are common and are filled with hematite. The pseudoconglomerate texture is interpreted to be 'durchbewegung' structure, the result of deformation of a layered sequence with large competency contrasts including sulphide minerals (Marshall and Gilligan, 1989; Keim, 2012).

Ultramafic-mafic schist and gneiss A

Three units are dominated by ultramafic to mafic igneous rocks that include some rocks with a volcanic origin. All weather distinctive shades of dark green. The lowest ultramafic unit (ultramafic-mafic schist and gneiss A) is 105 m thick in the Mischief Glacier map area and up to 70 m thick in the Clephane Bay map area (Fig. 5). Upper and lower contacts with pelitic schist are sharp in both areas. The character of this lower unit differs between the two areas as follows.

In the Mischief Glacier map area this unit is composed of metre-scale layers of fine- to medium-grained ilmenite-chlorite-hornblende schist. Some of the rocks preserve a pyroclastic texture with lapilli- and bomb-sized fragments, whereas massive varieties locally contain plagioclase-rich, millimetre-wide varioles. The fragmental texture and presence of varioles indicate that much of this unit had a volcanic origin. Toward the stratigraphic top of this unit are centimetre- to decimetre-thick layers of more felsic composition (Fig. 6c). Two such layers are hornblende-plagioclase-chlorite-quartz gneiss and hornblende-quartz-plagioclase gneiss, both with a colour index of about 30. Given their association with volcanic rocks, these horizons may be andesite or dacite, or their intrusive equivalents, and locally abundant veining suggests a portion of these layers were hydrothermally altered.

The tentatively correlated unit in the Clephane Bay map area does not display recognizable primary features. Rather, the rocks are fine-grained plagioclase-hornblende gneiss with a colour index of 60–80 (Fig. 7c). Medium-grained clinopyroxene grains, partially replaced by epidote and hornblende, may be relict phenocrysts.

Quartzite A

Distinctive quartzite-dominated strata, 35 m thick, occur within a succession of pelitic schist between ultramafic-mafic schist and gneiss A and the Totnes Road formation (described below) in the Mischief Glacier map area (Fig. 5). The stratigraphically lower contact is sharp. The quartzite consists mainly of muscovite-biotite-bearing quartzite (Fig. 6d) locally interlayered with 5–50 cm thick layers of pelitic muscovite-biotite±garnet schist. The quartzite contains calcareous lenses similar to those in the pelitic schist units.

Middle Hoare Bay group

Ultramafic-mafic schist and gneiss B (Totnes Road formation)

Stratigraphically above the uppermost pelitic schist unit of the lower Hoare Bay group, a sharp contact defines the base of a unit of ultramafic and mafic igneous rocks designated the Totnes Road formation (Keim, 2012). In the Mischief Glacier map area this unit is 110 m thick, whereas in the Clephane Bay map area it is up to 50 m thick and locally pinches out (Fig. 4, 5). It is composed of plagioclase-hornblende schist and gneiss, and schistose and granofelsic hornblendite. Chlorite-hornblende schist and plagioclase-hornblende-clinopyroxene gneiss with very coarse-grained clinopyroxene are present locally in the Clephane Bay map area.

Some fine- to very fine-grained rocks in the Mischief Glacier map area contain millimetre-wide plagioclase-rich varioles and others have a fragmental texture (Fig. 6e). Medium- and coarse-grained rocks in both map areas lack primary textures and it is unclear if they are intrusive. Based on chemical analyses of Totnes Road formation samples collected throughout Cumberland Peninsula, the volcanic rocks are ultrabasic to basic and characterized as Karasjok-type komatiite, komatiitic basalt, and tholeiitic basalt (Keim et al., 2011; Keim, 2012).

Clephane Bay formation

Several types of iron-formation, collectively referred to as the Clephane Bay formation (Keim, 2012), overlie the Totnes Road formation in both map areas.

