Summary of Bedrock Geology Mapping in the Robertson and Palmer Lakes Area, Glennie Domain, Reindeer Zone

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Abstract

Bedrock mapping was completed in the area surrounding Robertson and Palmer lakes in north-central Saskatchewan in the summer of 2018 at a scale of 1:20 000. This work is the western extension of adjacent mapping in 2017, centred on Wapassini and Glennie lakes. The area around Robertson Lake is dominated by sedimentary rocks, and is part of the Kyaska lithotectonic sheet. The Palmer Lake area is underlain by abundant intermediate plutonic rocks and minor mafic volcanic and associated gabbroic rocks, and is part of the Wapassini lithotectonic sheet. Syntectonic, anatectic, quartzofeldspathic intrusive rocks generated during the regional D_2 event, and syn- to post-tectonic medium-grained to pegmatitic granite were emplaced across the entire area.

The main regional foliation trends east-northeast and represents a composite S_1/S_2 fabric resulting from isoclinal F_2 folding of the original S_1 fabric. Map-scale F_3 folds are open to close, upright, and northwest trending, whereas F_4 folds are open to close, typically coaxial to F_2 folds, and east-northeast trending. East of Robertson Lake, a basin structure, defined by mafic volcanic rocks and gabbroic rocks, has resulted from F_3 - F_4 fold interference. A number of high-strain zones were mapped this summer, including a discontinuous zone that marks the boundary between the Kyaska and Wapassini lithotectonic sheets; a large corridor of consistently high-strained rocks surrounding Nugent Lake termed the Nugent Lake high-strain corridor; and the Boyce Lake high-strain zone, which is a mylonite zone that delineates the boundary between the Wapassini and Cartier lithotectonic sheets. Rocks in the mapped area have been metamorphosed under upper amphibolite–facies conditions.

The mapped area is centred 30 km west of the Seabee gold operation and 35 km north of the Pitching Lake copper deposit. Based on regional geological considerations and anomalously high gold and copper assays from samples collected in 2017, it is believed that the area has some potential to host orogenic gold and volcanogenic massive sulfide deposits.

Keywords: *Reindeer Zone, Trans-Hudson Orogen, Glennie Domain, Robertson Lake, Palmer Lake, Paleoproterozoic, Kyaska lithotectonic sheet, Wapassini lithotectonic sheet*

1. Introduction

During an eleven-week field season in the summer 2018, the bedrock geology of an approximately 160 km^2 area surrounding Robertson and Palmer lakes was investigated. The area is approximately 40 km northeast of the nearest town of Missinipe, Saskatchewan (Figure 1) and lies within National Topographic System (NTS) map sheets 73P/09 and 73P/16. This 1:20 000-scale mapping project continues west and southwest of the Wapassini–Glennie lakes

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area previously mapped by Maxeiner and Kaczmer (2017). One inch to one mile (1:63 360) geological maps from the 1950s and 1960s, and accompanying reports (Budding, 1955; Padgham, 1966), also served as a basis for this investigation.

The aim of this investigation is to improve the geological understanding of the Glennie Domain through detailed 1:20 000-scale bedrock mapping with accompanying analytical work. This contributes to the interpretation of the region's tectonic history and assessment of its economic mineral potential.

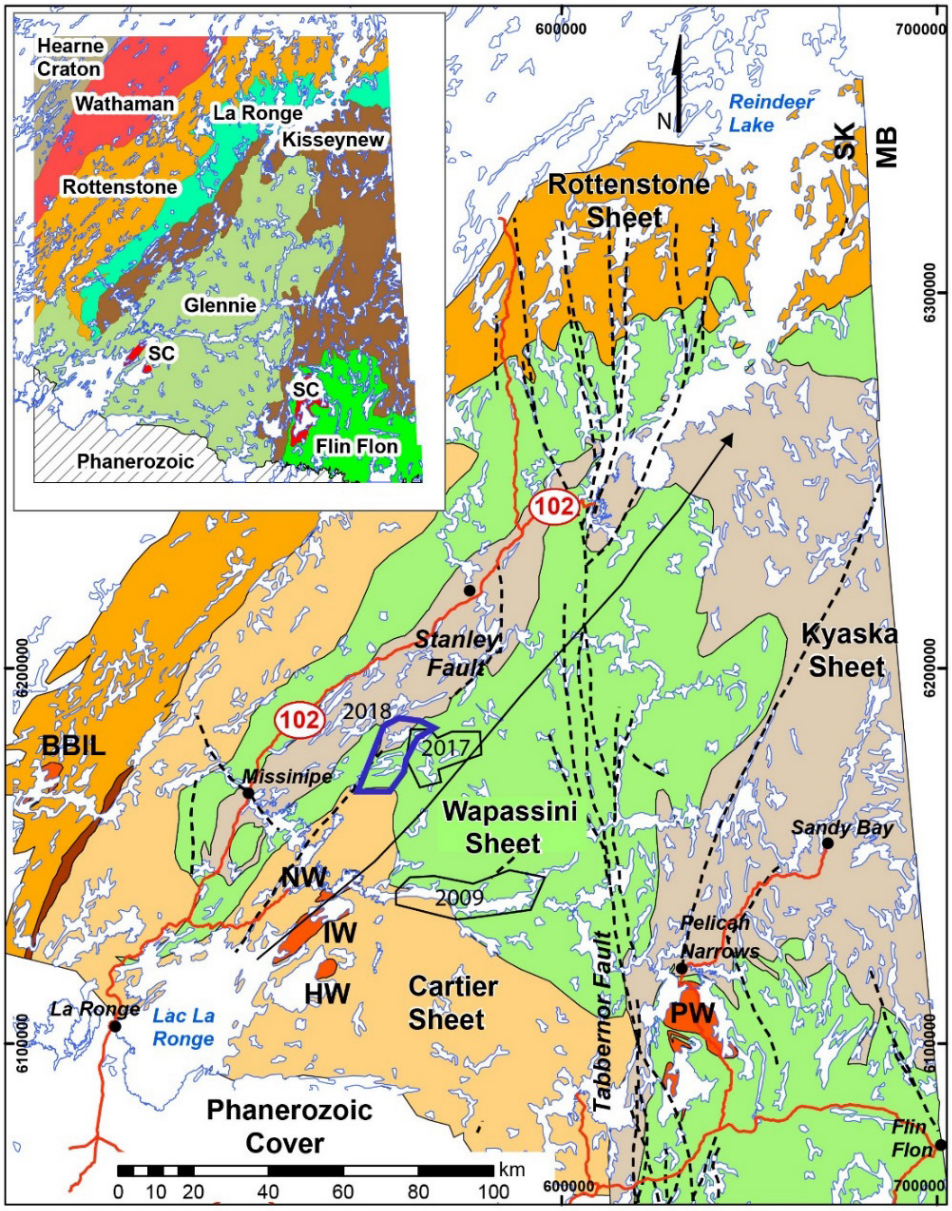

***Figure 1** – General location of the study area (blue polygon) relative to interpreted boundaries of thrust sheets within the Reindeer Zone of northern Saskatchewan* (modified from *Lewry* et al.*, 1990), and relative to the lithotectonic domain subdivisions (inset; SC = Sask craton). The 2018 map area is denoted by a bold blue line, whereas the 2017 and 2009 map areas are outlined in black. The long arrow shows approximate axial trace of the northeast-trending D_4 anticlinorium. Dashed lines represent regional faults. Inliers of Archean to Siderian rocks: Black Bear Island Lake window (BBIL); Hunter Bay window (HW); Iskwatikan window (IW); Nistowiak window (NW); and Pelican window (PW). Other abbreviations: MB = Manitoba; SK = Saskatchewan. (All UTM coordinates in this document are in North American Datum 1983 (NAD83), Zone 13.)*

2. Regional Geology

The Robertson–Palmer lakes area is within the Paleoproterozoic Trans-Hudson Orogen (THO), an extensive collision zone between several Archean cratons separated by intervening Paleoproterozoic island arcs (Lewry, 1981; Hoffman, 1988). The Reindeer Zone (Stauffer, 1984) comprises primitive to evolved volcanic arc rocks, sedimentary basins, and a variety of arc plutons that formed between 1.92 and 1.83 Ga during closure of the Manikewan Ocean (Stauffer, 1984; Bickford *et al.*, 1990; Hoffman, 1990; Lewry *et al.*, 1990). Juvenile intra-oceanic rocks were amalgamated into a collage (Flin Flon–Glennie Complex; Ashton *et al.*, 1997) prior to continental collisions involving the Hearne, Superior and Sask cratons.

The Reindeer Zone has historically been divided into the Wathaman, Rottenstone, La Ronge, Kisseynew, Flin Flon, and Glennie domains (Figure 1, inset); the project area lies within the central part of the latter. An alternative lithostructural subdivision of the Reindeer Zone by Lewry *et al.* (1990) highlights the gross three-dimensional structural geometry and is characterized by polydeformed and stacked allochthonous thrust sheets (*e.g.*, Cartier, Wapassini and Kyaska sheets, from structurally lowest to highest; Figure 1) that are inferred to be separated by D_2 high-strain zones. Within this lithostructural framework, the Robertson–Palmer lakes area straddles the boundary between the Kyaska and Wapassini sheets.

Ages of rocks, and deformational events within the Wapassini and Kyaska sheets are summarized in Figure 2. Regional peak metamorphic conditions in the Wapassini sheet vary from lower to upper amphibolite–facies (Ashton *et al.*, 2009) and were attained between *ca.* 1.81 to 1.79 Ga (Syme *et al.*, 1998) in the eastern and central Reindeer Zone.

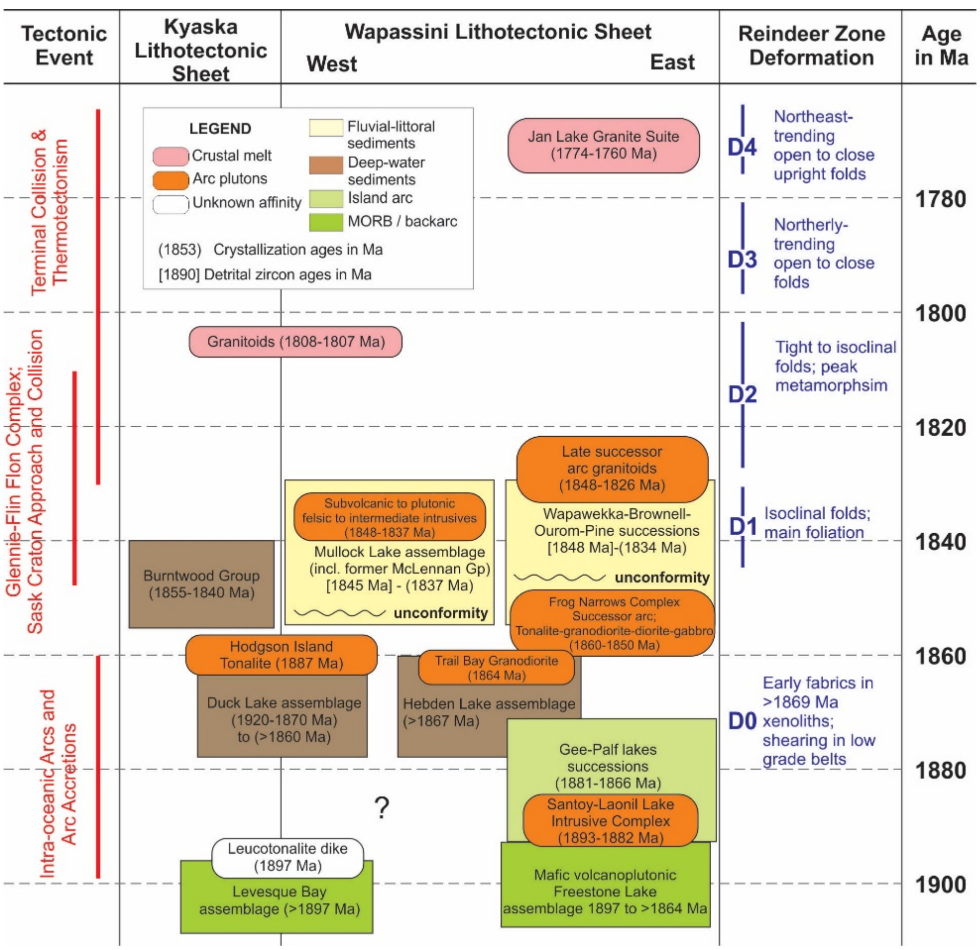

***Figure 2 –** Inferred geological history of the Wapassini thrust sheet, including relevant rocks from the Kyaska thrust sheet; deformational events and ages* adapted from *Saskatchewan Geological Survey (2003), Ashton* et al. *(2005), Zwanzig (1999, 2008), Maxeiner* et al. *(2010) and Maxeiner* et al. *(2015).*

3. Previous Work

Previous bedrock geological mapping in the Robertson Lake area was conducted by Budding (1955), and in the Palmer Lake area by Padgham (1965). Early mapping in the Wapassini Lake area was conducted by Johnston (1968).

The central Glennie Domain mapping project was initiated by Maxeiner and Normand (2009) in the Trade Lake area, approximately 40 km to the southeast of the present study area. After a hiatus of eight years, bedrock mapping on the project was continued directly east of this year's study area by Maxeiner and Kaczmer (2017). Based on this previous work, the rocks interpreted to be the oldest are mafic volcanic rocks and mafic calc-silicate gneisses of the 1897 to >1864 Ma Freestone Lake assemblage, which are interpreted as oceanic crust (Maxeiner *et al.*, 2013a). They are overlain by a sequence of supracrustal rocks, which likely equate to the siliciclastic-dominated Hebden Lake assemblage that was deposited between *ca.* 1870 and 1860 Ma (Rayner *et al.*, 2009; Maxeiner *et al.*, 2012; Maxeiner and Rayner, 2016). The intermediate volcanic rocks and calcic psammopelitic rocks in the 2017 map area were correlated to the lower Hebden Lake assemblage, and the psammopelitic to pelitic rocks were correlated to the upper Hebden Lake assemblage (Maxeiner and Kaczmer, 2017). Gabbroic to granodioritic rocks of the 1860 to 1850 Ma Frog Narrows complex intruded the supracrustal rocks (Lewry, 1981; Maxeiner *et al.*, 2013a).

