GS2022-8

Preliminary interpretation of aeromagnetic data from poorly exposed and sub-Phanerozoic basement rocks east and southeast of Snow Lake, north-central Manitoba (parts of NTS 63F15, 16, 63G13, 14, 63J3–6, 11–14, 63K1, 2, 8, 9, 16, 63O3, 4)

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In Brief:

- The area east and south of Snow Lake is subdivided into 13 aeromagnetic domains based on total magnetic intensity and structural patterns
- Each aeromagnetic domain is subdivided lithologically and often contain multiple rocks types
- Sub-Phanerozoic basement rocks of the eastern Trans-Hudson orogen contain a variety of economically significant mineral deposit types

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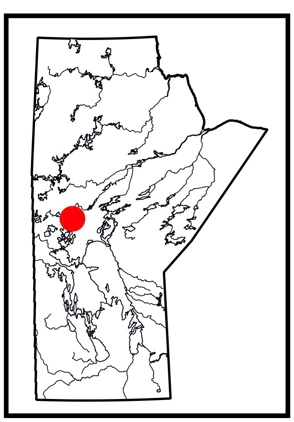

Summary

The Manitoba Geological Survey is conducting research on metavolcanic and metasedimentary rocks of Paleoproterozoic age that extend beneath Phanerozoic limestone and dolomite south and southeast of Snow Lake in north-central Manitoba. The goal is to produce new 1:50 000 scale geological maps using industry and government aeromagnetic, lithological, geochemical and geochronological data. Presented here are brief descriptions of 13 interpreted aeromagnetic domains in the project area and their proposed lithological subdivisions. In the northern half of the study area, some lithological subdivisions have been tested by reviewing drillcore and the associated geochemical and geochronological analytical results.

Introduction

Isotopically juvenile volcanic-arc and arc-rift sequences are economic producers of volcanogenic massive-sulphide (VMS) in the Flin Flon domain (FFD), and, as such, have long been subject to extensive exploration. Volcanogenic massive-sulphide orebodies commonly have both magnetic and conductive properties detectable by airborne magnetic and electromagnetic surveys, thus these surveys are routinely applied exploration tools. South of where the FFD is exposed, Phanerozoic limestone and dolomite cover rocks have little magnetic response and thus behave largely as 'transparent' material, allowing the more magnetic basement rocks to be observed.

The project area extends over an irregular 9350 km^2 area southeast of Snow Lake (Figure GS2022-8-1), covering both poorly exposed and sub-Phanerozoic basement rocks along the southeasterly flank of the FFD. This report provides a summary of the interpreted aeromagnetic domains and potential lithological subdivisions for the project area as determined from magnetic intensity, internal magnetic complexity and electrical conductivity. In addition, some aspects of drillcore observations are reviewed from previous work (e.g., Simard et al., 2010; Reid, 2020).

Regional setting

The FFD is one of a series of volcanic-sedimentary assemblages that make up the internal Reindeer zone of the Paleoproterozoic Trans-Hudson orogen (Lewry, 1990). In Manitoba, 1.92–1.87 Ga juvenile island-arc, juvenile ocean-floor/back-arc and ocean-island basalt (Syme et al., 1999) were tectonically accreted during 1.88–1.87 Ga closure of the Manikewan Ocean (e.g., Stauffer, 1984; Lucas et al., 1996). Successor-arc plutonism (1.87–1.84 Ga) 'stitched' this accretionary complex. Southwest-directed thrusting resulted in uplift and erosion during the waning stages of successor-arc magmatism (e.g., Ansdell et al., 1999). This led to deposition of voluminous continental alluvial-fluvial deposits (Paleoproterozoic metasediments; medium blue in Figure GS2022-8-1) and broadly coeval marine turbidites (Paleoproterozoic greywacke; light grey in Figure GS2022-8-1) into the Kisseynew paleobasin to the north (ca. 1.85–1.84 Ga; Zwanzig, 1990; Lucas et al., 1996). South-directed thrusting continued and resulted in the FFD being overthrust by nappes of marine turbidites of the Kisseynew domain (Zwanzig, 1990). Arc and successor-arc processes were followed by a protracted interval of deformation and metamorphism in the Trans-Hudson orogen (1.84–1.69 Ga) related to collision between the juvenile Paleoproterozoic Reindeer zone and Archean cratons (Gordon et al., 1990; Lewry, 1990; Ansdell et al., 1995).