<u>*Garnet-quartz-grunerite gneiss*</u>

Both map areas contain a unit of predominantly garnet-quartz-grunerite±magnetite gneiss (Fig. 6f, 7d) interpreted to be silicate iron-formation. In the Mischief Glacier map area, this unit occurs both as a 5 m thick lens within the Totnes Road formation and as a 5–12 m thick layer above it (Fig. 3). It is unclear if the former is a structural repetition or a temporally distinct horizon. In the Clephane Bay map area, garnet-quartz-grunerite gneiss is up to 20 m thick and pinches out to the west (Fig. 4). Gneissic bands are millimetres to decimetres thick. The relative abundance of the minerals in different layers varies from nearly monomineralic quartz (chert) to quartz-grunerite or garnet-quartz (Storey, 2012) and thin monomineralic magnetite layers locally constitute up to 40% of the rock in the Clephane Bay map area (Fig. 7d). Biotite, hornblende, and plagioclase are less commonly present.

Semimassive pyrite and garnet-grunerite-pyrite-graphite-quartz gneiss (sulphide iron-formation B)

Sulphide iron-formation B is a gossanous, recessively weathering, pyrite- and graphite-rich unit that is about 10 m and 15 m thick in the Mischief Glacier map area and Clephane Bay map area, respectively (Fig. 5). It is lithologically similar to sulphide iron-formation A and is either gneissose or has durchbewegung structure. Rocks with durchbewegung structure contain schistose or gneissose fragments composed of quartz, plagioclase, biotite, graphite, and muscovite in various proportions set in a matrix (40–75%) of semimassive granofelsic pyrite and some graphite (Fig. 6g). The gneissose rocks have 0.5–20 mm thick layers consisting of quartz, graphite, pyrite, grunerite, and garnet in widely varying modal proportions. In the eastern part of the Clephane Bay map area, porous, gossanous rocks with graphite-dominated subrounded fragments are thought to belong to this unit.

Similar rocks elsewhere on Cumberland Peninsula have been variably referred to as shale±siltstone, black shale (Sanborn-Barrie et al., 2011c, 2013a), graphite-rich shale and/or pelite (Sanborn-Barrie and Young, 2011), semimassive sulphide exhalite (Keim et al., 2011), pyritic graphitic schist, graphitic schist, and sulphide iron-formation (Keim, 2012). The variety of terminology reflects both the heterogeneity of the rocks and the difficulty in naming them. Elsewhere on Cumberland Peninsula, similar rocks were found to have anomalously high concentrations of zinc, copper, silver, and gold (Sanborn-Barrie and Young, 2011).

Quartz-magnetite gneiss

In the Mischief Glacier map area, sulphide iron-formation B is stratigraphically overlain by a 30 m thick layer of mostly quartz-magnetite gneiss (Fig. 6h) interpreted to be oxide iron-formation. Another layer of quartz-magnetite gneiss, at least 4 m thick, occurs within semipelitic and psammitic schist in the southern part of the Mischief Glacier map area (Fig. 4). This unit is layered on a millimetre to centimetre scale and consists of chert, garnet-grunerite schist, and hematite-quartz gneiss in addition to quartz-magnetite gneiss. The substantial amount of magnetite in this unit causes a prominent lineament on aeromagnetic survey maps (Coyle, 2009a, b).

Upper Hoare Bay group

Semipelitic and psammitic schist

The upper Hoare Bay group in both the Mischief Glacier and Clephane Bay map areas consists mostly of semipelitic and psammitic biotite±muscovite schist. The Clephane Bay map area has two such packages separated by ultramafic-mafic schist and gneiss C that are stratigraphically distinct, but lithologically indistinguishable (Fig. 5). The lower package, between the Clephane Bay formation and ultramafic-mafic schist and gneiss C, is 780 m thick in the Clephane Bay map area and over 300 m thick in the Mischief Glacier map area. The upper package, exposed only in the Clephane Bay map area, is over 3300 m thick.

Rocks of this unit have centimetre- to decimetre-thick layers. The majority of layers are biotite-plagioclase-quartz±muscovite schist with between 10% and 30% biotite, thought to be metamorphosed wacke. Sillimanite, garnet (2–5 mm), andalusite (<7 mm), and rarely staurolite are present in some outcrops. Calcareous lenses are common. The Clephane Bay map area contains rare examples of graded bedding (Fig. 4, 7e); however, folding hampers reconstruction of the stratigraphic sequence.