The structure in this central part of the Glennie Domain is extremely complex due to multiple folding events. Previous attempts to explain the nature and sequence of folding (Padgham, 1966; Lewry, 1977; Lewry *et al.*, 1990) have been summarized by Maxeiner and Kaczmer (2017) who interpreted the complicated map pattern as resulting from type 1–type 2 fold interference. In their scheme, D_2 structures are preserved as outcrop-scale isoclinal F_2 folds that are overprinted by north- to northwest-trending F_3 folds and northeast-trending F_4 folds (Maxeiner and Kaczmer, 2017).

Maxeiner and Kaczmer (2017) inferred upper amphibolite–facies conditions that developed during the D_2 event (Lewry, 1977). Emplacement of derived anatectic leucotonalite to leucogranite was interpreted to span development of the D_2 and D_3 structures (Maxeiner and Kaczmer, 2017).

4. Field Access and Methods

Data collection was completed in two-person teams. Shoreline outcrops were accessed using rigid inflatable boats and inland outcrops were accessed on foot. Rugged handheld tablets (Trimble, Yuma 2) were used for navigation and data collection. Junior assistants collected magnetic data using a KT-10 magnetic susceptibility meter, and gamma radiometric data (concentrations of U, Th and K) using an RS-230 handheld spectrometer.

The area covered in 2018, approximately 160 km^2, was affected by a series of forest fires in the 1990s that has resulted in dense new growth and deadfall. The best exposures were found on shorelines and topographic highs such as at Ahasew Lake (Figure 3). Topographic relief ranges from 470 m east of Propp Lake to about 362 m at Boyce Lake. Lake levels were relatively high this summer, leaving the best exposed shoreline outcrops underwater.

5. Rock Descriptions[3]

The map area can be divided into two geological regions. The Roberson Lake area is dominated by sedimentary rocks of the Kyaska thrust sheet, whereas the Palmer Lake area contains predominantly igneous, mainly plutonic, rocks of the structurally underlying Wapassini thrust sheet (Figure 3). The southern edge of the map area corresponds with the boundary between the Wapassini and Cartier thrust sheets (Figure 3).

[3] As all the rocks in the study area, except for some of the late pegmatites, have been metamorphosed, the prefix 'meta' has been omitted in the discussion of the rock units.

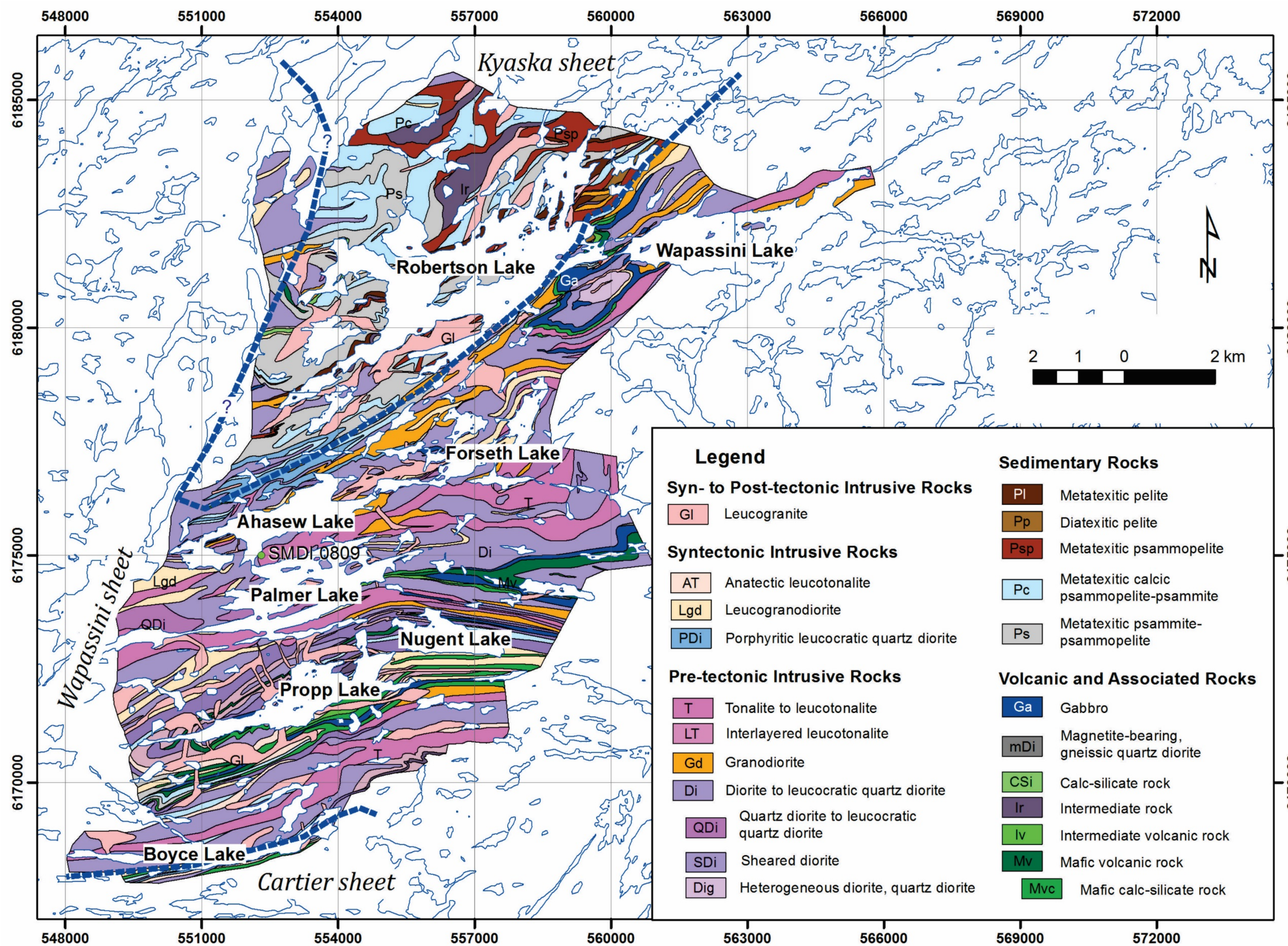

***Figure 3 –** Simplified bedrock geology for the Robertson–Palmer lakes area, based on accompanying 1:20 000-scale map. Updated boundaries between the Kyaska and Wapassini thrust sheets and the Wapassini and Cartier thrust sheets are denoted by dashed navy lines.*

Many of the sedimentary and plutonic rocks have been partially melted to varying degrees, creating migmatites[4]. Mafic to intermediate rocks[5] are relatively less affected by partial melting; however, they appear to have been recrystallized. As such, no primary features have been recognized in any of the supracrustal rocks, apart from compositional layering that has been transposed and enhanced by tectonism.

In the descriptions that follow, rock codes in brackets after a rock type (*e.g.*, '(**unit Mv**)') are keyed to the legend in Figure 3, and are the same as those on the accompanying map.

a) Mafic to Intermediate Igneous Rocks

The perceived oldest unit comprises mafic volcanic rocks and amphibolite (**unit Mv**). This unit occurs most commonly in the Wapassini sheet as xenoliths within intermediate plutons, and as 10 to >100 m thick layers, transposed parallel to the main regional S_1/S_2 foliation. These mafic volcanic rocks are dark grey, black or greenish black. They are fine to very fine grained, equigranular, and typically contain millimetre- to centimetre-scale compositional layering (Figures 4A and 4B). A typical mineral assemblage includes hornblende and subordinate plagioclase, along with minor garnet, epidote, pyroxene and sulfide minerals. Where the mafic volcanic rocks have been sheared, biotite has variably replaced the hornblende. Mafic volcanic rocks and amphibolite commonly contain injected millimetre- to centimetre-scale, leucotonalitic to leucogranodioritic leucosome, locally leucogranitic (Figure 4A), and metre-scale, coarse to very coarse tonalite to granodiorite has been injected in the Propp Lake area. Mafic calc-silicate rocks (**unit Mvc**) are commonly interlayered with, or laterally grade into, the mafic volcanic rocks. The mafic calc-silicate rocks are fine to very fine grained, and composed of centimetre- to millimetre-scale, layered, light grey, dark grey, green, black and locally orange rock (Figure 4C). The layering is defined by alternating hornblende-rich and calc-silicate–rich (diopside, epidote, actinolite) compositions. This unit locally contains trace sulfide minerals and titanite, and is interpreted as an altered version of unit Mv. These units are interpreted to have been derived from volcanic flows and minor gabbroic sills.

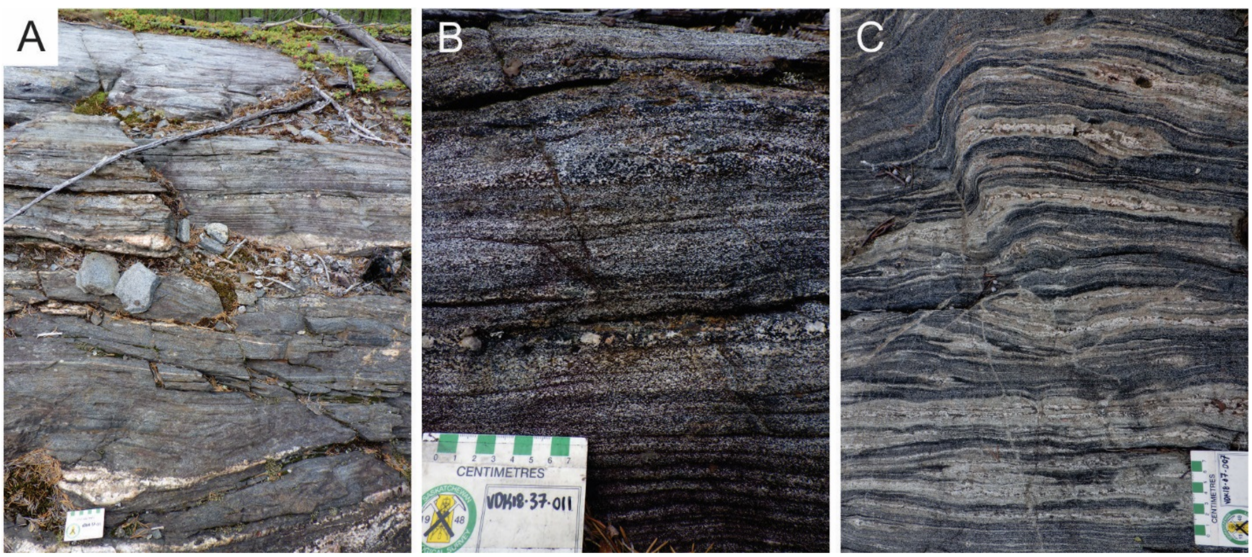

***Figure 4 –** Outcrop photographs of mafic volcanic rocks and associated mafic calc-silicate rocks. **A)** Outcrop of mafic volcanic rocks (bottom) grading into intermediate volcanic rocks (top) with millimetre-scale compositional layering and centimetre-scale, layer-parallel, leucogranitic leucosome; station VDK18-37-011 (UTM 557461E, 6174250N). **B)** Detailed view of mafic volcanic rocks displaying slight variations in grain size and compositional layering; station VDK18-37-011 (UTM 557461E, 6174250N). **C)** Compositional layering in mafic calc-silicate rock; station VDK18-07-007 (UTM 559519E, 6181681N). (Note: station numbers correspond to those on accompanying map.)*

[4] When describing these migmatitic rocks, terminology follows an 'in-house' classification (Maxeiner *et al.*, 2017). Description of plutonic and sedimentary rocks follows the IUGS classification of igneous rocks (Streckeisen, 1976) and an 'in-house' classification of metamorphosed clastic sedimentary rocks (Maxeiner *et al.*, 1999), respectively.
[5] A metamorphic colour index (CI) is used to classify igneous rocks. This index refers to the percentage of mafic minerals present. Mafic rocks are defined as having a colour index greater than 35, intermediate rocks have a CI of 35 to 15 and felsic rocks are less than 15.

A unit of intermediate rock (**unit Ir**) is most abundant north of Robertson Lake, and is quartz dioritic to dioritic in composition, homogeneous, grey or salt-and-pepper in colour, and fine to medium grained (Figures 5A and 5B). The intermediate rock commonly contain 5 to 10% centimetre-scale injected tonalitic stromatic leucosomes, but lack melanosomes. It is locally interlayered with psammopelitic or calcic psammopelitic rocks. This unit may have an intermediate volcanic rock protolith; however, it is also possible that it is derived from sheared dioritic plutons, relatively finer-grained dioritic dykes or sills, or a combination of all three.

