GS2023-8

Geological investigations in the areas of Niblock Lake and Crowduck Bay (Wekusko Lake), north-central Manitoba (parts of NTS 63J13, 14)

by K.D. Reid

In Brief:

- Niblock Lake contains subaqueously deposited mafic-pillowed flows and associated felsic volcaniclastic rocks of probable arc volcanic affinity
- Missi group sediments at Niblock Lake record a transition from low energy fluvial meandering river to slightly deeper water basin
- Pre-existing structural fabrics and faults in the Crowduck Bay area play a role in controlling emplacement of both barren and Li-bearing pegmatite dikes

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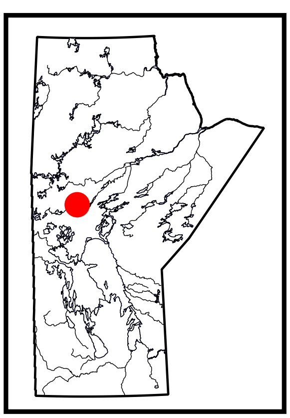

Summary

Bedrock investigations during the 2023 field season focused on geology east of Wekusko Lake, in the Crowduck Bay and Niblock Lake areas. Mapping at Niblock Lake confirmed the presence of subaqueously deposited bimodal mafic and felsic volcanic rocks. A unique facies transition from cross-bedded feldspathic sandstone to mudstone to poorly sorted conglomerate is indicative of deposition in an environment that transitions from terrestrial to below wave base, possibly with considerable adjacent relief.

Historical occurrences of lithium-bearing pegmatite in the Crowduck Bay area have garnered significant exploration attention in recent years. The lithological and structural character of rocks in the Crowduck Bay area was investigated to determine controls on pegmatite emplacement. Pre-existing ductile fabrics appear to play a role as ground preparation for later dilatational structures that host the lithium-bearing pegmatite.

Introduction

The structure and stratigraphic context of rocks between Wekusko Lake and the Superior boundary zone (Figure GS2023-8-1) are poorly understood; this is partly a result of poor outcrop exposure and lack of recent geological mapping (Frarey, 1950; Bailes, 1985). However, the presence of critical minerals such as spodumene (lithium-bearing pyroxene) as well as base metals (e.g., volcanogenic copper-zinc) and precious metals (e.g., orogenic gold) has resulted in renewed exploration interest and research activity in the area.

In 2023, the Manitoba Geological Survey initiated geological compilation and targeted mapping projects to expand geoscience knowledge in the Niblock Lake and Crowduck Bay (Wekusko Lake) areas, the objectives of which were to

- investigate volcanic and sedimentary rocks in the Niblock Lake area, with emphasis on determining age, geochemical affinity and potential tectonic setting; and
- examine possible lithological and structural controls on the emplacement of pegmatite from the Wekusko pegmatite field in the Crowduck Bay area along the Crowduck Bay fault.

Regional geology

The Snow Lake domain is one of several Paleoproterozoic domains that form the internal Reindeer zone of the Trans-Hudson orogen in Manitoba (Lewry and Collerson, 1990). The Snow Lake domain is bounded to the east by the Superior boundary zone (Figure GS2023-8-1) and to the north, the Snow Lake domain gives way to turbiditic greywacke and mudstone of the Kisseynew domain. Volcanic rocks west of Reed Lake are considered part of the Amisk collage (Figure GS2023-8-1; Lucas et al., 1996). Stern et al. (1995) suggested that stratigraphic and geochemical differences between the Snow Lake arc assemblage and volcanic rocks of the Amisk collage were likely the result of their having formed in distinct tectonic settings. To the south, the Snow Lake domain continues under younger Phanerozoic platform carbonate rocks (Figure GS2023-8-1).

The eastern half of the Snow Lake domain is subdivided into three structural panels bounded by the northeast-trending Berry Creek shear zone and Crowduck Bay fault (Figure GS2023-8-1). The Berry Creek shear zone separates the Snow Lake arc assemblage (SLA) and the Herblet gneiss dome (HGD) from a northeast-trending panel of greywacke and mudstone 15–20 km wide that Ansdell et al. (1999) referred to as the Central Wekusko block (CWB; Figure GS2023-8-1). In the southwestern corner of the Wekusko Lake area, greywacke and mudstone are in structural contact with the Hayward Creek arc assemblage (HCA). Though no age determination is available for the Hayward Creek arc assemblage, it is thought to consist of ca. 1.89 Ga juvenile-arc rocks (Gilbert and Bailes, 2005).