Previous work

Leclair et al. (1997) conducted regional mapping of the sub-Phanerozoic portion of the FFD in the early 1990s by integration of high-resolution aeromagnetic and gravity data. Leclair's compila-

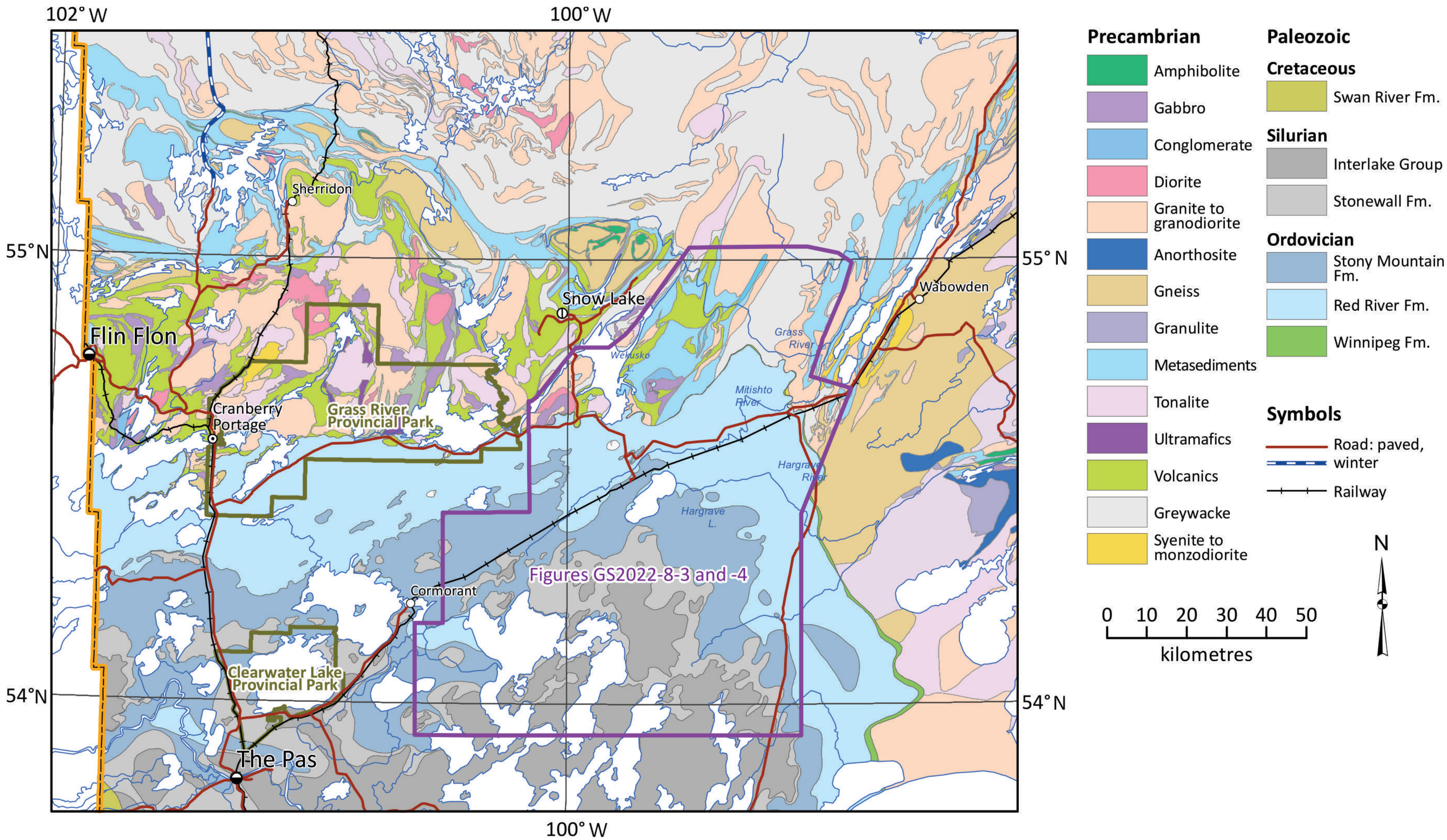

Figure GS2022-8-1: *Geology of the Flin Flon domain in west-central Manitoba (geology from Manitoba Geological Survey, 2022), with the study area outlined in purple. Rocks in the northern portion of the study area are poorly exposed. Abbreviation: Fm., Formation.*