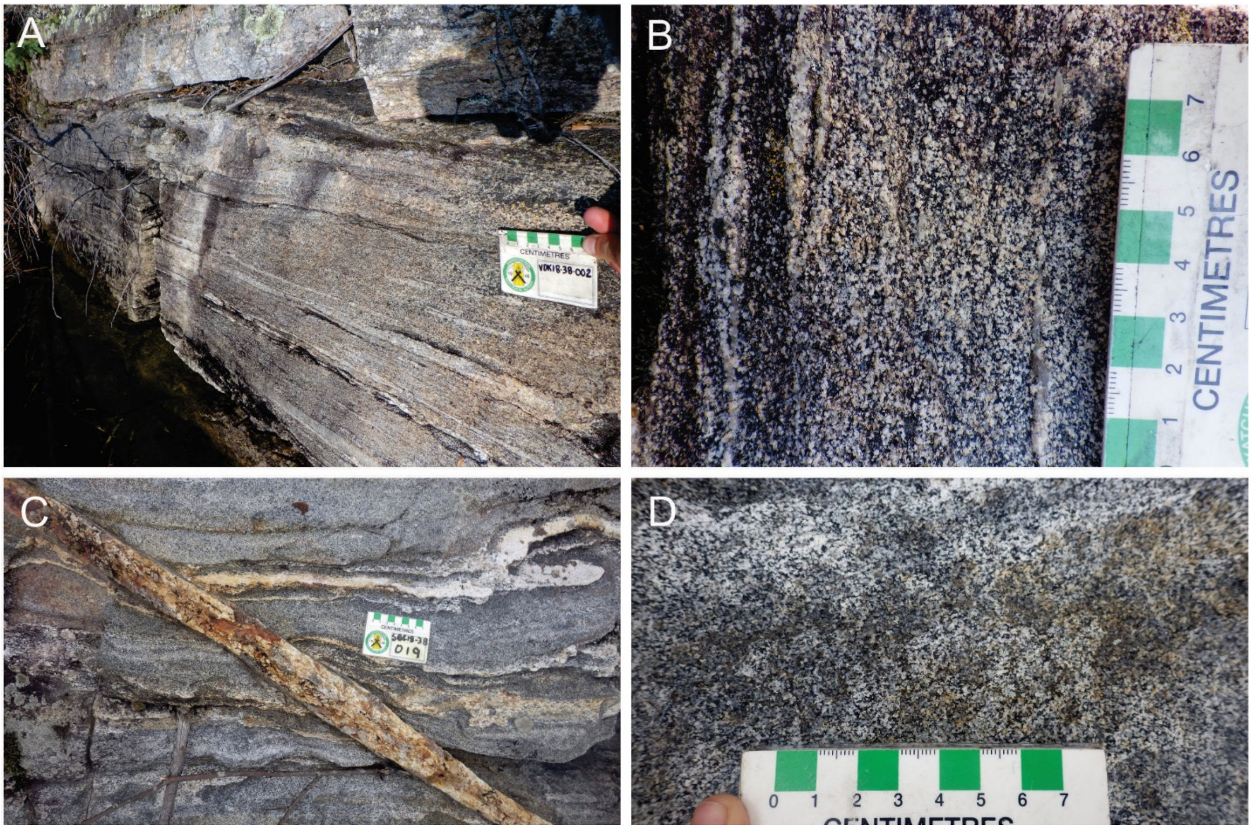

***Figure 5 –** Outcrop photographs of intermediate rocks and intermediate volcanic rock. **A)** Intermediate rock with sheared leucosomes, possibly intermediate volcanic rock, or sheared diorite; station VDK18-38-002 (UTM 554405E, 6172569N). **B)** Close-up of intermediate rock in A. **C)** Intermediate volcanic rock with* in situ *leucosome; station SBt18-38-019 (UTM 553086E, 6171220N). **D)** Close-up of intermediate volcanic rock in C.*

Intermediate volcanic rock (**unit Iv**), associated with unit Mv, has a colour index of 15 to 35, and is light grey to brownish grey, typically fine grained and equigranular (Figures 5C and 5D). This unit is composed of plagioclase, hornblende, biotite, accessory titanite, local diopside, and local trace sulfide minerals, the latter of which produces a light orange-brown colour on some weathered surfaces. Intermediate volcanic rocks locally have slight compositional layering, and, similar to unit Mv, commonly contain layers of *in situ* and injected leucocratic tonalite to granodiorite. The intermediate volcanic rocks are interpreted to have been derived from intermediate volcanic flows or volcaniclastic rocks.

Calc-silicate rock (**unit CSi**) occurs as concordant, discrete, metre-scale zones in the northwest portion of the Robertson Lake area, not associated with any rock type in particular. The calc-silicate rocks are aphanitic to fine grained, and layered on a centimetre scale with white, green and locally orange-coloured rock. Layers are defined by variable proportions of quartz, plagioclase, diopside, epidote, carbonate, an unidentified orange mineral, and accessory titanite (Figure 6). Unit CSi commonly contains vuggy pores on its weathered surface, possibly due to dissolution of carbonate minerals. No protolith was determined for this rock unit; it is interpreted simply as an alteration rock.

***Figure 6 –** Outcrop photograph of calc-silicate rock displaying variation in colour and vuggy weathered surface; station VDK18-12-008 (UTM 554191E, 6181878N).*

There are elongate, attenuated outcrops of gabbro (**unit Ga**), typically associated with the mafic volcanic and mafic calc-silicate rocks. These rocks are medium to coarse grained, homogeneous, and massive to strongly foliated or lineated, and dark in colour (colour index (CI) of 35 or greater; Figures 7A and 7B). Typical gabbro is composed of hornblende and plagioclase, with local clinopyroxene and trace sulfide minerals. At some outcrops, the gabbro is net-textured due to centimetre-scale veinlets of injected leucocratic tonalite or granodiorite.

***Figure 7 –** Outcrop photographs of gabbro. **A)** Homogeneous and massive gabbro; station VDK18-06-017 (UTM 558994E, 6181009N). **B)** Coarse, lineated gabbro; station VDK18-02-008 (UTM 559186E, 6180529N).*

Gneissic quartz diorite containing garnet and magnetite (**unit mDi**) is exposed as a thin, metre-scale sliver southeast of Palmer Lake, where it is spatially associated with gabbro and mafic volcanic rocks and amphibolite. The gneissic quartz diorite is fine to medium grained, strongly foliated to potentially sheared, and has 15% transposed millimetre- to centimetre-scale leucosome (Figure 8). It is composed of quartz, plagioclase, hornblende, biotite, garnet and magnetite (average magnetic susceptibility (MS) of 11.8). This rock has a colour index of 20 with a quartz content of 30% or more, which is too high for a quartz diorite; however, this anomalous quartz content is interpreted as predominantly secondary. While this rock was given a plutonic name, the protolith is uncertain.

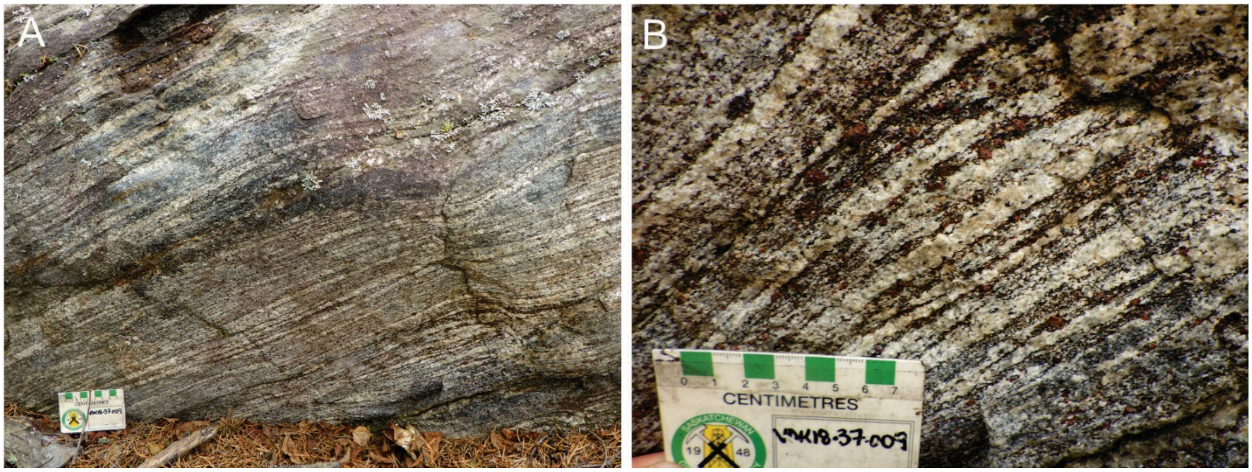

Figure 8 – *Outcrop photographs of the garnet- and magnetite-bearing, gneissic quartz diorite; station VDK18-37-009 (UTM 558251E, 6174136N).* ***A)*** *Overview of gneissic texture.* ***B)*** *Detail showing the quartzofeldspathic gneissic quartz diorite containing garnet and magnetite, termed a stromatic migmatite, displaying abundant leucosome and accompanying melanosome.*

b) Sedimentary Rocks

The area surrounding Robertson Lake in the Kyaska thrust sheet is dominated by metatexitic psammite to psammopelite (**unit Ps**) (Figures 9A and 9B). These rocks are typically grey, or less commonly brownish grey, fine grained, equigranular and contain 5 to 15% (locally up to 25%) combined biotite, garnet, and, rarely, sillimanite. The unit is dominated by psammitic layers, but in some locations contains centimetre- to metre-scale layers of psammopelite or pelite, and locally comprises a near-equal mix of interlayered psammite and psammopelite. The foliation is typically defined by stromatic leucosome, with the paleosome being homogeneous and massive to weakly foliated. The rock contains 5 to 50% *in situ* and injected white, medium- to coarse-grained, tonalitic to granodioritic leucosome. Most leucosome occurs as centimetre-scale, *lit-par-lit* layers, however, wider, decimetre-scale layers and patch-textured metatexites are also common. Psammitic layers contain up to 35 to 55% quartz, along with plagioclase, biotite, garnet and locally graphite.

Outcrops of metatexitic calcic psammopelite to psammite (**unit Pc**) are also extensive in the Robertson Lake area and range from a stromatic metatexite to nebulitic metatexite. Its paleosome is light grey, fine grained, quartzofeldspathic, and contains 15 to 25% combined biotite, garnet and hornblende, with minor local graphite, titanite, diopside, epidote, carbonate and pyrrhotite. Hornblende is common within the *in situ* leucosome (Figure 9C), although locally very coarse porphyroblasts of tremolite were observed instead. There are commonly centimetre-scale layers of intermediate rock within this unit (Figure 9D), interpreted as thin layers of intermediate volcaniclastic rock.

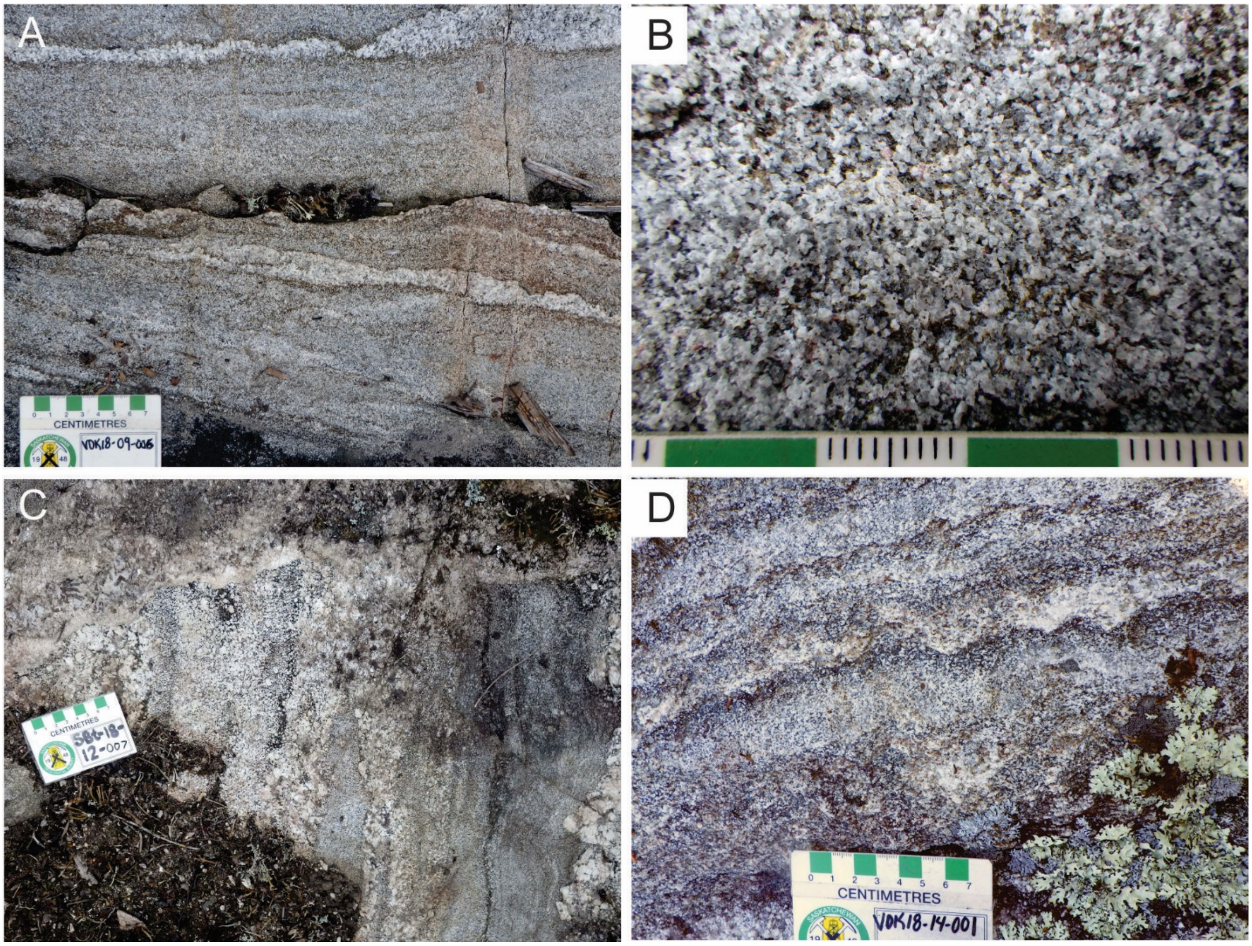

Figure 9 – *Outcrop photographs of psammite to psammopelite and calcic psammopelite to psammite.* ***A)*** *Overview of psammite outcrop with* in situ *leucosome; station VDK18-09-005 (UTM 559092E, 6182687N).* ***B)*** *Close-up of psammite displaying mauve garnet porphyroblasts within a quartzofeldspathic fine-grained rock; same station as A.* ***C)*** *Calcic psammopelite showing* in situ *leucosome with dioritic composition, cut by very coarse leucogranite (top of photo); station SBt18-12-007 (UTM 555718E, 6179336N).* ***D)*** *Detail of calcic psammopelite with thin layers of intermediate rock; station VDK18-14-001 (UTM 557730E, 6181300N).*

Metatexitic psammopelite (**unit Psp**) is also abundant in the northern portion of the map area, surrounding Robertson Lake. It is typically a tan to brownish grey colour, fine to medium grained, and includes 10 to 40% medium- to coarse-grained, centimetre-scale, *in situ* tonalitic to granodioritic leucosome (Figures 10A and 10B). The rocks are moderately to strongly foliated with stromatic to patch leucosome that locally increases in abundance to become diatexitic. Centimetre- to metre-scale interlayered psammite and pelite layers account for approximately 20% of the unit. In addition to quartz and feldspar, the metatexitic psammopelite contains 10 to 25% biotite, 2 to 10% garnet, minor graphite and local muscovite. Magnetic susceptibility readings for this unit are typically below 1 (10^{-3} SI units), however, one outcrop north of Robertson Lake, at its east edge, yielded an average reading of 37, and a maximum of 60.