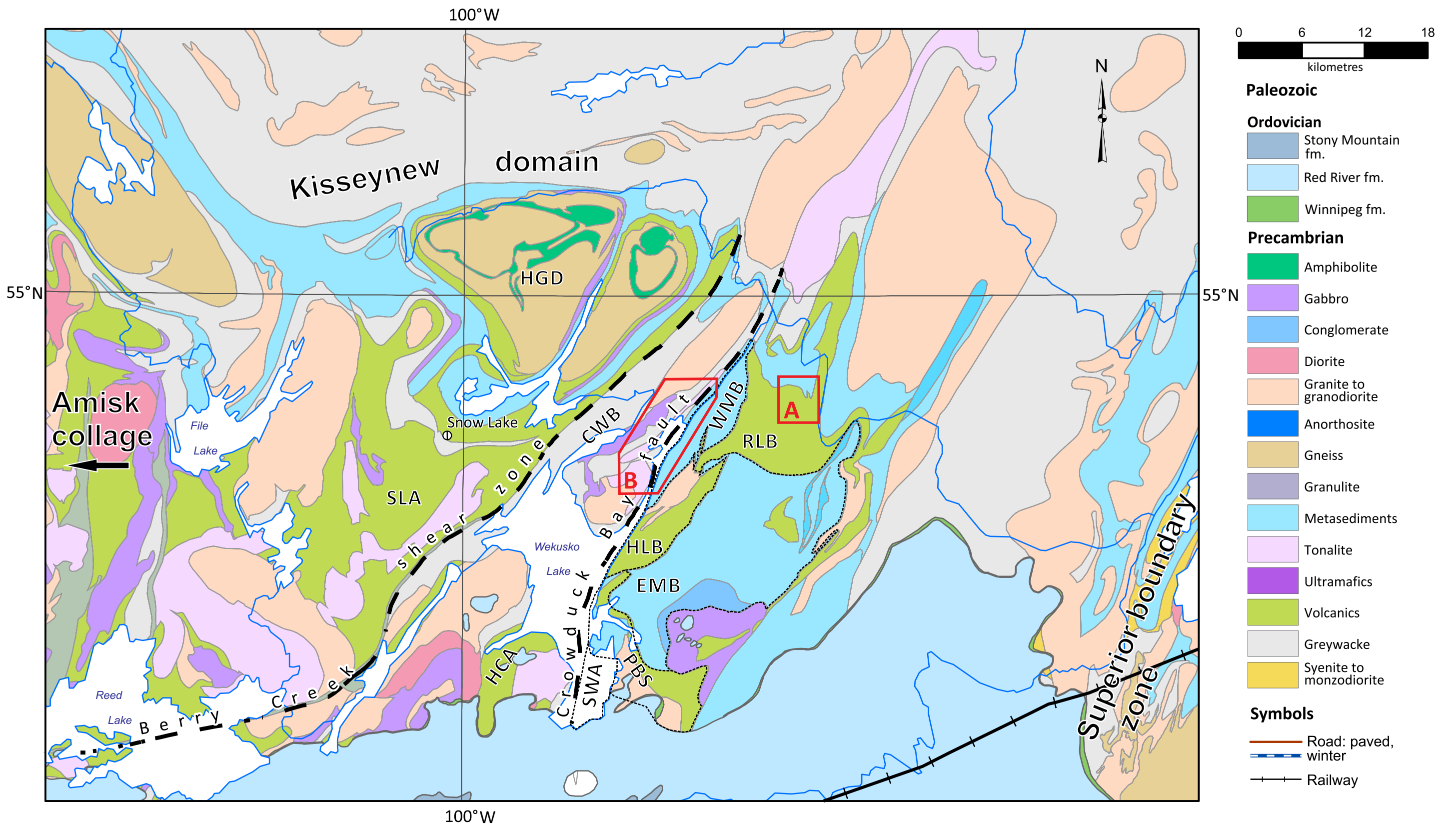

Figure GS2023-8-1: *Regional geology showing the Snow Lake domain, including the areas examined in 2023 (red polygons labelled A and B corresponding to Figure GS2023-8-2a, b) in north-central Manitoba (modified from Manitoba Geological Survey, 2022). Note the Kisseynew domain to the north, the Superior boundary zone to the east and Paleozoic cover rocks to the south. The Snow Lake arc assemblage (SLA), Herblet Gneiss dome (HGD), Hayward Creek arc assemblage (HCA), South Wekusko assemblage (SWA), Puella Bay suite (PBS), Eastern Missi fault block (EMB), Herb Lake fault block (HLB), Western Missi fault block (WMB), Roberts Lake block (RLB) and Central Wekusko fault block (CWB) are shown relative to the Berry Creek shear zone and Crowduck Bay fault. Small dashed lines show the approximate boundaries of assemblages and structural blocks on the eastern side of Wekusko Lake.*

The Crowduck Bay fault, a crustal-scale structure with a ductile and brittle-ductile history, separates the Central Wekusko block from rocks to the east (Connors et al., 1999). There is no formal designation for this panel to the east of the Crowduck Bay fault, but previous researchers have subdivided some rocks of similar lithotectonic character into fault-bounded blocks and/or related assemblages (e.g., Connors et al., 1999; Gilbert and Bailes, 2005; Reid, 2021). These include ocean-floor basalts of the South Wekusko assemblage (SWA) and Roberts Lake block (RLB); evolved-arc volcanic rocks of the Puella Bay suite (PBS) and Herb Lake fault block (HLB); and fluvial-alluvial sedimentary rocks of the Western Missi fault block (WMB) and Eastern Missi fault block (EMB; Figure GS2023-8-1; e.g., Ansdell et al., 1999; Connors et al., 1999; Gilbert and Bailes, 2005; Reid, 2021).