tion resulted in the recognition of several major domains (Figure GS2022-8-2). Some rock assemblages similar to those found in the exposed portion of the FFD and Kisseynew domain were recognized in the sub-Phanerozoic, whereas others appear to be unique to the sub-Phanerozoic. In the project area, Leclair et al. (1997) recognized four lithotectonic domains in the FFD (Figure GS2022-8-2): 1) the 1.83 Ga Cormorant batholith; 2) the Clearwater domain (interpreted to be correlative to the 1.90–1.88 Ga Snow Lake assemblage); 3) the Eastern Kisseynew domain; and 4) the Superior boundary zone.

Simard and McGregor (2009) started compilation of new geochronological, isotopic and geochemical data to aid in mapping the sub-Phanerozoic portion of the Flin Flon and Kisseynew domains, with the objective of characterizing the various geophysical domains outlined by Leclair et al. (1997). Simard et al. (2010) conducted detailed work on eight poorly understood VMS deposits from the Clearwater and Eastern Kisseynew domains, showing that they formed in different lithotectonic environments. They were able to show that deposits in the Clearwater domain (Moose, Limestone, Sylvia, Kofman deposits) are hosted in bimodal tholeiitic to transitional oceanic-arc rocks at 'lower metamorphic grade', whereas those of the Eastern Kisseynew domain (Watts River, Fenton, Harmin, Talbot deposits) are hosted by volcanic and sedimentary rocks formed in a rifted arc and/or back-arc environment and metamorphosed at relatively 'high metamorphic grade'. Reid (2017, 2018) re-examined drillcore and coupled it with aeromagnetic interpretation to characterize the area south of Wekusko Lake, and the Watts, Mitishto and Hargrave rivers areas. Reid (2020) reviewed geochemical and geochronological data from drillcore from these areas with a focus on metasedimentary rocks.

Aeromagnetic data and observation methodology

High-resolution aeromagnetic data used in this interpretation were compiled by Keating et al. (2012) using aeromagnetic surveys from the Geological Survey of Canada and industry that were flown at line spacing ranging from 200 to 400 m and sensor heights ranging from 90 to 150 m. Details regarding microlevelling and upward continuation to merge the datasets is provided in Keating et al. (2012). The total magnetic intensity (TMI) and first vertical derivative (1VD) were gridded using Geosoft plugins in Esri® ArcMap 10.6. Regardless of survey parameters, with the