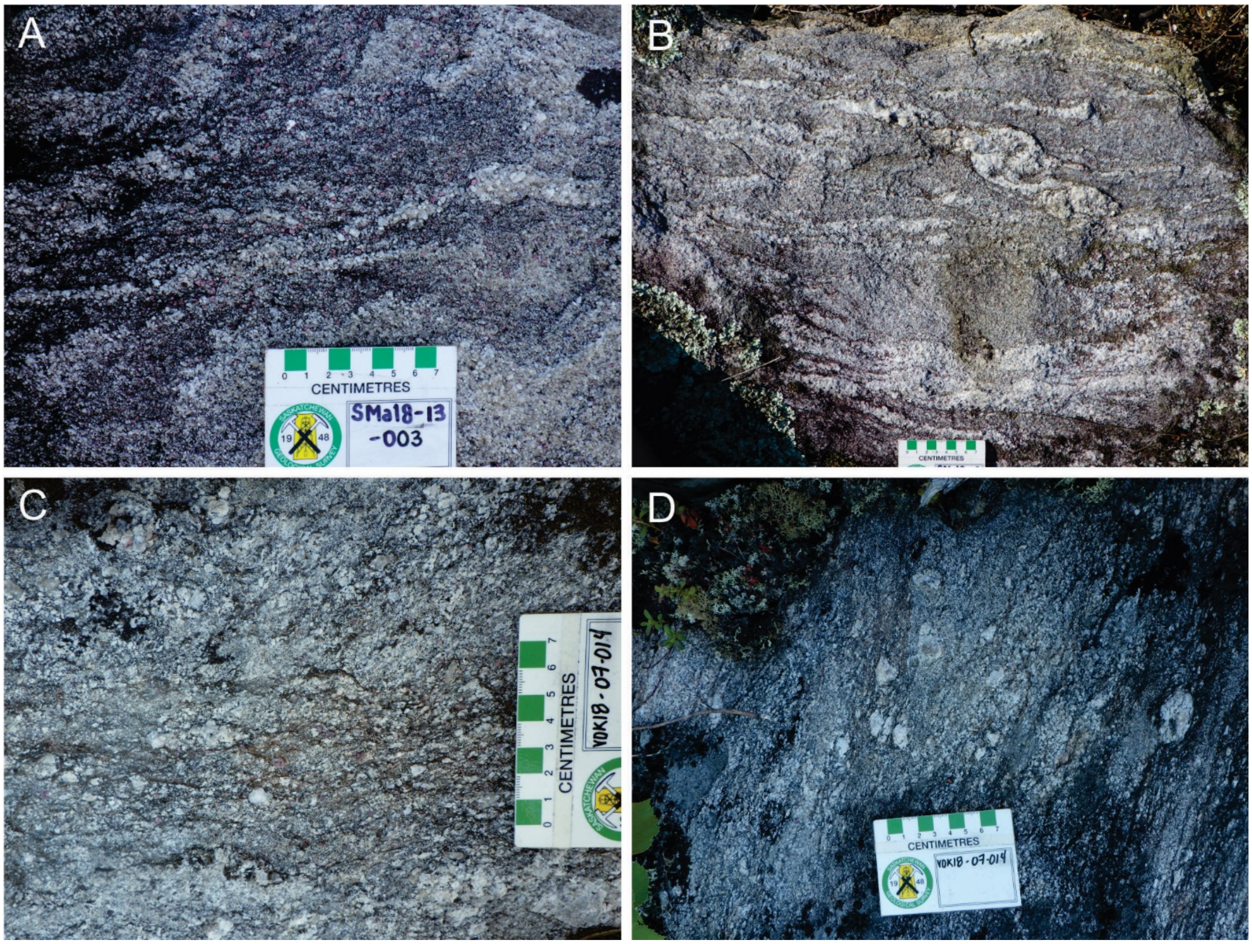

***Figure 10** – Outcrop photographs of metatexitic psammopelite and diatexitic pelite. **A)** Detail of metatexitic psammopelite displaying abundant mauve-coloured garnet, biotite and leucosome; station SMa18-13-003 (UTM 555752E, 6179978N). **B)** Overview of an outcrop of metatexitic psammopelite; same station as A. **C)** Detail of diatexitic pelite; station VDK18-07-014 (UTM 559007E, 6181645N). **D)** Porphyritic texture in metatexitic psammopelite; same station as C.*

Diatexitic pelite (**unit Pp**) is abundant in the 2017 map area, but it is restricted to the east edge of the Robertson Lake area (Figure 3). The rocks are typically grey to light brown, massive to moderately foliated, inequigranular with a fine- to medium-grained matrix containing coarse-grained porphyroblasts of garnet (partially retrogressed to biotite) and sillimanite, and coarse plagioclase up to 3 cm in size (Figures 10C and 10D). This rock is quartzofeldspathic with a combined content of 25 to 35% biotite, garnet and sillimanite.

Metatexitic pelite (**unit Pl**) is compositionally similar to the diatexitic pelite, however, it rarely displays porphyritic or patch diatexitic textures. This unit is coarser grained than the surrounding sedimentary units, is typically nebulitic, and contains characteristic coarse to very coarse masses of fibrolitic sillimanite. The metatexitic pelite is exposed on the shore, and to the north, of Robertson Lake, where it is associated with the other sedimentary units, but does not appear elsewhere in the area. Typical rocks comprise quartz, plagioclase, biotite (20 to 30%), garnet (2 to 5%), sillimanite (5 to 15%), and local K-feldspar, muscovite, cordierite and magnetite (Figure 11B). Garnet commonly forms centimetre-scale clusters, with intergrown magnetite and/or plagioclase. Magnetite and cordierite porphyroblasts, millimetres to centimetres across, are common in exposures along the northeast shore of Robertson Lake. Some large sillimanite masses grade from cream coloured into pink; where pink, they are locally intergrown with a hard, glassy pink mineral that is likely andalusite (Figure 11C). The atypical presence of magnetite porphyroblasts within sedimentary rocks is likely due to proximity to an alteration corridor that trends along the southeast shore of Robertson Lake.

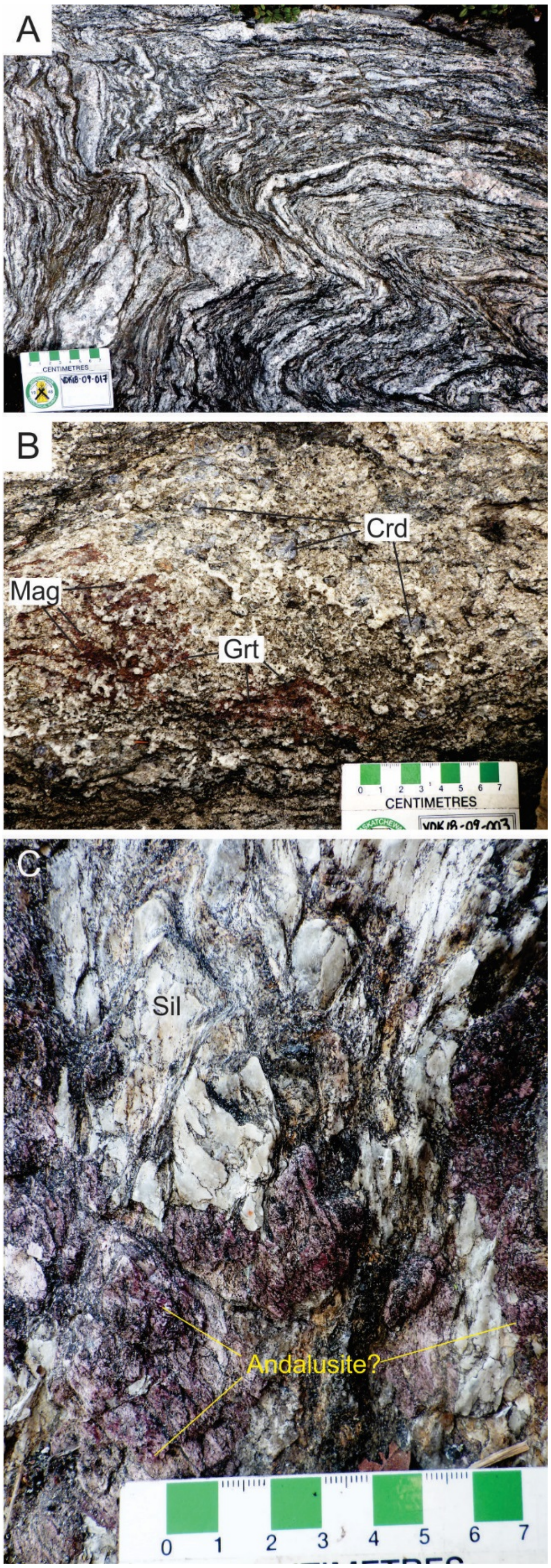

***Figure 11 –** Outcrop photographs of metatexitic pelite. **A)** Overview of irregularly folded metatexitic texture; station VDK18-09-017 (UTM 559379E, 6183680N). **B)** Garnet[6] clusters intergrown with magnetite and cordierite porphyroblasts; station VDK18-09-003 (UTM 559040E, 6182575N). **C)** Sillimanite mass that is cream and pink in colour, intergrown with fine-grained, pink, glassy mineral, potentially andalusite; same station as B.*

[6] Mineral abbreviations in photos follow Whitney and Evans (2010).

c) Pre-tectonic Intrusive Rocks

The predominant rock unit in the Palmer Lake area is diorite to leucocratic quartz diorite (**unit Di**). This unit is typically speckled salt-and-pepper, coarse grained, and foliated; grain size and intensity of strain vary slightly throughout the map area. Typical rocks contain 15 to 35% hornblende variably replaced by up to 15% biotite, and minor scapolite, particularly along the shore of Forseth Lake. Quartz is ubiquitous and makes up as much as 20% in the quartz-dioritic end member. Centimetre- to metre-scale, concordant to slightly crosscutting sheets of leucogranodiorite, leucotonalite, or leucogranite can account for up to 25% of the rock (Figures 12A and 12C). In a couple of locations at the west end of Ahasew Lake, diorite rocks have a red-coloured alteration, not associated with sulfide minerals. Although boundaries between rocks of diorite, quartz diorite and leucocratic quartz diorite composition are gradational and typically indistinguishable, an extensive zone of the quartz diorite to leucocratic quartz diorite end member surrounding Forseth Lake and Palmer Lake justified its designation as a separate unit (**unit QDi**). Centimetre- to metre-scale mafic xenoliths derived from units Ga, Mv and Mvc can be found within the diorite to leucocratic quartz diorite unit. In some locations, the proportion of injected melt and mafic resistors/xenoliths dominates the outcrop, giving rise to a unit of heterogeneous diorite and quartz diorite (**unit Dig**) (Figure 12D).