Ultramafic-mafic schist and gneiss C

The third sequence of ultramafic to mafic igneous rocks in the Hoare Bay group occurs within the succession of semipelitic and psammitic schist (Fig. 5). The unit is 155–220 m thick and has sharp contacts (Fig. 5). It is mostly composed of fine-grained plagioclase-titanite-hornblende schist and gneiss with a colour index of 75–95. Medium-grained hornblende, clinopyroxene, and plagioclase give the rocks a spotted appearance, and may be relict phenocrysts. About half of the rocks are massive and the others have a pyroclastic fragmental texture. Lapillistone to tuff breccia has deformed fragments (5 mm to 30 cm) and a colour index of 85–95 (Fig. 7f). Plagioclase-rich varioles rarely occur only in fragments. Near the top of the unit there is medium-grained plagioclase-hornblende gneiss (amphibolite) with a colour index of 70–90. No feeder dykes or sills were recognized in the semipelitic and psammitic schist unit.

Garnet-grunerite-quartz gneiss (silicate iron-formation) and chert occur near the top of the unit as 0.5–2 m thick layers and lenses. Gossanous grunerite-pyrite-quartz-graphite gneiss with layers of nearly monomineralic pyrite was found in one outcrop and likely represents sulphide iron-formation.

Quartzite B

A layer or lens of distinctive quartzite lithologies occurs within the upper semipelitic and psammitic schist succession in the Clephane Bay map area, above ultramafic-mafic schist and gneiss C (Fig. 4). The unit is at least 20 m thick, with unknown lateral extent. The quartzite is interlayered on a millimetre to decimetre scale with semipelitic muscovite-biotite-plagioclase-quartz schist to gneiss.

PLUTONIC ROCKS

Hoare Bay group rocks in the Clephane Bay map area were intruded by granitoid, gabbroid, and ultramafic rocks. Most of these were later deformed and metamorphosed, although one generation of pegmatitic granite and diabase intrusions are undeformed.

Granitoid and gabbroid gneiss

There are two lithologically similar units of orthogneiss in the Clephane Bay map area. One, more than 650 m thick, is at the deepest structural level exposed, and another, 80 m thick, is separated from the former by 170 m of pelitic schist (Fig. 5). Two of the three contacts with pelitic schist were observed to be sharp and parallel to foliations; therefore, the contacts could be either intrusive or fault contacts.

Leucogranodiorite to leucomonzogranite gneiss comprise half of the rocks in this unit. They are typically equigranular and fine- to medium-grained, but rarely contain microcline porphyroclasts (3–15 mm) or carbonate-silicate gneiss xenoliths. Biotite±hornblende monzogranite to tonalite gneiss with a colour index of 20–30 and millimetre- to decimetre-thick gneissic bands constitute one quarter of the unit. The remaining quarter consists of layers, centimetres to tens of metres thick, of medium-grained biotite-hornblende gabbro to monzodiorite gneiss with a colour index from 30 to 70 and coarse-grained granofelsic hornblendite.

The gabbroid and granitoid gneisses are closely associated at the outcrop scale and granitoid gneisses are locally cut by gabbroic gneisses and vice versa (Fig. 7g), suggesting coeval emplacement and magma mingling. Intermediate orthogneiss, such as monzodiorite gneiss, could have been formed by magma mixing of granitoid and gabbroid end-members. Gneissosity in both the intermediate-ultramafic gneiss and the leucogranitoid gneiss is cut by leucogranodiorite gneiss veins, indicating there were at least two intrusive phases of leucogranitoid.

Monzogranite augen gneiss

A 30 m thick layer of granite orthogneiss occurs above sulphide iron-formation A in the Clephane Bay map area (Fig. 5). The unit has a tabular shape, does not crosscut any map units, and has a sharp lower contact. Rocks of this unit are mostly fine-grained monzogranite augen gneiss (Fig. 7h) with 5–10% biotite and sparse microcline augen (1–30 mm). Rare centimetre-wide lenses of hornblendite occur in the monzogranite gneiss.