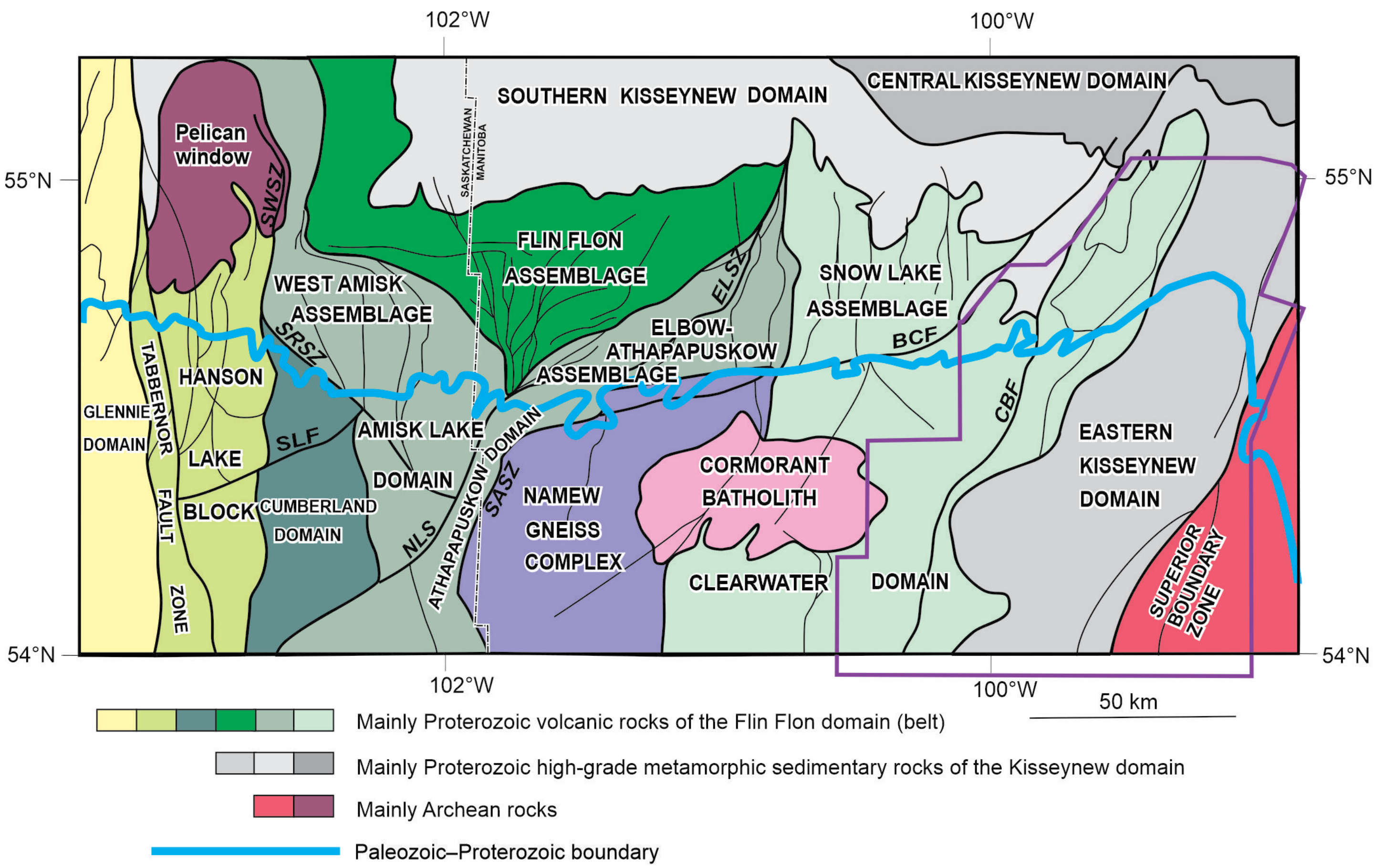

Figure GS2022-8-2: *Interpreted lithotectonic domains of the Flin Flon belt, referred to herein as the Flin Flon domain (after Leclair et al., 1997; NATMAP Shield Margin Project Working Group, 1998). Abbreviations of major faults and shear zones: BCF, Berry Creek fault; CBF, Crowduck Bay fault; ELSZ, Elbow Lake shear zone; NLS, Namew Lake structure; SASZ, South Athapapuskow shear zone; SLF, Suggi Lake fault; SRSZ, Spruce Rapids shear zone; SWSZ, Sturgeon-weir shear zone. The thick blue line is the contact between the exposed Precambrian rocks to the north and Paleozoic-covered Precambrian rocks to the south. The purple line shows the study area.*

increase in depth of the Phanerozoic cover, the distance of the sensor to the target rocks also increases, resulting in lower data resolution. This is observable in Figure GS2022-8-3, moving from where fine detail can be seen in the exposed bedrock area in the north (e.g., East Wekusko, Saw Lake domains) to becoming increasingly blurry with less clarity in more deeply buried areas in the southwest (e.g., Hayward-McClarty, Hargrave high domains). The current interpretation was aided by the availability of electromagnetic (EM) data associated with Spectrem airborne surveys. Though not levelled between surveys, the electromagnetic decay constant (TAU) in the Z-component was gridded to see comparable conductivity between different rocks. Linework and polygons were plotted digitally in ArcMap 10.6.