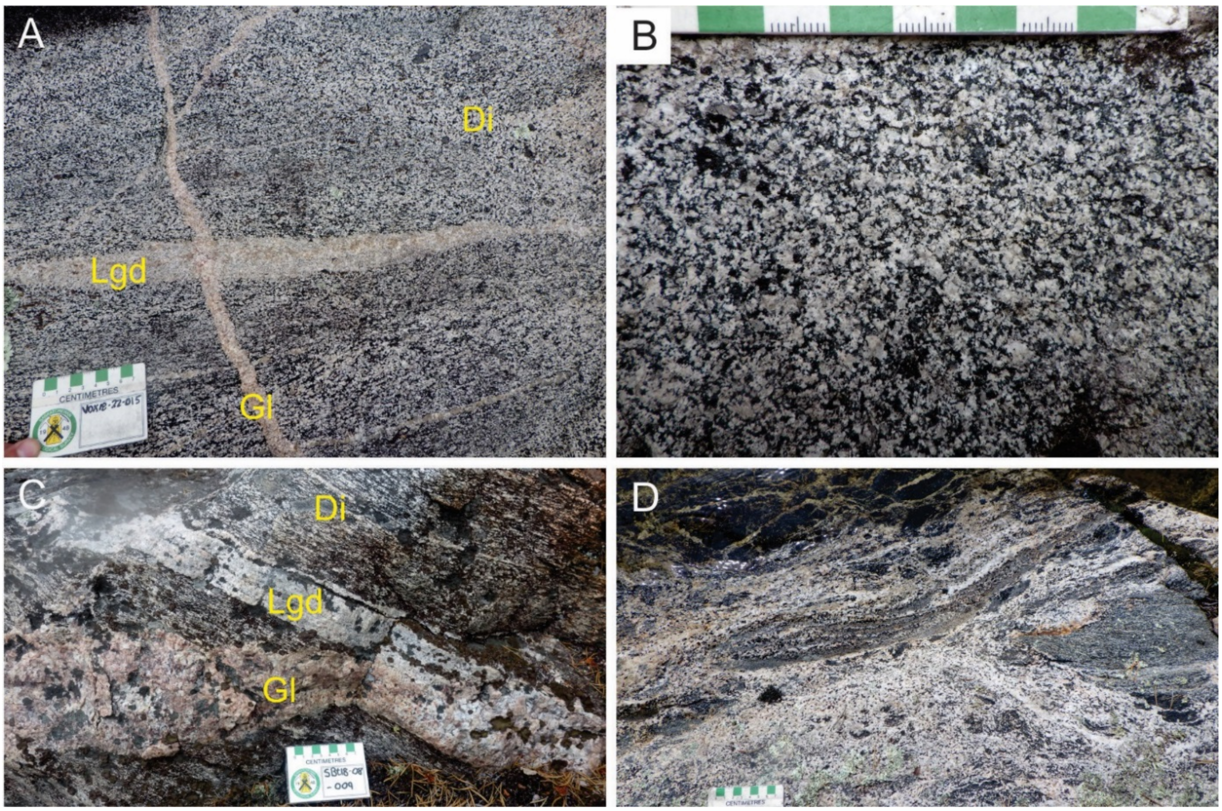

***Figure 12 –** Outcrop photographs displaying textural variation in diorite to leucocratic quartz diorite and heterogeneous diorite, quartz diorite. **A)** Homogeneous diorite (Di) with centimetre-scale layers of leucogranodiorite (Lgd) and thin crosscutting leucogranite dyke (Gl); station VDK18-22-015 (UTM 554944E, 6176431N). **B)** Close-up of typical quartz diorite; station VDK18-31-006 (UTM 551062E, 6168077N). **C)** Foliated diorite (Di) cut by leucogranodiorite (Lgd) and leucogranite (Gl); station SBt18-08-009 (UTM 561997E, 6182437N). **D)** Heterogeneous diorite, quartz diorite with mafic resistors, gabbroic xenoliths and abundant leucosome with peritectic hornblende; station VDK18-32-009 (UTM 553647E 6169285N).*

A subunit of sheared diorite (**unit SDi**) was mapped predominantly along the northern extent of Propp Lake, where it is interlayered with 30 to 80% leucotonalite and/or leucogranodiorite on a scale of centimetres to decimetres (Figures 13A, 13B and 13C). Locally, sheared diorite also contains amphibolite layers. The tonalite and leucogranodiorite layers are commonly highly strained, with elongate quartz grains/ribbons. The diorite layers are fine grained and massive to weakly foliated.

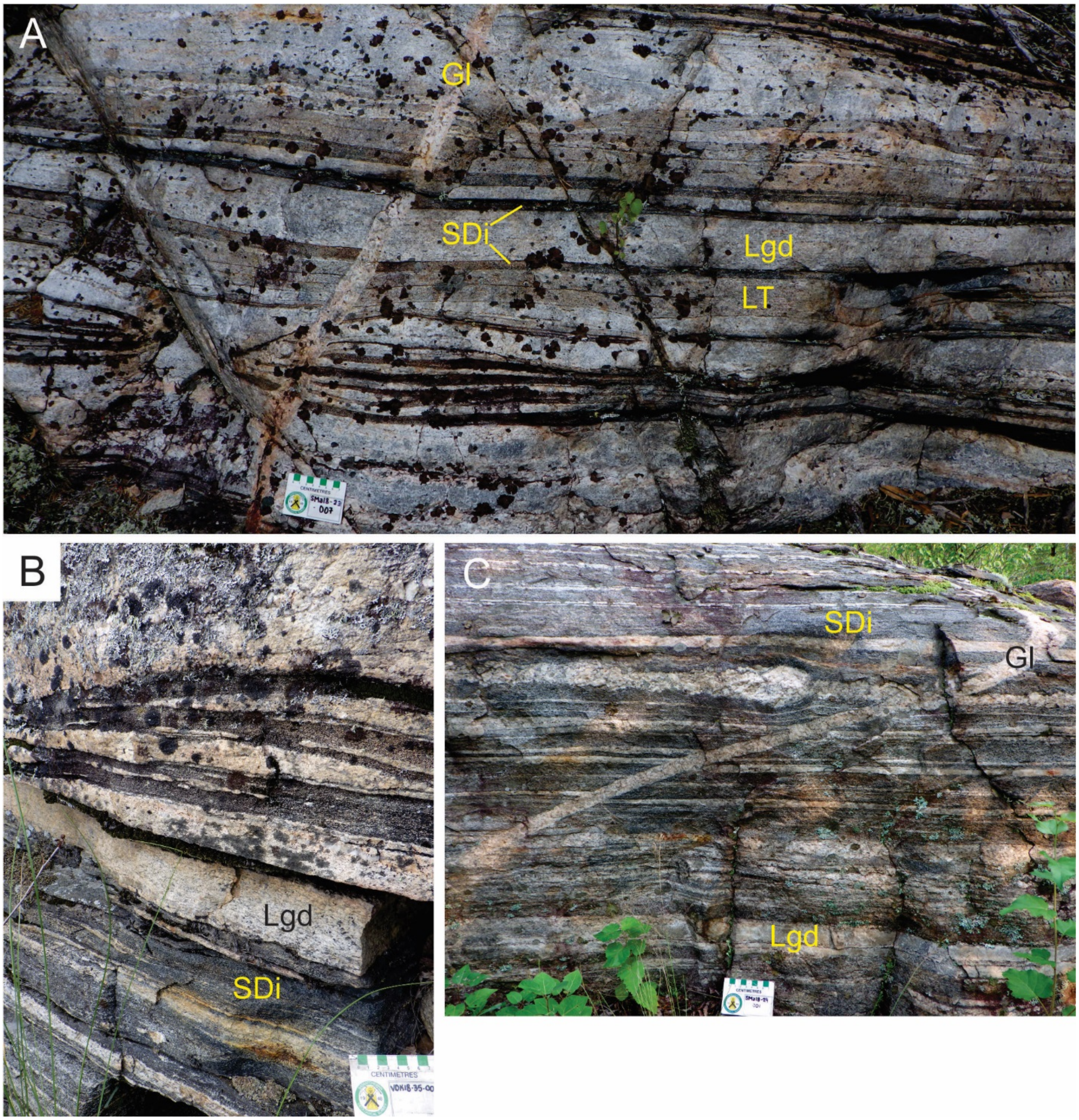

***Figure 13** – Outcrop photographs of sheared diorite. **A)** Predominantly sheared leucotonalite to leucogranodiorite (Lgd) with centimetre-scale sheared diorite (SDi) and fine-grained leucotonalite (LT) layers, cut by a thin leucogranite dyke (Gl); station SMa18-23-007 (UTM 555619E, 6173591N). **B)** Sheared leucogranodiorite (Lgd) interlayered with sheared diorite (SDi); station VDK18-35-002 (UTM 554364E, 6173228N). **C)** Interlayered sheared diorite (SDi) and leucogranodiorite (Lgd), cut by a thin leucogranite (Gl) dyke; station SMa18-29-001 (UTM 555700E, 6172408N).*

Granodiorite (**unit Gd**) forms elongate, kilometre-scale bodies throughout the area, and has gradational contacts with the diorite to leucocratic quartz diorite. Typical rocks are weakly foliated to gneissic, light grey to speckled black and white, and medium to coarse grained (Figure 14A). This unit contains 10 to 25% combined hornblende and biotite. In some locations, the granodiorite also contains centimetre-scale, layer-parallel, injected leucogranodiorite leucosomes.

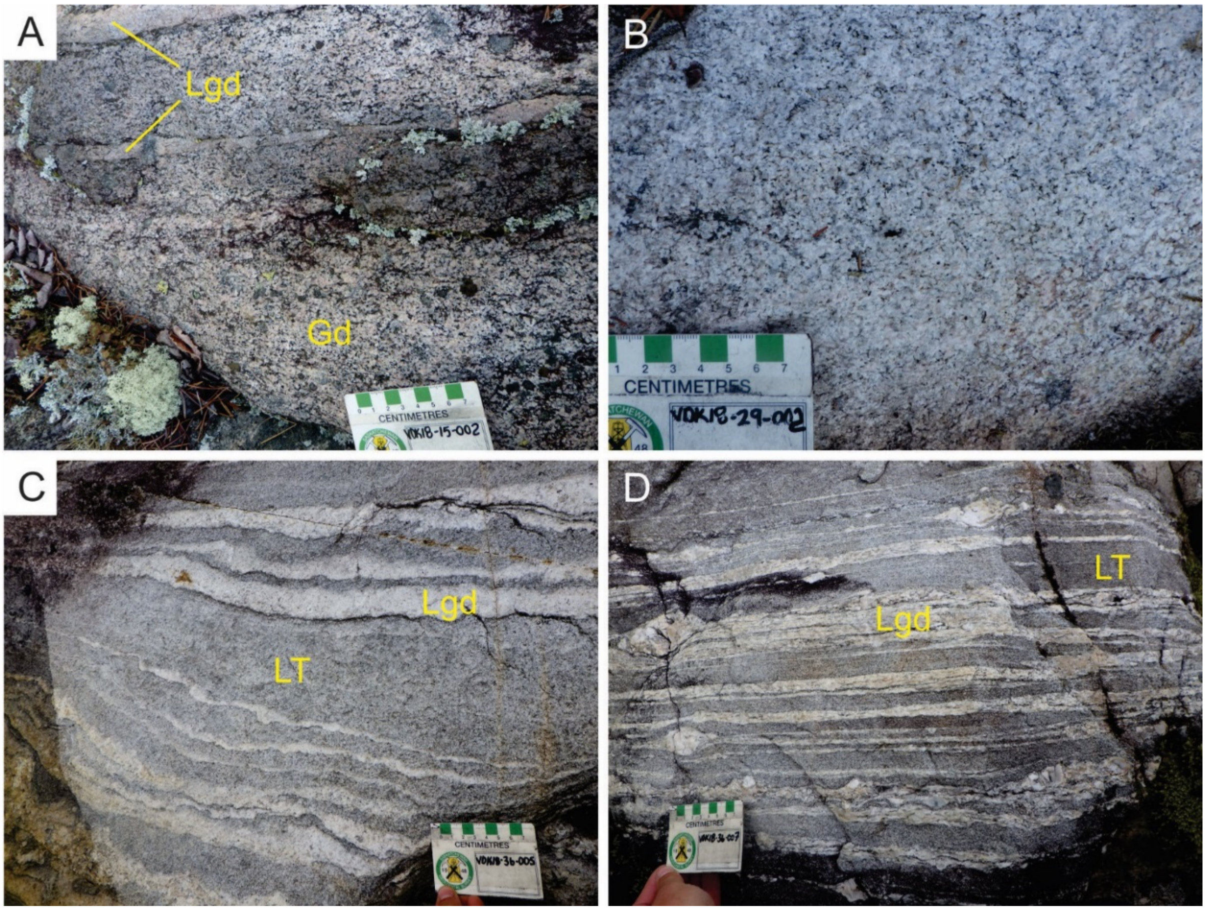

Figure 14 – *Outcrop photos of granodiorite, tonalite, and leucotonalite.* ***A)*** *Foliated granodiorite (Gd) with centimetre-scale leucogranodiorite (Lgd) layers; station VDK18-15-002 (UTM 554173E, 6176335N).* ***B)*** *Homogeneous tonalite; station VDK18-29-002 (UTM 552501E, 6175065N).* ***C)*** *Interlayered fine-grained leucotonalite (LT) and medium-grained leucogranodiorite (Lgd); station VDK18-36-005 (UTM 552036E, 6171235N).* ***D)*** *Leucotonalite (LT) with 1 to 10 cm wide layers of sheared leucogranodiorite (Lgd) showing ribboned quartz and sheared porphyroclasts; station VDK18-36-007 (UTM 551934E, 6171194N).*

Exposed in large bodies throughout the Wapassini sheet, tonalite to leucotonalite (**unit T**) is white to light grey, medium to coarse grained, homogeneous, and massive to moderately foliated (Figure 14B). Typical samples contain up to 5 to 15% combined hornblende and biotite, with local minor magnetite. This unit is commonly cut by very coarse to pegmatitic granite dykes, and locally injected by minor amounts of leucogranodiorite.

Interlayered leucotonalite (**unit LT**), locally tonalite crops out predominantly around Propp Lake. It is fine grained, equigranular, homogeneous, massive to well foliated and contains 5 to 10% (locally 15%) biotite (Figure 14C). It contains 5 to 60%, centimetre- to decimetre-scale layers of leucogranodiorite and leucogranite exhibiting quartz ribbons.

d) Syntectonic Intrusive Rocks

A folded and attenuated body of porphyritic leucocratic quartz diorite (**unit PDi**) occurs between Robertson Lake and Palmer Lake, and another thin (40 m wide or less), elongate body is located within a high-strain zone at the south edge of the map area. This unit is characterized by its porphyritic to seriate texture consisting of a fine- to medium-grained matrix with individual, locally euhedral feldspar grains up to >1 cm in size and patches of coarse to very coarse quartz-feldspar aggregates (Figures 15A and 15B). Hornblende and biotite together make up 15 to 20% of the rock. Porphyritic leucocratic quartz diorite is spatially associated with calcic psammopelite and is thought to be derived from the psammopelite by partial melting.