Pegmatitic granite dykes and sills

The Clephane Bay map area contains a number of pegmatitic to coarse-grained granite dykes. They are 30 cm to 25 m wide and the largest are steeply dipping to upright (Fig. 4). They contain minor muscovite, tourmaline, garnet, apatite, biotite, and/or andalusite. Most do not contain discernible tectonic fabrics, except for some dykes in the northwest corner of the Clephane Bay map area that display irregular pinch and swell structure. Isolated, 2–8 cm microcline porphyroclasts within orthogneiss and semipelitic and psammitic schist may be the remnants of dismembered pegmatitic intrusions.

Diabase dykes and sills

An unmetamorphosed 35 m wide diabase dyke and spatially associated 0.5 m thick diabase sill crosscuts the country rock in the northern Mischief Glacier map area. The biotite-magnetite-clinopyroxene diabase dyke has a medium-grained core with a subophitic texture, fine-grained chilled margins, and sharp contacts with the surrounding country rocks. These intrusions are likely part of the ca. 722 Ma Franklin dyke swarm that transects Cumberland Peninsula (Heaman et al., 1992).

STRUCTURES AND TECTONIC FABRICS

The majority of the rocks in both map areas are schist and gneiss with the exceptions of hornblendite granofels, diabase dykes and sills, and most granite pegmatite. The granofels bodies are wrapped by the schistosity or gneissosity of adjacent rocks, suggesting they were relatively competent during deformation and did not develop a tectonic fabric. Diabase intrusions and most pegmatitic granite intrusions are post-tectonic. Rocks in both map areas range from S to L tectonites and the variability appears to be controlled largely by lithology. Sedimentary schist units tend to be S or S>L tectonites, ultramafic and mafic schist and gneiss and garnet-quartz-grunerite gneiss are typically L>S to S>L tectonites, whereas the orthogneiss units tend to be L or L>S tectonites (Fig. 8a). Pyroclastic fragments are always flattened parallel to the mineral schistosity and are often elongate parallel to the mineral lineation (Fig. 8b); although, in several places the fragments are oblate, implying stretching was heterogeneous. All observed lithological contacts are parallel to the dominant schistosity and gneissosity.

Mischief Glacier map area

The rocks of the Mischief Glacier map area dip gently to the north-northwest and the dip increases from north to south (Fig. 3b). Mineral lineations mostly plunge gently or moderately to the west. There are two styles of folds in outcrop, those associated with an axial-planar schistosity (F_2; Fig. 8c), which are common in the northern part of the Mischief Glacier map area, and those that fold this schistosity (F_3; Fig. 8d), which are found mostly in the southern part. An early schistosity (S_1) is recognized only as an internal schistosity in porphyroblasts (Hamilton et al., 2013). Both generations of folds are typically subhorizontal or gently plunging to the west. The map-scale folds are thought to be F_3 folds because they contain minor F_3 folds almost exclusively.

Clephane Bay map area

The Clephane Bay map area consists of the hinge and northern limb of a map-scale west-trending antiform, herein called the Clephane Bay anticline (Fig. 4). On its north limb, lithological units dip moderately to the north-northwest and on the south limb they dip less steeply to the south-southeast, indicating the antiform is steeply inclined to the north (Fig. 4b). Most mineral lineations plunge shallowly to the west.

Folds with an axial-planar schistosity (Fig. 8e) and folds that fold this schistosity (Fig. 8f) are present in the Clephane Bay map area and are thought to be the same two generations of folds as in the Mischief Glacier map area (F_2 and F_3, respectively). Because F_3 folds are common in outcrop in the Clephane Bay map area, many of the map-scale folds are thought to be F_3. This includes the box-shaped gentle antiform and the isoclinal synform formed by folded contact between the Clephane Bay formation and the semipelitic and psammitic schist unit (east side of Fig. 4). The map-scale antiformal fold of ultramafic-mafic schist and gneiss C (west side of Fig. 4) has outcrop-scale F_2 folds in its hinge (Fig. 8e) and is consequently thought to be F_2. The map pattern in the southern part of the area is an elongate dome, which is best