Bailes (1985), who mapped the eastern half of Niblock Lake as part of the Saw Lake mapping project, described the northern and eastern shore of Niblock Lake as consisting of metasiltstone, fluviatile metasandstone and polymictic pebble conglomerate, intercalated with massive and pillowed basalt. The fluvial-alluvial character of the siliclastic rocks and the massive character of the basalt led to the interpretation that these rocks are part of the younger Missi group. The southwestern shore contains pillow basalt, heterolithic felsic breccia and massive rhyolite that were believe to be part of the broader Amisk group rocks of the Flin Flon belt, but due to the Saw Lake map area only extending to the eastern half of Niblock Lake, the western extent of these rocks remained undetermined. More current maps (e.g., NATMAP Shield Margin Project Working Group, 1998) show the Niblock Lake area as a structural wedge of fluvial-alluvial sediments, basaltic flows and subordinate felsic volcanic rocks of uncertain geochemical affinity and age.

Highlights of fieldwork

Bedrock mapping in the Niblock Lake area documented several structural and stratigraphic features used to update the geology of the area (Figure GS2023-8-2a). A brief description of each map unit (oldest to youngest) and related features is provided below. All rocks in the Niblock Lake area have been metamorphosed to amphibolite facies, but for the sake of brevity the prefix 'meta'- has been omitted.

Samples of mafic and felsic rocks were collected for whole-rock lithogeochemistry, samarium-neodymium (Sm-Nd) isotopes

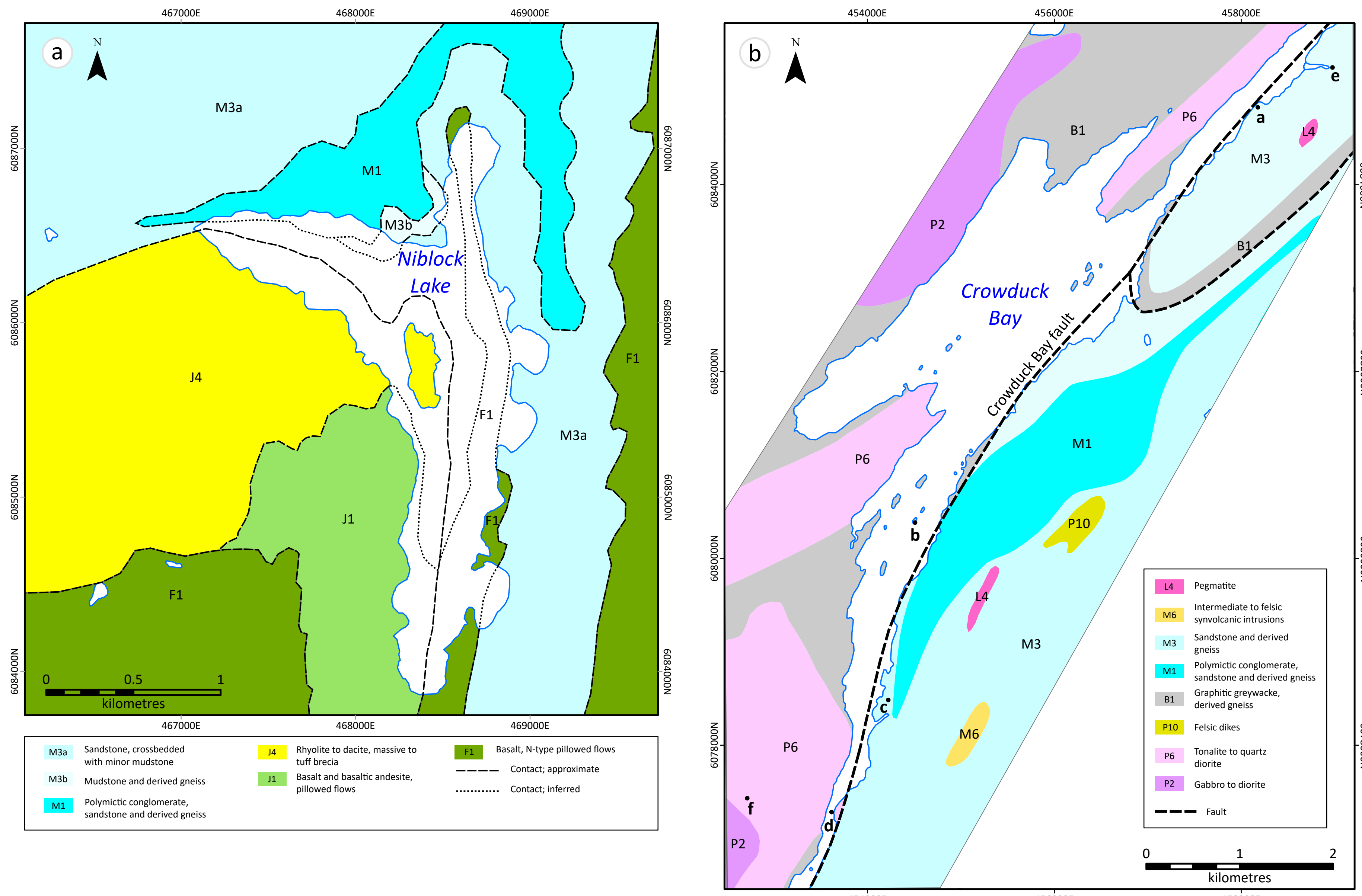

Figure GS2023-8-2: *Areas investigated during the 2023 field season (see Figure GS2023-8-1 for regional setting):* ***a)*** *updated geology of the Niblock Lake area;* ***b)*** *location of targeted outcrop visits in the Crowduck Bay area (geology from NATMAP Shield Margin Project Working Group, 1998) and location of outcrop photographs (points labelled with lower case letters) in Figure GS2023-8-4. All co-ordinates are in UTM Zone 14, NAD83.*