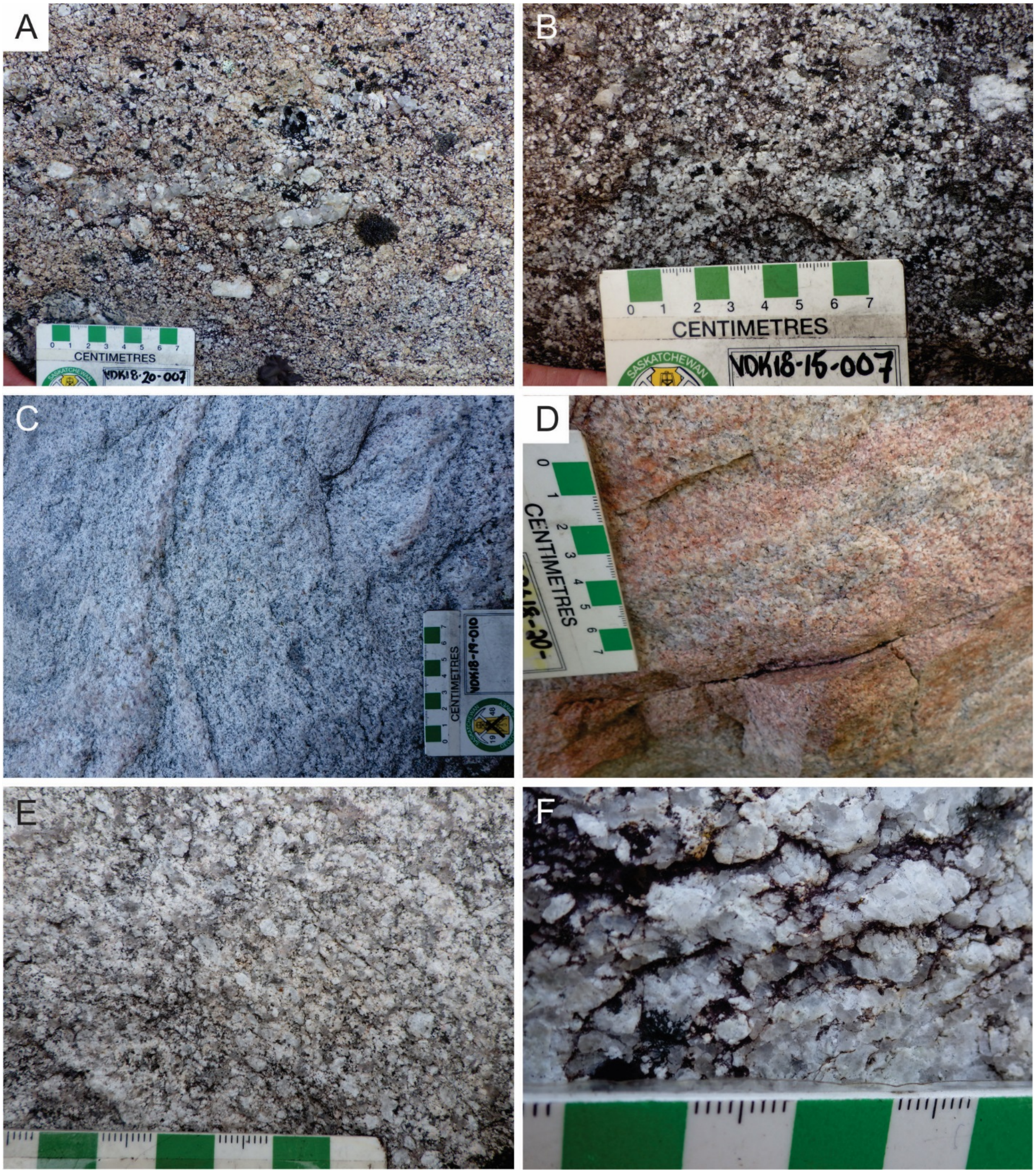

__Figure 15 –__ Outcrop photographs of leucogranodiorite, anatectic tonalite, and porphyritic leucocratic quartz diorite. __A)__ Porphyritic leucocratic quartz diorite displaying centimetre-scale phenocrysts; station VDK18-20-007 (UTM 551658E, 6176612N). __B)__ Porphyritic leucocratic quartz diorite; station VDK18-15-007 (UTM 554810E, 6177074N). __C)__ Overview of leucogranodiorite; station VDK18-19-010 (UTM 550759E, 6174693N). __D)__ Homogeneous leucogranodiorite with pink staining; station SBt18-20-002 (UTM 552784E, 6176140N). __E)__ Overview of anatectic tonalite; station VDK18-31-007 (UTM 550881E, 6168078N). __F)__ Detail of anatectic tonalite; station SBt18-30-009 (UTM 552742E, 6170675N).

Generally homogeneous, massive to moderately foliated leucogranodiorite (**unit Lgd**) forms elongate, attenuated map units that are tens of metres to a few hundred metres wide. Typical rocks are light pink to pinkish grey, medium to coarse grained (Figures 15C and 15D) and contain 2 to 5% combined biotite and garnet. Fine- to medium-grained leucogranite also occurs within many of the units throughout the area as centimetre- to metre-scale, layer-parallel to slightly crosscutting sheets. Although predominantly granodioritic, it can vary slightly, locally being granitic or tonalitic. This unit is interpreted to have formed from anatectic melting during D_2, and was emplaced syntectonically during D_2 and D_3 deformation.

Anatectic leucotonalite (**unit AT**) forms elongate sheets predominately around Propp Lake and Boyce Lake. It is bright white, coarse to locally pegmatitic, and contains a few percent biotite at most (Figures 15E and 15F). South of Propp Lake, anatectic leucotonalite is characteristically associated with mafic volcanic rocks. Outcrops of anatectic leucotonalite are typically massive, however, within the high-strain zone northeast of Propp Lake the rocks are highly sheared. Like the leucogranodiorite (Lgd), the anatectic leucotonalite probably formed during peak metamorphism, during D_2.

e) Syn- to Post-tectonic Intrusive Rocks

Leucogranite (**unit Gl**) is found throughout the entire map area and occurs as large, irregular, semi-concordant bodies up to 500 metres wide, and metre- to decametre-scale, straight-sided, mostly north-northwest– or east-northeast–trending dykes (Figures 16C and 16D). The leucogranite is typically pale peach, to pink, to orangey-red, massive, and commonly grades from medium grained to pegmatitic across a span of a few centimetres (Figure 16A). It ranges from syenogranite to monzogranite in composition, and is locally granodioritic. This unit contains minor biotite, and local muscovite and garnet. Rare outcrops south of Palmer Lake and on Boyce Lake contain an opaque, yellow, bladed or amorphous mineral within pegmatitic leucogranite with elevated eU (equivalent uranium) content (up to 24.4 ppm). This unknown mineral may be uranophane or another secondary uranium mineral (Figures 16E and 16F).

6. Structural Geology

The main foliation (S_1) across the map area is defined by the orientation of micaceous minerals, elongate/flattened mineral aggregates, compositional layering, and stromatic leucosomes. Where granitoid rocks display high strain, it is commonly defined by ribboned quartz. Outcrop- and map-scale tight to isoclinal folds are defined by the main regional S_1 fabric. The axial planes are oriented subparallel to S_1, thereby creating a composite S_1/S_2 fabric (Figure 17A).

a) Robertson Lake Area (Kyaska Lithotectonic Sheet)

The Robertson Lake area (Figure 3), which is dominated by sedimentary rocks, has well-preserved outcrop- and map-scale folding. The outcrop-scale folds include tight to isoclinal F_2 structures and asymmetrical parasitic F_2 or F_4 folds. One outcrop of layered psammite on the northeast shore of Robertson Lake displays variable fold geometry, ranging from close folds with disharmonic parasitic folds, to concentric, to box folds (Figures 17B and 17C). They have a consistent west-trending axial trace, axial planar sillimanite, and may have formed in the hinge zone of an F_2 fold.

F_3 folds were not observed in outcrop in the Robertson Lake area, however, they are defined by map-scale, broadly north- to northwest-trending open folds of the S_1/S_2 fabric, creating a wavy pattern on the map (Figure 18).

North of Robertson Lake, the main foliation is relatively flat lying to gently north dipping (Figure 3 and accompanying map), presumably resulting from regional F_4 folding.

Some sedimentary rocks have a preserved mineral lineation, commonly defined by sillimanite. In the Robertson Lake area, lineations consistently trend northward and have a shallow to moderate plunge.

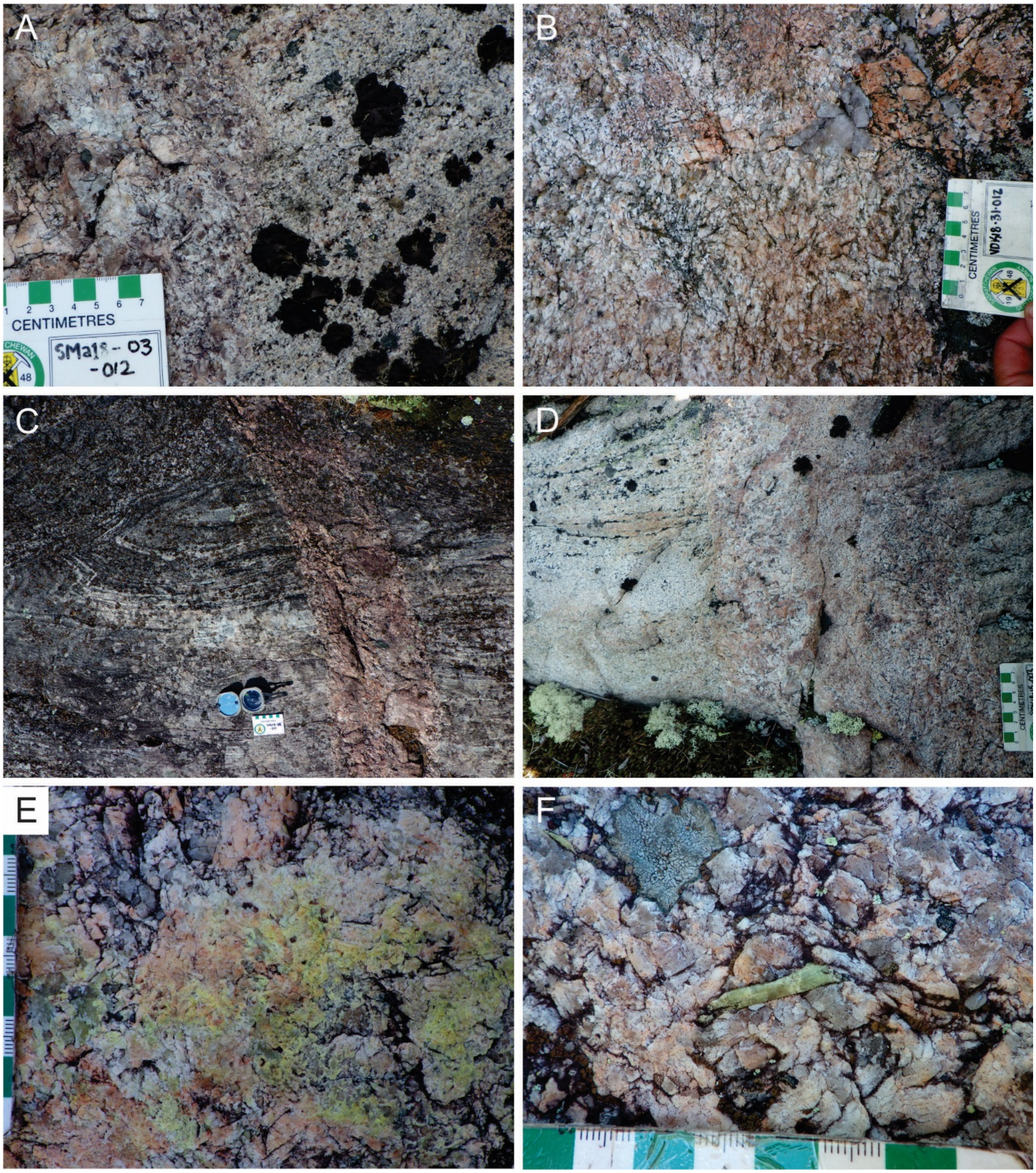

***Figure 16 –** Outcrop photographs of leucogranite. **A)** Leucogranite with medium and pegmatitic grain size; station SMa18-03-012 (UTM 557708E, 6178460N). **B)** Pegmatitic leucogranite; station VDK18-31-012 (UTM 550881E, 6168403N). **C)** Folded sheared diorite cut by a pegmatitic leucogranite dyke; station SMa18-26-001 (UTM 554630E, 6173541N). **D)** Foliated leucogranodiorite cut by zoned leucogranite with pegmatitic margin and aplitic core; station VDK18-15-003 (UTM 554415E, 6176476N). **E)** Amorphous yellow mineral in a biotite-bearing pegmatitic leucogranite; station SMa18-20-007 (UTM 552320E, 6171914N). **F)** Bladed yellow mineral within a pegmatitic leucogranite; station SMa18-27-008 (UTM 551285E, 6171559N).*