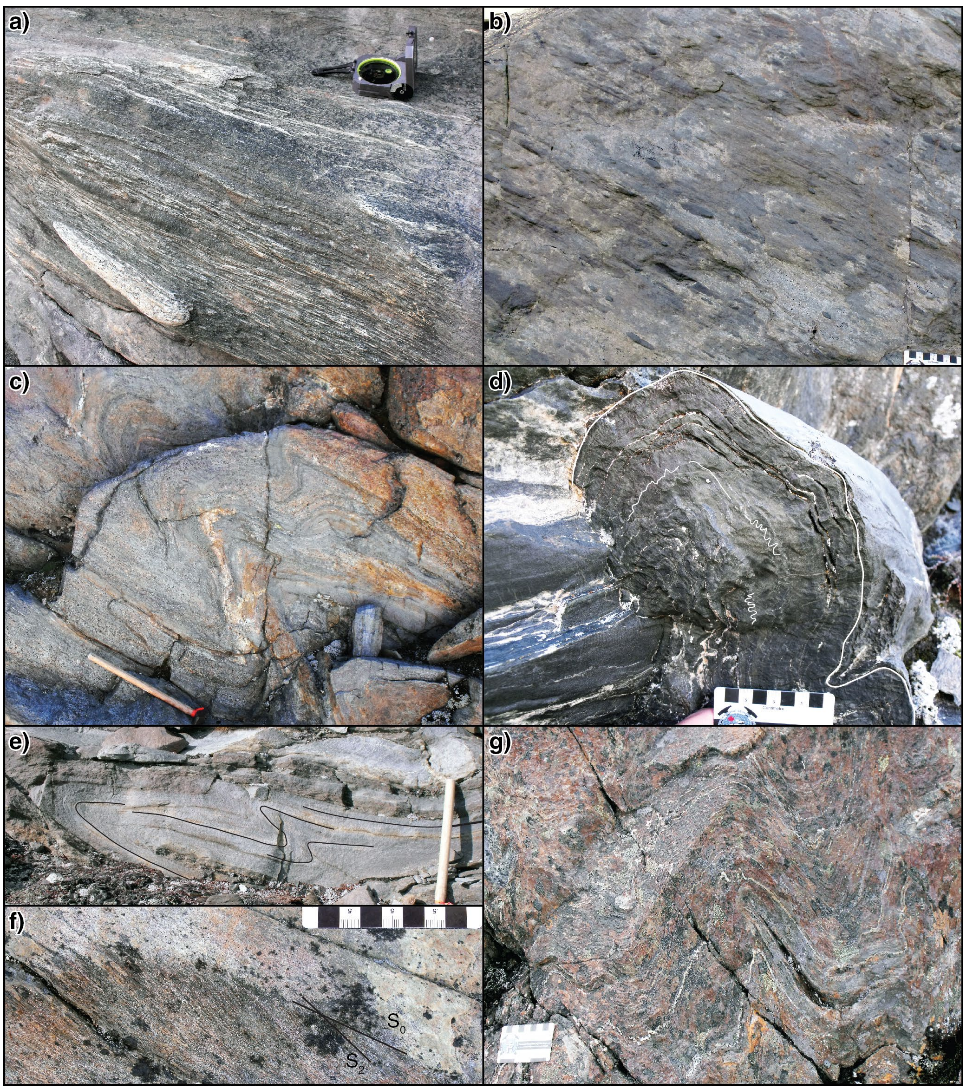

Figure 8. a) L tectonite orthogneiss typical of the granitoid and gabbroid unit; side of the compass is 9 cm long; 2014-052. **b)** Schistosity plane of hornblende schist in the Mischief Glacier area with very elongate pyroclastic fragments parallel to the mineral lineation; 2014-042. **c)** Close folds (F_2) of pelitic schist in the Mischief Glacier area; hammer handle is 59 cm; 2014-044. **d)** Tight, isoclinal, and box-shaped folds (F_3) of hornblende schist in the Mischief Glacier area fold the schistosity. Several layers are traced in white for clarity; 2014-062. **e)** A tight fold and smaller close and open folds (F_2; traced in black) in psammitic schist in the hinge of an overturned antiform in the Clephane Bay area and **f)** a nearby outcrop where the dominant schistosity (S_2) is oblique to the compositional layering (S_0) hammer handle in Figure 8e is 59 cm; e = 2014-055, f = 2014-054. **g)** Close and open folds (F_3) that fold the schistosity (S_2) in semipelitic and psammitic schist in the Clephane Bay area. 2014-053. All photographs by B. Hamilton. All black and white scales are in centimetres.

explained by a roughly north-trending fold. It is not associated with minor folds and is thought to have formed during a late phase of folding (F_4).