and uranium-lead (U-Pb) geochronology. Targeted outcrops in the Crowduck Bay area were visited to investigate the Burntwood (unit B1) and Missi (units M1, M3) groups, and their relationship to deformation along the Crowduck Bay fault (Figure GS2023-8-2b). Barren and spodumene-bearing pegmatite dikes were investigated to determine their level of deformation and relationship to the regional deformation history.

Niblock Lake

Mafic volcanic rocks (units F1 and J1)

Two variations of pillowed basalt flows are present in the Niblock Lake area. The first is observed along the southeastern shore and extends into a small bay at the northern end of the lake (unit F1; Figure GS2023-8-2a). The pillows are strongly attenuated (north trending) with dark green selvages, aphyric to weakly feldspar-pyroxene–phyric (Figure GS2023-8-3a), and commonly have concentric and radial cooling fractures. The pillowed flows are in sharp structural contact with feldspathic sandstone (unit M3a), possibly along a fault at a shallow angle to the sedimentary bedding. In the southeast corner of the lake, basalt and feldspathic sandstone alternate at the outcrop scale, which appears to be the result of very shallow-plunging, north-trending upright folds. Basalt of unit F1 is thought to be similar to basalt found in the Roberts Lake area and the South Wekusko assemblage, which has a normal (N-type) mid-ocean–ridge basalt chemical affinity (N-MORB; Gilbert and Bailes, 2005; Benn et al. 2018).

The second variation of pillowed basalt occurs along the southwestern shore of Niblock Lake (unit J1; Figure GS2023-8-2a). This feldspar-pyroxene–phyric basalt differs from the first in that it has pale grey-green selvages and contains abundant amygdules 1–3 mm in diameter (Figure GS2023-8-3b). Unit J1 is also characterized by an increased content of volcaniclastic rocks, with beds of mafic to intermediate lapilli tuff 1–2 m thick occurring between pillowed flows.

Felsic volcanic and volcaniclastic rocks (unit J4)

Angular rhyolite tuff breccia (unit J4) is the main rock type on the western side of Niblock Lake (Figure GS2023-8-3c). The contact between pillowed basalt (unit J1) and felsic volcaniclastic rocks (J4) is not directly observed, but is considered conformable given there is an increase in mafic matrix between clasts as well as the presence of intact pillow fragments with proximity to unit J1 (Figure GS2023-8-3d). The eastern part of the island in the centre of Niblock Lake contains feldspar-phyric dacite breccia and massive aphyric siliceous blue-grey rhyolite. Both the dacite and the rhyolite were sampled for whole-rock lithogeochemistry and U-Pb geochronology, and the results are pending.

Basalt dikes (unit J7)

Submetre, dark green, fine-grained basalt dikes (unit J7; not shown on Figure GS2023-8-2a) cut the mafic pillowed flows of unit J1 and the felsic volcaniclastic rocks of unit J4. The dikes have quartz-filled amygdules that define centimetre-scale zoning (Figure GS2023-8-3d). The dikes are tightly folded at the outcrop scale, with axial planes that strike between 345 and 360° and dip nearly vertically; the fold noses appear to plunge steeply to the north.

Sedimentary rock (units M1, M3a and M3b)

Examination of outcrops along the northern and eastern side of the lake confirms the presence of crossbedded feldspathic sandstone (unit M3a; Figure GS2023-8-2a), garnet- and staurolite-bearing mudstone (unit M3b), and poorly sorted heterolithic pebble and cobble conglomerate (unit M1; Figure GS2023-8-2a). Along the eastern shore, submetre beds of feldspathic sandstone alternate with garnet- and staurolite-bearing mudstone (Figure GS2023-8-3e). Heavy mineral laminations define tabular crossbeds in fine- to medium-grained feldspathic sandstone that are consistent with soft-sediment flame structures at the top of the mudstone. Locally, dark grey mudstone rip-up clasts as large as 10 cm are scattered within trough-crossbedded feldspathic sandstone. Stratigraphically above the feldspathic sandstone (unit M3a) is a garnet- and staurolite-bearing, millimetre- to centimetre-scale bedded mudstone (unit M3b; Figure GS2023-8-2a). Abundant parasitic (M) folds may result in the mudstone being fold thickened, but tracing this unit along shore suggests it is a minimum of 25 m thick. Stratigraphically above unit M3b is poorly sorted, clast-supported to matrix-supported conglomerate with a clast population that is dominated by mafic porphyritic and basaltic cobbles, and containing lesser amounts of yellow quartz, blue-grey dacite and dark grey mudstone (Figure GS2023-8-3f). The granule-rich matrix of the conglomerate contains a substantial dark grey wacke component.