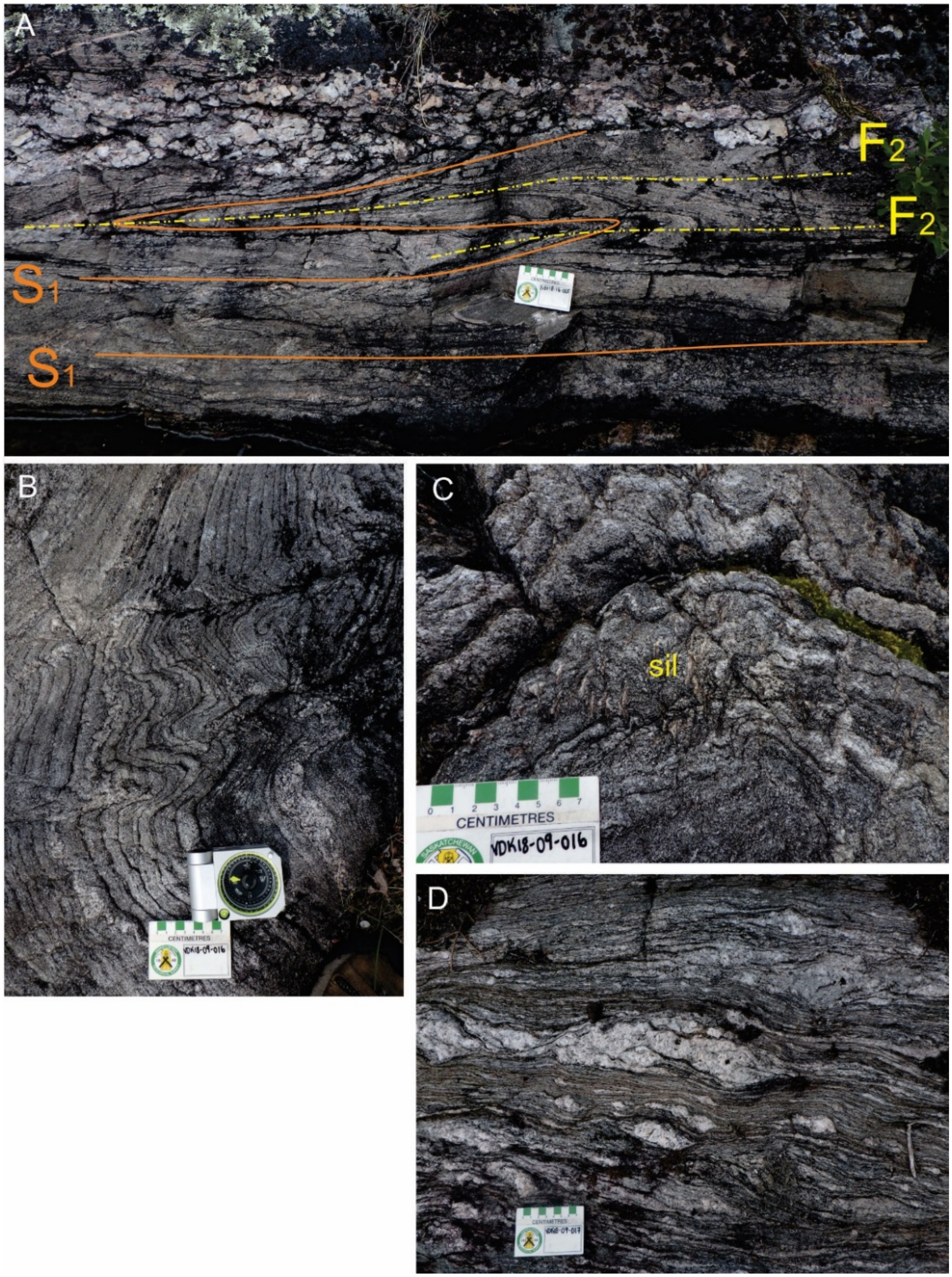

Figure 17 –** Outcrop photos from the Robertson Lake area and the Kyaska–Wapassini boundary.* ***A) *Isoclinal F_2 folds defining a composite S_1/S_2 fabric; station SBt18-16-005 (UTM 558147E, 6182659N).* ***B)*** *Layered psammite displaying concentric to box folds; station VDK18-09-016 (UTM 559360E, 6183637N).* ***C)*** *Slightly disharmonic parasitic folds with axial planar sillimanite (sil); same station as B.* ***D)*** *Sinistral sheared metatexitic pelite displaying attenuated leucosome; station VDK18-09-017 (UTM 559379E, 6183680N).*

b) Palmer Lake Area (Wapassini Lithotectonic Sheet)

The regional S_1/S_2 foliation in the Palmer Lake area dips consistently to the north-northwest. Near Forseth Lake, there are metre-scale, open, upright F_3 folds that trend north-northwest (Figure 18). Lineations are preserved in only a few locations within mafic rocks and are defined by hornblende.

West of the northern portion of Wapassini Lake, the intersection of F_3 and F_4 synclines has produced a southeast-verging asymmetrical basin structure (Northwest Wapassini basin), defined by refolded units of mafic volcanic rocks and gabbro (Figure 18). In the centre of the Northwest Wapassini basin, hornblende mineral lineations trend west-northwest and east-southeast.

At the southwest tip of Propp Lake, there is a map-scale, tight to isoclinal fold closure. The fold is mapped as an F_2 structure as it trends parallel to the regional foliation, but it is also in line with the projected trend of an F_4 fold from the Glennie–Wapassini lakes area (Figure 18; Maxeiner and Kaczmer, 2017).

The regional foliation is very steep surrounding Ahasew and Palmer lakes, and becomes shallow toward the south, where it is commonly subhorizontal surrounding Propp Lake. At the southernmost edge of the mapped area, around Boyce Lake, the foliation consistently dips moderately north to northwest. This variation in the dip of the planar fabric is attributed to regional F_4 folds. The rocks around Propp Lake make up the northwest limb of a map-scale F_4 fold, the trace of which is located south and southeast of the map area (Figure 18).

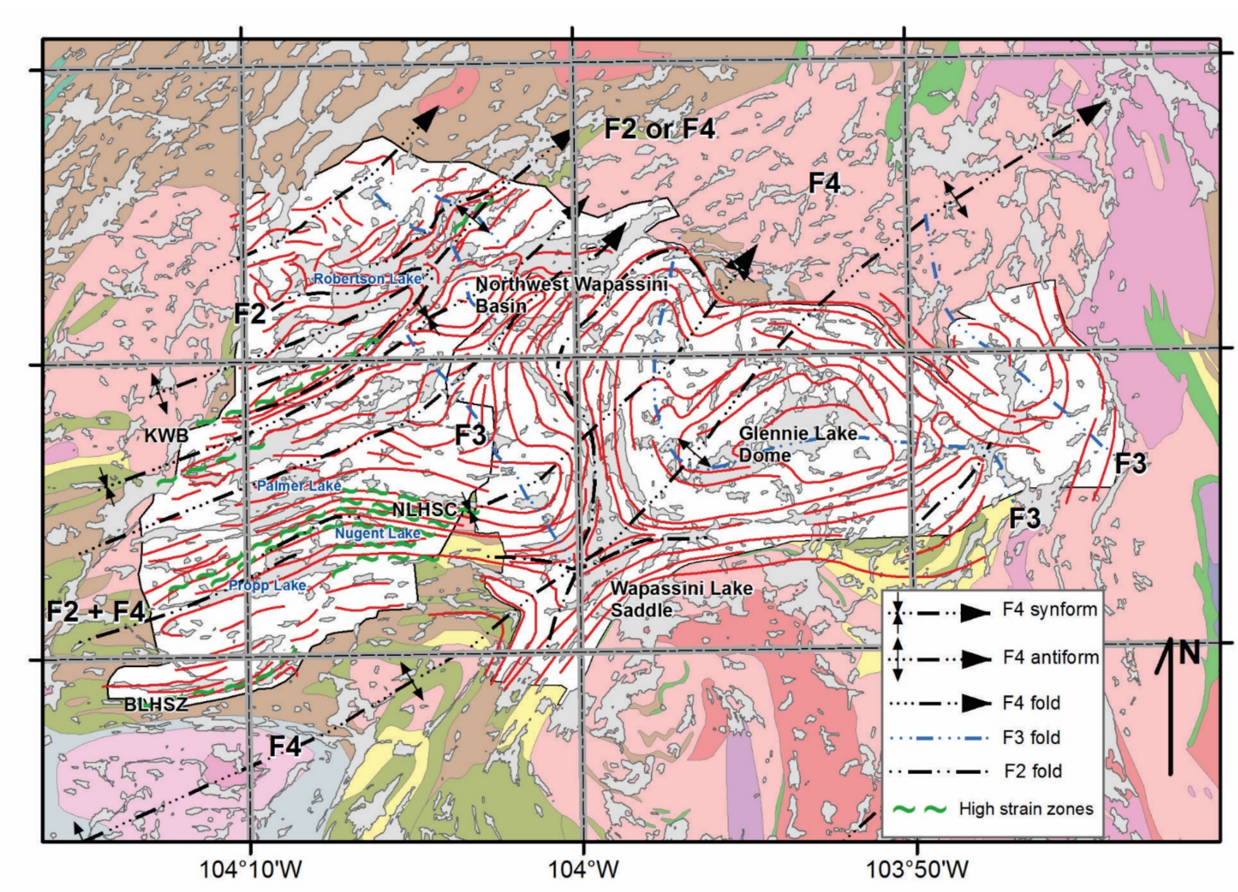

Figure 18 *– Fold geometry and structural interpretation (red lines show structural trends) of the Robertson–Palmer lakes area, in relation to the Glennie–Wapassini lakes area mapped in 2017. Abbreviations: KWB – Kyaska–Wapassini boundary; NLHSC – Nugent Lake high-strain corridor; BLHSZ – Boyce Lake high-strain zone.*

c) Kyaska–Wapassini Boundary

The southwest-northeast–trending portion of the Kyaska–Wapassini boundary coincides with a high-strain zone that contains an abundance of isoclinal folds (Figure 18), both outcrop and map scale, and commonly attenuated leucosomes. Highly sheared rocks are common along this boundary (Figure 17D), but not consistently present along the entire boundary. The north-south–trending portion of this boundary is not well constrained, and was loosely drawn on Figure 3 and the accompanying map to correspond with the change from predominantly sedimentary rocks to predominantly plutonic rocks. It does not correspond with a ductile high-strain zone, but it is parallel to a large airphoto lineament, likely corresponding to a brittle fault. It may represent a local offset in the overall high-strain thrust boundary between the two lithotectonic sheets.

d) Nugent Lake High-strain Corridor

To the north of Propp Lake, and extending east around Nugent Lake, there is an extensive high-strain zone (Figure 18). In this area, the rocks are layered on a scale of centimetres to metres, fine compositional layering is enhanced, granitoid rocks commonly have elongate ribboned quartz and feldspar, leucosomes are highly attenuated and straight-layered, and internal boudins are found locally (Figure 19A). Rotated δ-porphyroclasts, asymmetrical folded and imbricated leucosome (Figures 19B, 19C and 19D), and drag folds with Z-asymmetry (Figure 19E) all consistently indicate a dextral component of shear, however, no stretching lineation was observed, so an accurate direction of displacement could not be determined.

The Nugent Lake high-strain corridor, interpreted as a D_2 structure, extends west, north of Propp Lake and east toward Wapassini Lake, where it splits into coplanar north and south branches (Figure 18).

e) Boyce Lake High-strain Zone

At the very southern edge of the map area, along Boyce Lake, another high-strain, or mylonitic, zone marks the boundary between the Wapassini and Cartier lithotectonic sheets. This shallowly north-dipping high-strain zone is at least 300 m wide, but because it is at the edge of the mapped area, its complete thickness could not be determined. It is composed of many rock types interlayered on a centimetre to metre scale. The layers are typically straight, continuous and of homogeneous thickness (straight gneiss; Figure 20A), with local boundinage. Sheared granitoid layers and porphyroclasts are preserved locally, as well as ribboned quartz (Figures 20B and 20C). No shear-sense indicators or stretching lineations were observed. Rocks in this zone typically have fine to medium grain size, locally coarse.

7. Metamorphism

The Robertson–Palmer lakes area contains fewer diatexitic rocks than the Glennie–Wapassini lakes area (Maxeiner and Kaczmer, 2017), however, partial melt is still extensive throughout, indicating that metamorphic conditions attained upper amphibolite facies. The metamorphic mineral assemblage of the aluminous sedimentary rocks comprises quartz, biotite, plagioclase, garnet and sillimanite.

In a few outcrops along the northeast shore of Robertson Lake, a particularly aluminous metatexite exhibits a unique set of minerals: plagioclase, quartz, biotite, sillimanite, K-feldspar, muscovite, cordierite, garnet, magnetite and possibly andalusite. On these outcrops, the sillimanite masses grade from cream coloured to pink, and are intergrown with the potential andalusite, which form fine, hard, glassy pink crystals (Figure 11C), which appear to replace the sillimanite. Future petrographic work will investiage the nature of these minerals and their relationship to one another.