The Totnes Road and Clephane Bay formations are each up to 50 m thick; however, they commonly thin to 1–10 m and pinch out locally for at least 1 km of strike length. These features are interpreted to be map-scale boudinage. A granite pegmatite dyke abruptly cuts much of ultramafic-mafic schist and gneiss C. The pegmatite may have intruded along a fault.

METAMORPHISM

Metabasite in the Mischief Glacier and Clephane Bay map areas typically contains plagioclase+hornblende, indicating amphibolite facies. Epidote+plagioclase+hornblende assemblages, characteristic of the epidote-amphibolite facies, occur sporadically. Some metabasite additionally contains chlorite, which, although characteristic of greenschist facies, is stable at amphibolite-facies conditions in Mg-rich metabasite (Spear, 1993), such as that on Cumberland Peninsula (Keim et al., 2011; Keim, 2012).

Muscovite+biotite schist in the Mischief Glacier map area contains staurolite, andalusite, and/or garnet porphyroblasts in addition to 0.1–0.5% fibrolitic sillimanite. Samples have mineral assemblages indicative of three pelite zones: muscovite+sillimanite, muscovite+andalusite, and muscovite+staurolite. These diagnostic assemblages occur interspersed on the map, thus the entire Mischief Glacier map area is muscovite+sillimanite zone of the middle-amphibolite facies.

In the Clephane Bay map area, andalusite and garnet porphyroblasts are common, with sillimanite visible in outcrop. Matrix staurolite is present locally and less commonly than in the Mischief Glacier map area. Mineral assemblages are characteristic of the muscovite+sillimanite and muscovite+andalusite zones. The intermixed distribution of these samples on the map suggests the entire Clephane Bay map area is muscovite+sillimanite zone.

Equilibrium mineral assemblage diagrams calculated for Hoare Bay group rocks constrain the peak pressure-temperature conditions of the muscovite+andalusite zone to 575–610°C and 3.5–4.1 kbar, and the muscovite+sillimanite zone to 575–650°C and greater than 3.5 kbar (Hamilton et al., 2012). The presence of trace amounts of sillimanite overprinting muscovite+andalusite assemblages in the Mischief Glacier map area suggests peak conditions were slightly above muscovite+andalusite zone conditions. Abundant sillimanite in the Clephane Bay map area suggest higher peak conditions in the muscovite+sillimanite zone.

CORRELATIONS BETWEEN THE MISCHIEF GLACIER AND CLEPHANE BAY MAP AREAS

The strata in the Mischief Glacier and Clephane Bay map areas share many lithostratigraphic similarities and are proposed to be correlative. The association of ultramafic-mafic rocks of the Totnes Road formation with iron-formation of the Clephane Bay formation forms the most distinctive marker horizon in the Hoare Bay group. This lithological association was documented in both map areas, with some differences. The Totnes Road formation (and ultramafic-mafic schist and gneiss A) has primary features in the Mischief Glacier map area, but not the Clephane Bay map area. In the Mischief Glacier map area, garnet-quartz-grunerite gneiss is overlain by sulphide iron-formation, with quartz-magnetite gneiss above. In contrast, sulphide iron-formation is overlain by garnet-quartz-grunerite gneiss in the Clephane Bay map area and a quartz-magnetite unit is absent.

In both map areas, dominantly porphyroblastic pelitic schist occurs stratigraphically below the Totnes Road formation, whereas typically nonporphyroblastic semipelitic and psammitic schist occur above the Clephane Bay formation. The contrast between the lower pelitic schist and upper semipelitic and psammitic schist is distinct enough to be mapped in the Clephane Bay map area where both the Totnes Road and Clephane Bay formations pinch out.