Crowduck Bay

Early mapping in the Crowduck Bay area placed staurolite-garnet pelitic schist of the Burntwood group in sharp contact with sandstone and conglomerate of the Missi group (e.g., Stockwell, 1937; Frarey, 1950). Recent research indicates that this contact is a major structure, the Crowduck Bay fault, which juxtaposes these two lithologies for over 20 km along the Grass River and Crowduck Bay before trending southward along Wekusko Lake (e.g., Reid, 2019; Connors et al., 2002; Gilbert and Bailes, 2005). The fault is believed to be a deep-seated and long-lived structure (Connors et al, 2002) with links to observed mineralizing events, including orogenic gold (Stockwell, 1937; Reid, 2021), lithium-bearing pegmatites (Silva et al., 2022) and kimberlite-like intrusive rocks (Chakhmouradian and Reid, 2017). Presented here is a brief summary of lithological and structural observations in the Crowduck Bay area, including observed relationships with barren and spodumene-bearing pegmatite.

In the Crowduck Bay area, ductile fabrics that manifest as rod-shaped conglomerate clasts (axes ratio of 5:1:1) directly

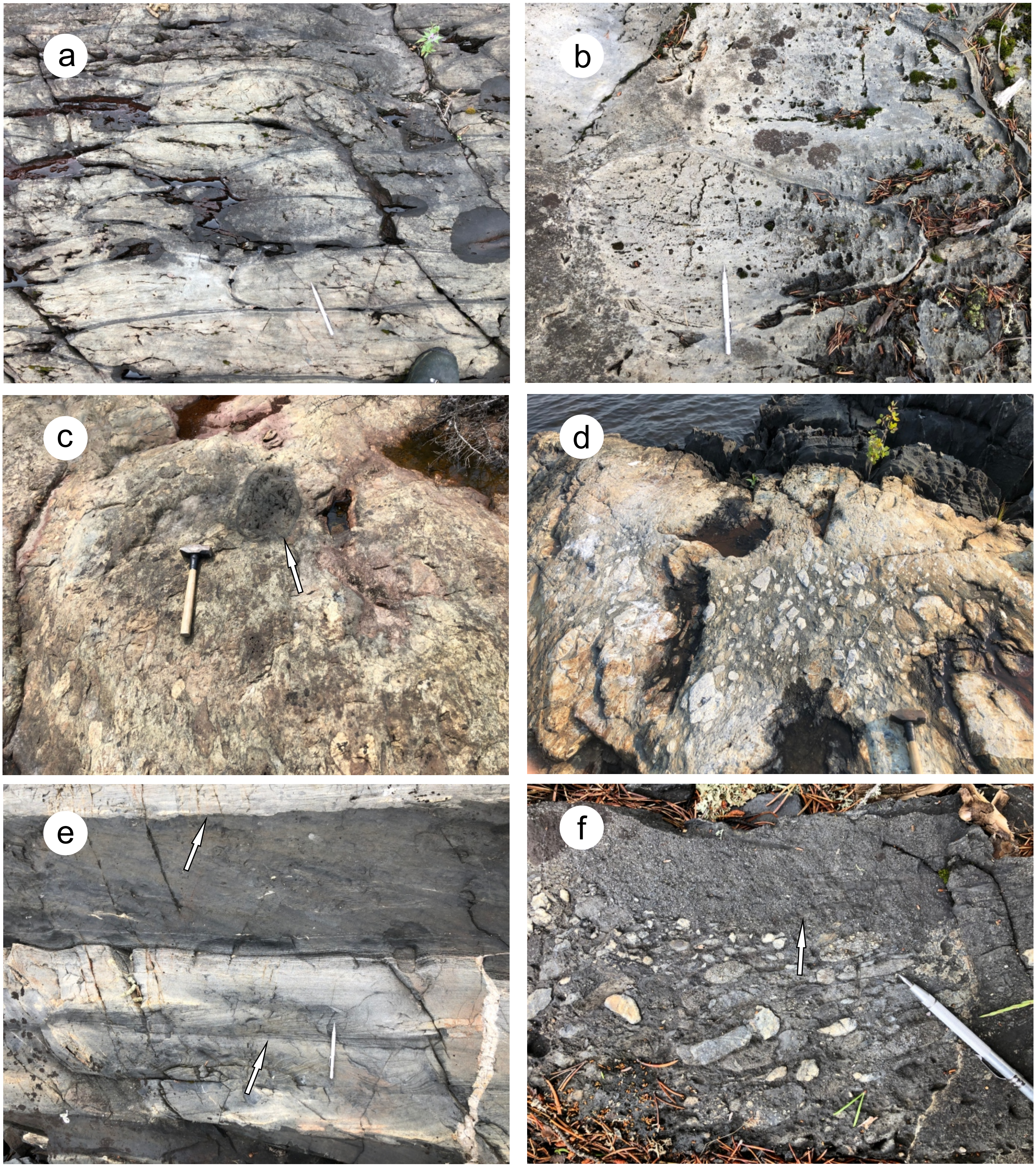

Figure GS2023-8-3: *Outcrop photographs from the Niblock Lake area:* ***a)*** *aphyric to weakly feldspar-pyroxene–phyric pillow basalt (unit F1; 468285E, 6084344N);* ***b)*** *feldspar-pyroxene–phyric pillow basalt with abundant quartz-filled amygdules (unit J1; 468169E, 6085542N);* ***c)*** *felsic tuff breccia with an intact pillow fragment indicated by the arrow (unit J4; 468111E, 6085766N);* ***d)*** *felsic tuff breccia cut by amygdule-rich mafic dike (units J4 and J7; 468002E, 6085913N);* ***e)*** *alternating <1 m planar beds of tabular to trough crossbedded feldspathic sandstone (lower arrow) and staurolite-bearing mudstone with flame structures at its upper contact (upper arrow; unit M3a; 468821E, 6086184N);* ***f)*** *poorly sorted heterolithic conglomerate with granule-rich dark grey wacke matrix and mudstone clasts indicated by the arrow (unit M1; 467234E, 6086609N) . All co-ordinates are in UTM Zone 14, NAD83.*

adjacent to the Crowduck Bay fault trend 043° and plunge 16° (Figure GS2023-8-4a). Staurolite porphyroblasts in biotite-staurolite-garnet schist in the Crowduck Bay area commonly have quartz-filled pressure shadows that show signs of sigma-type rotation indicative of dextral movement (Figure GS2023-8-4b). A unit of feldspathic wacke and conglomerate hostrock to the Thompson Brothers spodumene-bearing pegmatite dike has two fabrics: 1) a near-vertical penetrative cleavage in the feldspathic wacke that strikes 217° (S_2; 217°/87°), and 2) a weak clast-flattening/rodding in the conglomerate that trends 013° and plunges approximately 10 to 25°, likely related to D_4 overprinting (Figure GS2023-8-4c). In the narrows between Wekusko Lake and Crowduck Bay, a gabbro within several metres of the Crowduck Bay fault is cut by parallel shear bands that have associated S-C fabrics indicating sinistral movement (Figure GS2023-8-4d).