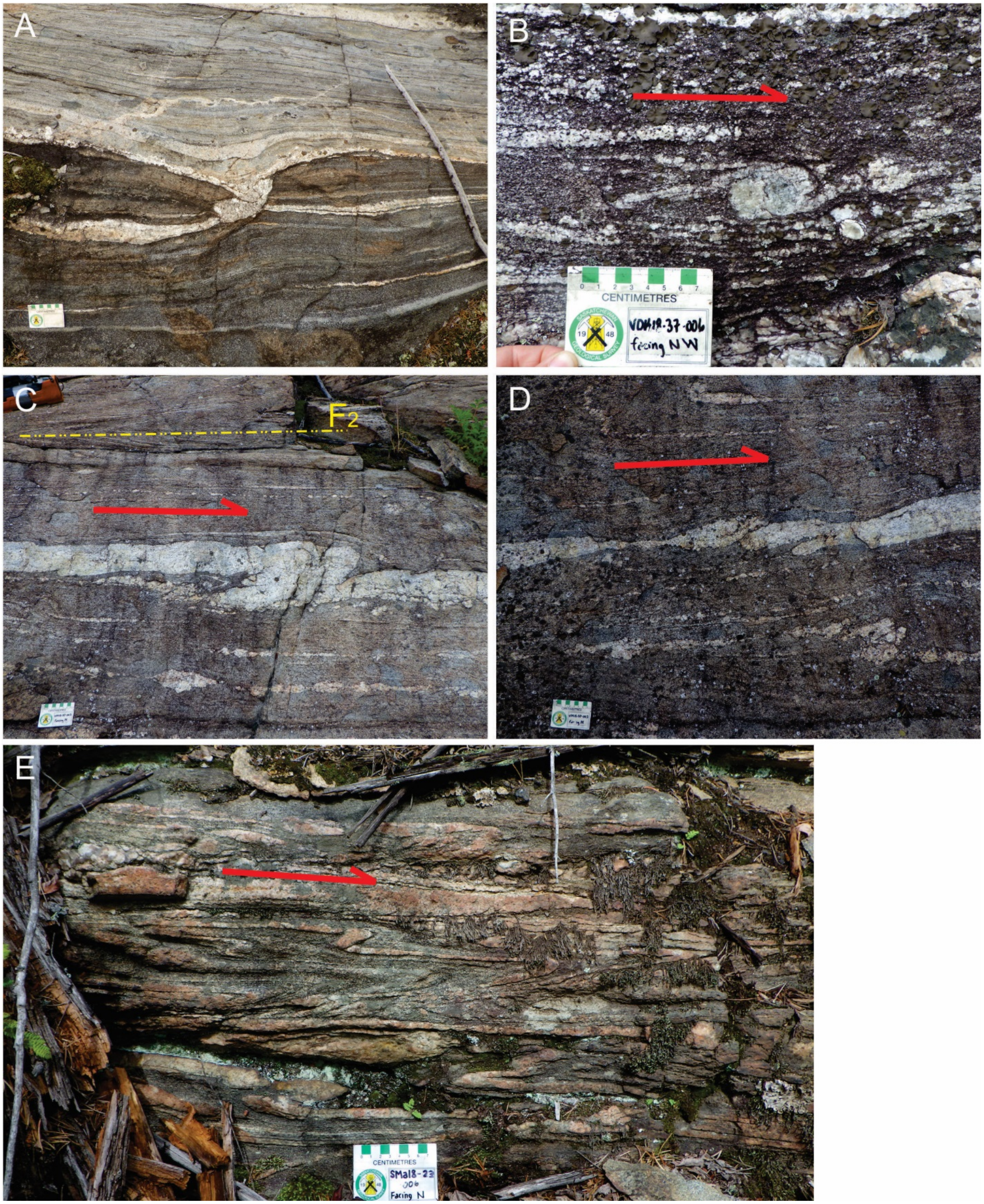

***Figure 19 –** Outcrop photos from the Nugent Lake high-strain corridor. **A)** Internal boudinage within mafic volcanic rock (bottom) at contact with intermediate volcanic rock (top); leucosome infilling the neck of the boudin; photo taken facing north; near station VDK18-37-012 (UTM 557160E, 36174320N). **B)** Dextrally rotated porphyroclast; station VDK18-37-006 (UTM 557971E, 6173605N). **C)** Thin, attenuated and asymmetrical, Z-folded leucosome; station VDK18-37-003 (UTM 557571E, 6173118N). **D)** Imbricated or stacked leucosome and asymmetrical Z-folded leucosome (bottom); same station as C. **E)** Asymmetrical Z-folds in a shear zone; near station SMa18-23-006 (UTM 555673E, 6173802N).*

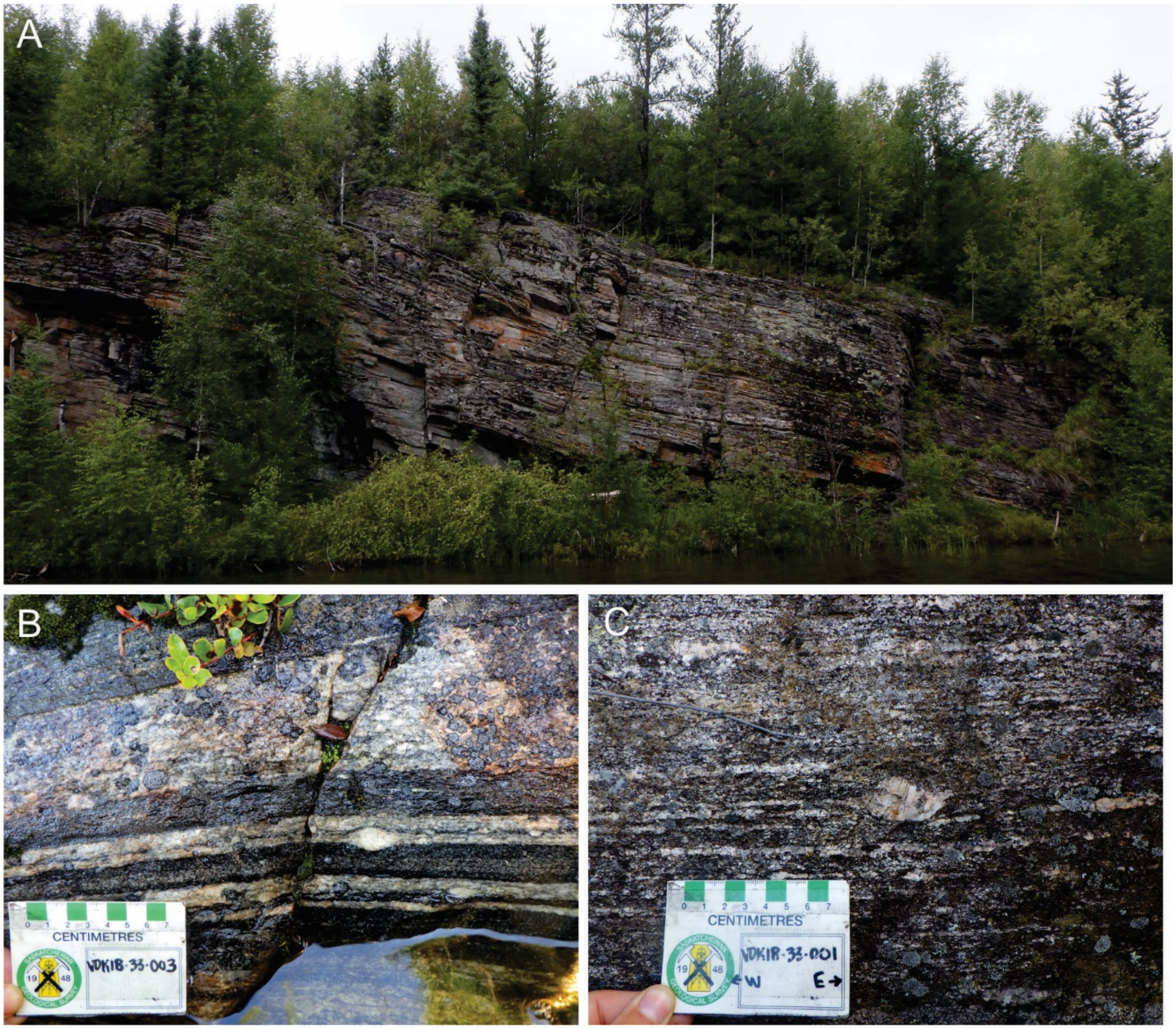

Figure 20 – *Outcrop photos from Boyce Lake high-strain zone.* ***A)*** *Cliff face displaying the straight-layered nature of the Boyce Lake high-strain zone; station VDK18-31-009 (UTM 550491E, 6168121N).* ***B)*** *Sheared diorite and coarse leucogranodiorite yielding a protomylonite texture; station VDK18-33-003 (UTM 550520E, 6168453N).* ***C)*** *Sheared quartz diorite containing feldspar porphyroclasts and quartz ribbons; station VDK18-33-001 (UTM 550721E, 6168544N). All photos were taken facing north.*

8. Economic Considerations

The mapped area is centred approximately 30 km west of the Seabee gold operation and 35 km north of the Pitching Lake copper deposit (SMDI[7] #0801). The gold at Seabee is hosted by quartz veins associated with shear zones within supracrustal and plutonic rocks (Schultz, 1990). The Pitching Lake copper deposit is interpreted as a mafic volcanic–hosted volcanogenic massive sulfide deposit (*e.g.*, Maxeiner and Normand, 2009). A sample of strongly deformed mafic volcanic rock containing quartz veins and minor sulfides in the area to the east (Maxeiner and Kaczmer, 2017), returned anomalously high gold values of 433 ppb (analysis 1) and 1100 ppb (analysis 2; sample RMx17-21-010 (UTM 569834E, 6174140N); Maxeiner, 2018). Two other samples from the 2017 mapping returned elevated copper concentrations of 337 ppm and 576 ppm (stations RMx-17-30-009 (UTM 563110E, 6173563N) and RMx-17-39-025 (UTM 560309E, 6181740N), respectively; Maxeiner, 2018). The sample from RMx-17-30-009 is

[7] Saskatchewan Mineral Deposit Index number.

interpreted as a calc-silicate rock in an interlayered succession of mixed calcic siliciclastic rocks, and the sample from RMx-17-39-025 is a highly sheared and oxidized magnetite-bearing gabbroic rock.

Rocks similar to those described above are also found in the Robertson–Palmer lakes area, and a number of shear zones were mapped in this area, although few quartz veins were observed. One notable exception is a ≥4 m wide quartz vein within gabbro, just southeast of Robertson Lake, located at station VDK18-06-018 (UTM 558966E, 6180999N), however, no sulfides were observed in the vein or the host gabbro.

A bedrock geochemical anomaly known as the PROP Claim Trench (SMDI #0809; Figure 3) is located between Palmer and Ahasew lakes, along a north-striking set of electromagnetic anomalies 6.4 km long. Samples collected from the approximately 60 cm wide gossan zone contain as much as 10% pyrrhotite and assayed 0.22% Cu with a trace of gold (Padgham, 1966). At this location in 1967, the Great Plains Development Co. of Canada Ltd. found disseminated pyrrhotite, pyrite, bornite and chalcopyrite, associated with shearing. The company mapped minor pyrrhotite and traces of magnetite filling fractures, which may explain the magnetic anomaly forming the northwest flank of the string of occurrences. Great Plains Development Co. collected samples from trenches that returned values of 0.01 to 0.1% Cu and 0.01% Ni.

The trenches could not be located during 2018, but tonalite and diorite mapped near to the PROP Claim Trench yielded relatively high magnetic susceptibility readings (2 to 83 $SI*10^{-3}$ *versus* the <1 $SI*10^{-3}$ of surrounding rocks). No notable alteration was observed, but trace pyrrhotite was noted in a 30 cm wide, quartz-dominated pegmatite dyke.

No new extensive alteration was recognized during the present study, but a number of rusty weathering outcrops were mapped (see accompanying map). A number of these at the northeast corner of the map area contain visible arsenopyrite, pyrite and pyrrhotite.

9. Discussion and Conclusions

Mafic volcanic and associated rocks are interpreted as the oldest rock units in the study area. Their lithological similarities and along-strike configuration suggest that these rocks may be correlative with the >1864 Ma Freestone Lake assemblage (Maxeiner *et al.*, 2013a). The sedimentary rocks in the Robertson Lake area are compositionally equivalent to the sedimentary rocks at Glennie Lake, which have been assigned to the *ca.* 1870 to 1860 Ma Hebden Lake assemblage (Maxeiner and Kaczmer, 2017). It is possible that the sedimentary rocks surrounding Robertson Lake are also correlative with the Hebden Lake assemblage, however, they are not contiguous with those found at Glennie Lake, and have undergone relatively less partial melting. Some of the sedimentary rocks at Robertson Lake could also be correlative with the Mullock Lake assemblage, which is a *ca.* 1848 to 1837 Ma siliciclastic succession containing minor intermediate to felsic volcanic rocks (Maxeiner *et al.*, 2013b). Although no felsic volcanic rocks were identified in this study, a significant amount of intermediate rock is associated with these sedimentary rocks. These intermediate rocks may be interpreted as intermediate volcanic rock.

The most likely possibility is that the sedimentary rocks surrounding Robertson Lake are part of a compositionally similar, but younger, package of rocks, equivalent to the *ca.* 1855 to 1840 Ma marine turbidites found in the Kyaska sheet (*i.e.*, the Burntwood Group; Zwanzig, 1999, 2008). The Burntwood Group rocks are compositionally similar to those observed at Robertson Lake, and are at the same structural level (Kyaska sheet).

The granodioritic to dioritic plutonic rocks, which dominate the Palmer Lake area, are interpreted to be synchronous with the Frog Narrows complex (Lewry, 1981; Maxeiner *et al.*, 2013a), which is part of a suite of *ca.* 1870 to 1850 Ma arc plutonic rocks, widespread throughout the Reindeer Zone.

Rocks in the Robertson–Palmer lakes area have been affected by at least four deformation events, creating complex map patterns. F_2 isoclinal folds are common in outcrop, but rare at the map scale. F_3 folds are generally open, upright, north-northwest–trending structures, some of which can be recognized at map scale in the northeastern portion of the map area. The intersection of F_3 and F_4 folds create rare map-scale dome-and-basin structures.

10. Acknowledgments

This project would not have been possible without the hard work and enthusiasm of the junior geological assistants: Charlotte Alexander, Iliajah Pidskalny, Jonathan Lafreniere, Keegan Arnyek and Keith Halkett. These students helped keep camp running smoothly and our lines running straight. Each student went above and beyond when it came to preparing meals for the crew; there is no better way to keep a camp happy than with great food! Thank you so much for all your hard work. Also, thank you to Ken Ashton and Heather Brown for reviewing and editing earlier versions of this report.

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