If these correlations are accepted, it implies the strata in one of the map areas are entirely overturned. The Totnes Road formation is known to be older than the Clephane Bay formation; therefore, Clephane Bay map area strata are upright, whereas Mischief Glacier map area strata are overturned and the Mischief Glacier map area is the lower limb of a large overturned fold. This lower limb has gently dipping layering and schistosity, and is over 1200 m thick; therefore, the fold may be classified as a fold nappe. This gently or moderately inclined fold nappe may be an F_2 fold because most F_2 folds are likewise gently or moderately inclined (Fig. 3b) or it may be an F_1 fold. Third-generation folds are upright or steeply inclined, so the fold nappe must have formed prior to F_3.

The present-day deformed thickness of each unit in the Mischief Glacier map area is noticeably greater than its correlative counterpart in the Clephane Bay map area (Fig. 5). The thickness variation may be a result of deformation. Alternatively, the stratigraphic thickness may increase to the northeast, consistent with observations made across Cumberland Peninsula (M. Sanborn-Barrie, M. Young, N. Wodicka, J. Whalen, B. Hamilton, R. Keim, R. Berman, and J. Craven, unpub. paper, 2014).

PALEOPROTEROZOIC PLUTONIC HISTORY

The granitoid and gabbroid gneiss units contain carbonate-silicate gneiss xenoliths that were likely sourced from the carbonate-silicate gneiss unit. Such carbonate-silicate rocks were not identified in Archean rocks elsewhere on Cumberland Peninsula; the most similar Archean rock is limy arenite (Sanborn-Barrie et al., 2011b), which lacks the more than 50% carbonate minerals found in the xenoliths. Therefore, the leucogranodiorite-leucomonzogranite gneiss intruded into the Hoare Bay group in the Orosirian or later. In addition to carbonate-silicate gneiss xenoliths, this unit is distinguishable from Archean tonalite-granodiorite and tonalite gneiss by the common presence of muscovite and thick packages of hololeucocratic granitoid gneiss.

The plutonic rocks exposed in the Clephane Bay map area are a part of a more than 60 km long band of Paleoproterozoic tonalite-trondhjemite-granodiorite-syenite suite rocks (Sanborn-Barrie et al., 2011c, 2013a; Whalen et al., 2012). Leucocratic gneiss of the granitoid and gabbroid gneiss unit likely correlate with monzogranite aplite gneiss from this suite that yielded a U-Pb zircon crystallization age of 1873 ± 16 Ma at a locality 8 km west of the Clephane Bay map area (Rayner et al., 2012; Whalen et al., 2012).

Gabbroid to ultramafic gneiss of the granitoid and gabbroid gneiss unit, at least in part, both cut and is cut by leucogranitoid gneiss (Fig. 7g), implying at least some gabbroid-ultramafic gneiss is younger than both the Hoare Bay group and some of the leucogranitoid gneiss. The mutually crosscutting relations suggest they intruded contemporaneously, likely at ca. 1873 Ma.

LITHOSTRATIGRAPHIC COMPARISON OF THE HOARE BAY GROUP AND KARRAT GROUP

The Hoare Bay group, as described from reconnaissance studies, has been correlated with the Piling Group on central Baffin Island and the Karrat Group on west Greenland (St-Onge et al., 2009), and also supracrustal rocks on Hall Peninsula on southeast Baffin Island (Jackson, 2000; Corrigan et al., 2009). Testing the correlation between the Hoare Bay group and the stratigraphy under Hall Peninsula will be more conclusive once an ongoing study of the Hall Peninsula bedrock is complete (Machado et al., 2013). Whereas the possible correlation of the Piling and Hoare Bay groups has been discussed recently (Sanborn-Barrie and Young, 2011; Keim, 2012), the potential Hoare Bay group-Karrat Group correlation remains untested.