Silva et al. (2022) indicated that there are two varieties of pegmatite dikes in the Crowduck Bay area: barren pegmatites containing albite, quartz, K-feldspar and muscovite, with trace tourmaline and garnet; and spodumene-bearing pegmatite with albite, K-feldspar, quartz, tourmaline and muscovite. For a complete description of pegmatite dikes in the Wekusko Lake pegmatite field, the reader is referred to Černý et al. (1981) and Silva et al. (2022, 2023).

Barren pegmatite dikes form elongated, lobate, northeast-trending bodies at the metre- to decametre-scale in conglomerate and sandstone (units M1 and M3; Figure GS2023-8-2b) southeast of the Crowduck Bay fault, and in staurolite-garnet-biotite schist (unit B1; Figure GS2023-8-2b) northeast of the Crowduck Bay fault. These have irregular, but often sheared, contacts with folded keels (Figure GS2023-8-4e). Examination in cross-sectional view of a northeast-trending pegmatite ridge suggests that these are shallow, northeast-plunging, cigar-shaped bodies.

Spodumene-bearing dikes in Crowduck Bay (e.g., Sherritt-Gordon and Violet-Thompson groups; Silva et al., 2023) occur mainly as metre-scale, sheet-like features that trend 320 to 340°, with the exception of the Thompson Brothers dike, which trends ~040° and is slightly oblique to the Crowduck Bay fault. Intriguingly, the spodumene in the Thompson Brothers dike has a distinct lineation (~335°/10°) that appears to be the result of igneous crystallization during extension rather than later ductile deformation; this is broadly similar to the apparent strike of the Sherritt-Gordon group pegmatite dikes (320–340°). Work on microtextures from this dike should help provide additional constraints (Silva et al., 2023).

Exceptional exposures of the Sherritt-Gordon group pegmatite dikes show that contacts are sharp, straight and cut across all lithologies (Figure GS2023-8-4f) and earlier ductile fabrics, with minor extensional jogs and comb-structure mineral growth (feldspar, muscovite, tourmaline and spodumene) perpendicular to the wall margin of the dike. The pegmatite is very gently folded perpendicular to its strike length, with a wavelength of 2 m and a height of 0.2 m.

Discussion

Niblock Lake

Mapping conducted by Frarey (1950) indicated that the western side of Niblock Lake is composed of basaltic flows with an intrusive quartz-feldspar porphyry directly west of the lakeshore. Alternatively, field mapping by Bailes (1985) and the current study show that much of the western shoreline is composed of felsic volcanic rocks (unit J4; Figure GS2023-8-2a). At present, the geochemical affinity of volcanic rocks at Niblock Lake is unknown, but the presence of pillowed basalt flows (unit J1) suggests, at least in part, the subaqueous deposition of basalt. Mapping conducted by VMS Ventures Inc. identified felsic and mafic volcanic rocks to the west of Niblock Lake, at their Sails Lake project (between Sails Lake and Niblock Lake). Geochemical analyses indicate that both mafic and felsic rocks have an volcanic-arc signature (Bailes, unpublished report prepared for VMS Ventures Inc., 2010).

Bailes (1985) recognized that sedimentary rocks of the Missi group between Wekusko Lake and Saw Lake differed from their type localities at Flin Flon and Amisk Lake (Stauffer, 1990) in that they were more recrystallized and lithologically more diverse. Bailes (1985) considered two factors affecting this: a depositional environment that included marine as well as terrestrial conditions; and a modification of typical fluvial-alluvial sedimentation by localized volcanic activity, which provided volcanic flows and immature detritus.

The progression in sedimentary facies from <1 m interbedded, crossbedded feldspathic sandstone and mudstone (unit M3a) to mudstone (unit M3b) prior to deposition of poorly sorted, immature heterolithic conglomerate (unit M1) is considered to be part of a lateral and stratigraphic transition. Alternation of tabular crossbedded sandstone and mudstone likely reflects deposition in a meandering river system. The tabular crossbedded foreset beds probably reflect the lateral migration of the river channel, whereas the mudstone layers are likely the result of overbank deposition in meander cutoffs (e.g., Miall, 1996). The presence of fine centimetre-scale lamination and lack of fluvial sedimentary features in mudstone (unit M3b; Figure GS2023-8-2a) suggest that the fluvial system may transition into a slightly deeper water basin below extensive wave action or fluvial reworking. The presence of poorly sorted conglomerate overlying mudstone might indicate that the basin had considerable relief and that the conglomerate represents localized debris flows, which could explain the presence of mudstone clasts in granule-rich beds.

Crowduck Bay

Rocks along the Crowduck Bay fault have been affected by multiple deformation events and subsequent metamorphism (e.g., Connors et al., 1999; Connors et al., 2002; Reid, 2021). Connors et al. (1999) recognized two main periods of deformation