The Karrat Group consists of the laterally equivalent Qeqertarssuaq and Mârmorilik formations underlying the Nûkavsak Formation (Henderson and Pulvertaft, 1987). The Mârmorilik Formation is mostly a thick carbonate succession and dissimilar to the Hoare Bay group. The Qeqertarssuaq Formation consists mainly of porphyroblastic semipelitic to pelitic schist, quartzite, impure quartzite, and subordinate biotite amphibolite, actinolite-rich schist units, and minor marble with a combined structural thickness of up to 3 km. It is similar to the pelitic schist, quartzite A, carbonate-silicate gneiss, and sulphide iron-formation A units of the lower and middle Hoare Bay group. Quartzite-dominated strata can comprise over half of the Qeqertarssuaq Formation. Although considerably less quartzite was observed in the Mischief Glacier and Clephane Bay map areas, elsewhere on Cumberland Peninsula the Hoare Bay group contains appreciable quartzite (Sanborn-Barrie et al., 2011a, 2013a). Altered ultramafic lenses (mostly tremolite+talc) within the Qeqertarssuaq Formation are similar to the hornblendite sills and dykes unit in the Hoare Bay group except for the extent of alteration. The Qeqertarssuaq Formation has no units similar to ultramafic-mafic schist and gneiss A.

A marker horizon at the top of the Qeqertarssuaq Formation consists of hornblende schist and amphibolite. Amphibolite with 50–90% green amphibole are similar to rocks of the Totnes Road formation. Biotite-cummingtonite-hornblende±garnet schist in the Qeqertarssuaq Formation marker unit is similar to rocks of the garnet-quartz-grunerite gneiss unit.

The base of the overlying Nûkavsak Formation consists of a quartz-pebble 'conglomerate' with a pyrrhotite-graphite matrix, similar to the durchbewegung-structured semimassive pyrite unit in the Clephane Bay formation. Monotonous interlayered granular nonporphyroblastic semipelite, with local graded bedding and rare crossbedding, channels, and flute casts (Grocott and Vissers, 1984), comprise the majority of the more than 4 km thick Nûkavsak Formation. Layers and lenses of siliceous calc-silicate and nonporphyroblastic pelitic schist are common. It is similar to the semipelitic and psammitic schist unit of the Hoare Bay group. Locally, the Nûkavsak Formation includes a 100 m thick succession of quartzite, marble, and calc-silicate rocks overlain by metavolcanic rocks including pillow basalt, pillow breccia, and hyaloclastite tuff (Grocott and Vissers, 1984). Ultramafic-mafic schist and gneiss C is crudely similar to these volcanic rocks, but is not associated with quartzite, marble, or calc-silicate rocks.

The overall lithostratigraphic similarities shared by Hoare Bay group in the Mischief Glacier and Clephane Bay map areas and the Qeqertarssuaq and Nûkavsak formations supports correlation of the Hoare Bay group with the Karrat Group by St-Onge et al. (2009); however, with the exception of the Totnes Road formation and upper Qeqertarssuaq marker unit, the volcanic units are not easily correlated, suggesting divergent volcanic histories for different parts of the basin.

CONCLUSIONS

Mapping two areas on Cumberland Peninsula that underwent relatively little deformation and metamorphism refined the stratigraphy of the Hoare Bay group and provided pertinent insights into the Paleoproterozoic intrusive history of the peninsula.

There is a distinct change in the nature of the clastic sedimentary rocks on either side of the Totnes and Clephane Bay formations. Porphyroblastic pelitic and semipelitic schist is common in the lower Hoare Bay group, whereas nonporphyroblastic semipelitic to psammitic schist dominates the upper Hoare Bay group.

The lower, middle, and upper parts of the Hoare Bay group each contain a unit with ultramafic to mafic pyroclastic rocks.

The Mischief Glacier map area strata are overturned with respect to Clephane Bay map area strata. The Mischief Glacier map area strata were gently dipping prior to F_3 folding, implying the existence of a pre-F_3 fold nappe with a more than 1200 m thick overturned limb.

Gabbroid sills and dykes intruded into one of at least two generations of Paleoproterozoic granitoid rocks in the Clephane Bay map area.

Future studies should aim to understand the depositional environments for the Hoare Bay group, a challenging proposition due to deformation and metamorphism, and ultimately develop a basin-tectonic model.

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