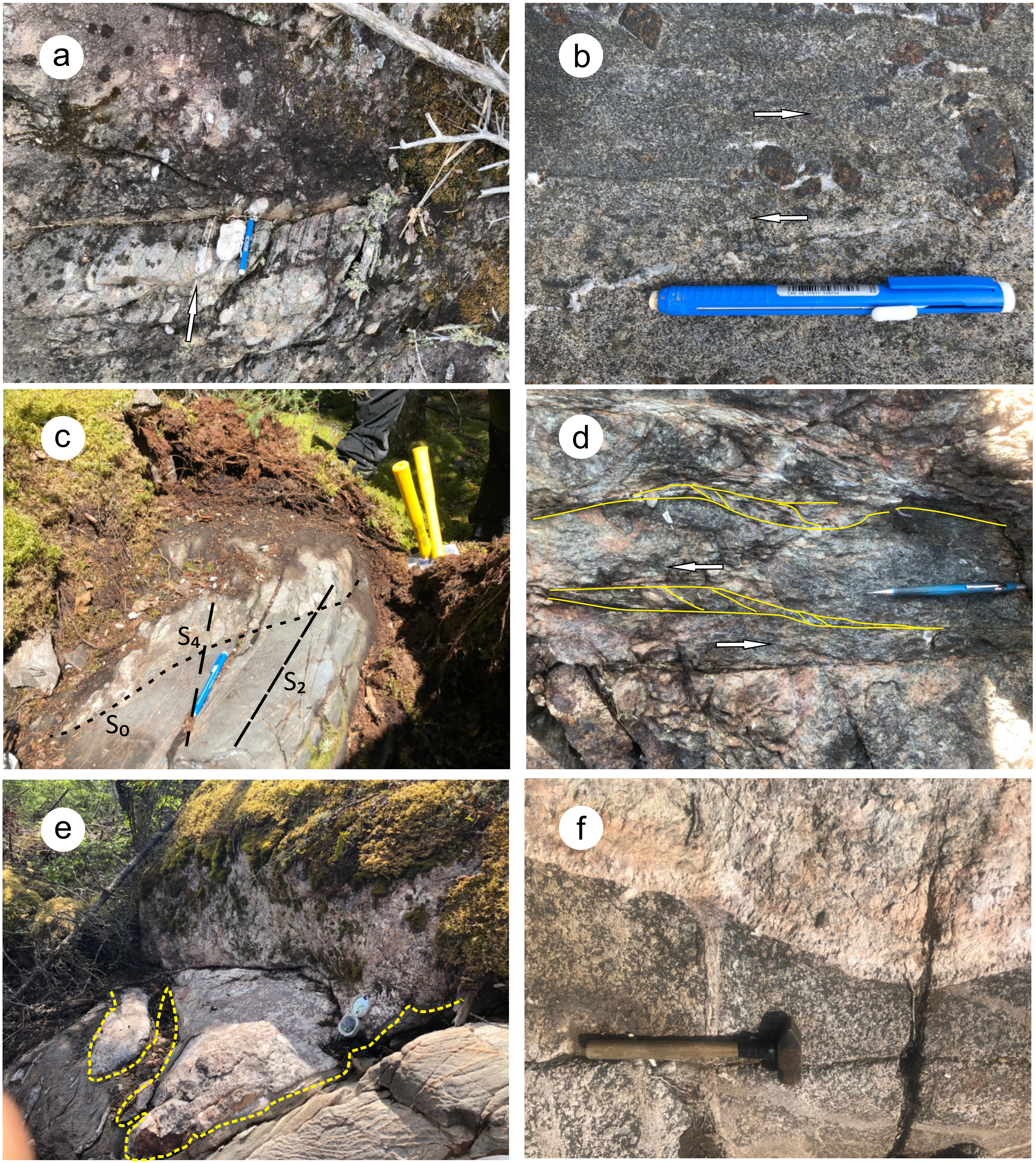

Figure GS2023-8-4: *Outcrop photographs from the Crowduck Bay area:* ***a)*** *rodded conglomerate clasts (arrow) with a 5:1:1 axes ratio (unit M3; 458177E, 6084830N);* ***b)*** *dextral sigma-type rotation of staurolite porphyroblasts (indicated by arrows; unit B1; 454509E, 6080384N);* ***c)*** *bedding S_0 overprinted by S_2 foliation and S_4 clast flattening/stretching (units M3 and M1; 454271E, 6078551N);* ***d)*** *S-C shear fabric (yellow lines and arrows) showing sinistral movement (453616E, 6077286N);* ***e)*** *barren pegmatite forming shallowly northeast-plunging body with tightly folded keel (yellow dashed line; 458976E, 6085256N);* ***f)*** *sharp contact between seriate gabbro and spodumene-bearing pegmatite (unit P2; 452713E, 6077434N). All co-ordinates are in UTM Zone 14, NAD83.*

affecting the rocks east of Wekusko Lake: 1) D_2, which involved thrust faulting and folding linked with southwest-directed transport between 1840 and 1830 Ma; and 2) D_3, characterized by north-northeast-trending, moderately to shallowly dipping stretching lineation and associated foliation that overprints D_2, and which resulted from northwest–southeast transpression between 1815 and 1805 Ma. Recent mapping by Reid (2021) summarized a similar history of fabrics, with a S_2 spaced cleavage linked to tight to isoclinal folding of Herb Lake volcanic rocks and adjacent sandstone and conglomerate. The axial planes of these folds strike from 045 to 060° and verge steeply to the northwest (equivalent to D_2; Connors et al., 1999). A less prominent near vertical S_3 spaced cleavage/jointing that strikes 330 to 340° overprints S_2 in the vicinity of Puella Bay (Wekusko Lake; D_3 of Reid, 2021). Closer to the Crowduck Bay fault, a strong penetrative foliation (S_4; 010–030°) related to D_4 (equivalent to D_3 of Connors et al., 2002) overprints all earlier fabrics.

It is important to note that deformation and peak metamorphism linked to D_3 folding and extension (D_3 of Connors et al., 2002; D_4 of Reid, 2021), between 1815 and 1805 Ma, have a strong control on emplacement and structural orientation of barren pegmatite dikes, which mimic clast elongation as seen in Figure GS2023-8-4a. The observed spodumene-bearing pegmatite dikes from the Sherritt-Gordon and Violet-Thompson groups, with the exception of the Thompson Brothers dike, intrude into brittle to brittle-ductile extensional structures trending 320 to 340° that cut the D_2 and D_3 fabrics of Connors et al. (1999) in the Crowduck Bay area. These mineralized dikes are younger than the barren pegmatite dikes, postdate peak metamorphism and are quite possibly linked to orogenic collapse or relaxation. This interpretation is supported by a recent 1780.0 ±8.1 Ma U-Pb radiometric age for dike 1 of the Green Bay group (Martins et al., 2019).

Interestingly, the S_3 spaced cleavage/jointing observed by Reid (2021) has a similar 320 to 340° orientation as the Sherritt-Gordon group spodumene-bearing pegmatite dikes. Arguably, this fabric potentially acts as ground preparation for later brittle-ductile extensional faults, especially in rocks with competent rheology such as gabbro. In addition to S_3 (320–340°) fabrics, it is likely the S_2 (045–060°) spaced cleavage and associated faults formed during D_2 deformation, which played a role in forming dilatational zones during postpeak metamorphic structural reactivation. The Thompson Brothers spodumene-bearing pegmatite has a trend of 040°, which is oblique to the adjacent 015° trending Crowduck Bay fault, likely formed along an early D_2 structure. As with many long-lived ductile structures, the Crowduck Bay fault likely did not have accommodation space for the emplacement of the mineralized pegmatite, but the secondary structures around it did.

Economic considerations

The presence of subaqueously deposited bimodal mafic and felsic volcanic rocks indicates that the rocks west of Niblock Lake have the potential to produce volcanogenic massive-sulphide deposits; rhyolite tuff breccia and conglomerate along the western shoreline have a strikingly similar appearance to rhyolite breccia observed in the Millrock member of the Flin Flon formation (e.g., Bailes and Syme, 1989). Structurally brecciated massive rhyolite and dacite in the Niblock Lake area is locally flooded with quartz and disseminated sulphide (gold-assay results are pending).

Understanding property-scale rheological differences, coupled with regional structural history and fabrics, is imperative to understanding potential emplacement sites for mineralized lithium-bearing pegmatite.

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