The reader is referred to Isles and Rankin (2013) for a detailed discussion regarding the interpretation of aeromagnetic data. Based on these authors' guidelines, two distinct classes of

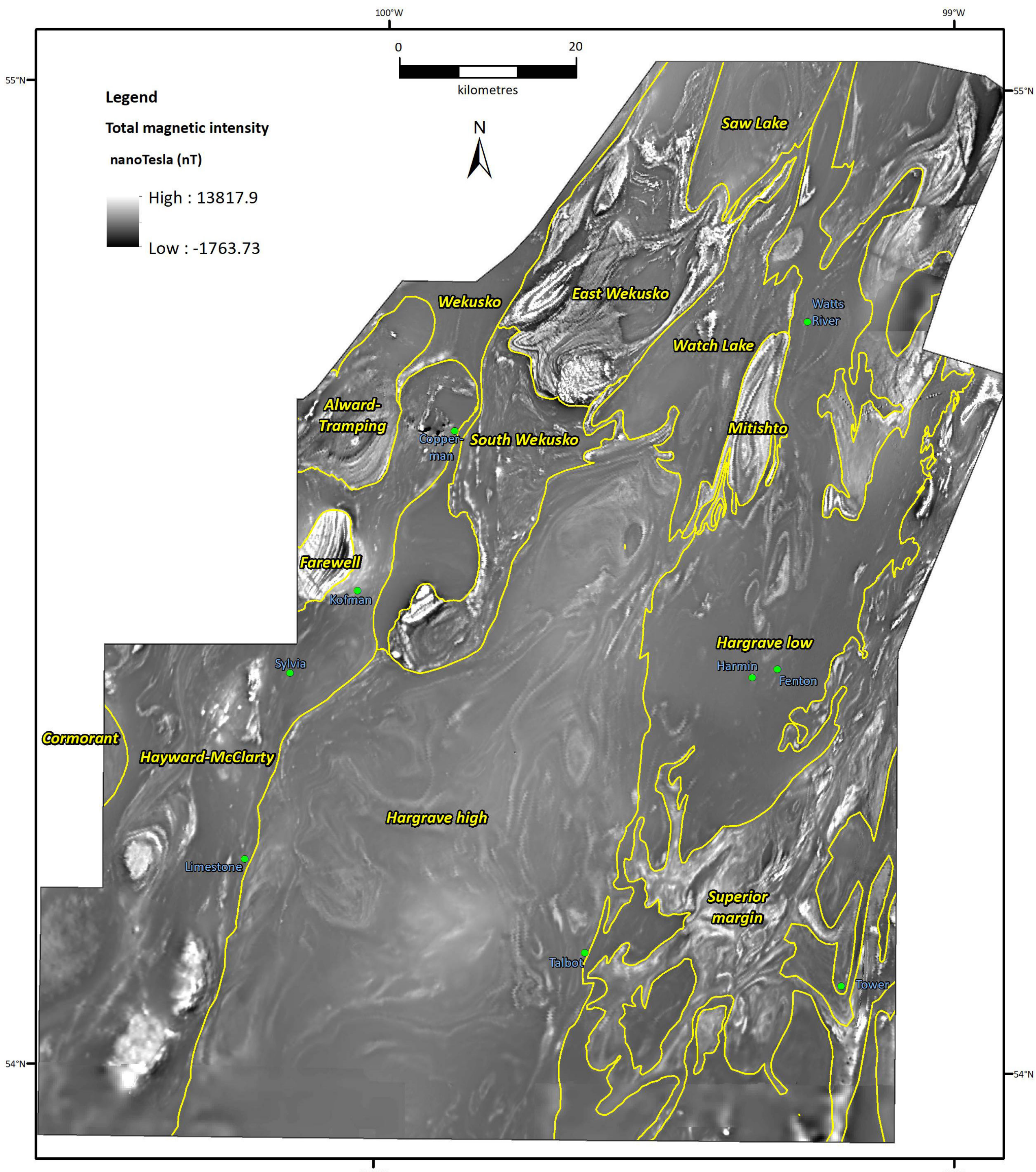

Figure GS2022-8-3: *Greyscale total magnetic intensity overlain by first vertical derivative with 50% transparency, with aeromagnetic domains outlined in yellow. Green dots indicate location of known mineral deposits.*

observations have been made: 1) the magnetic rock units from TMI, and 2) pattern trends and discontinuities (trend breaks) derived from the 1VD. For simplicity in this report, a combination of the TMI overlain by the 1VD with 50% transparency is used here for discussion (Figure GS2022-8-3). Figure GS2022-8-4 shows proposed lithological subdivisions; however, a complete discussion of all lithological subdivisions is beyond the scope of this report. A publication containing all form lines and structural data used to create the aeromagnetic domains and associated lithological subdivisions, is to be released at a later date.

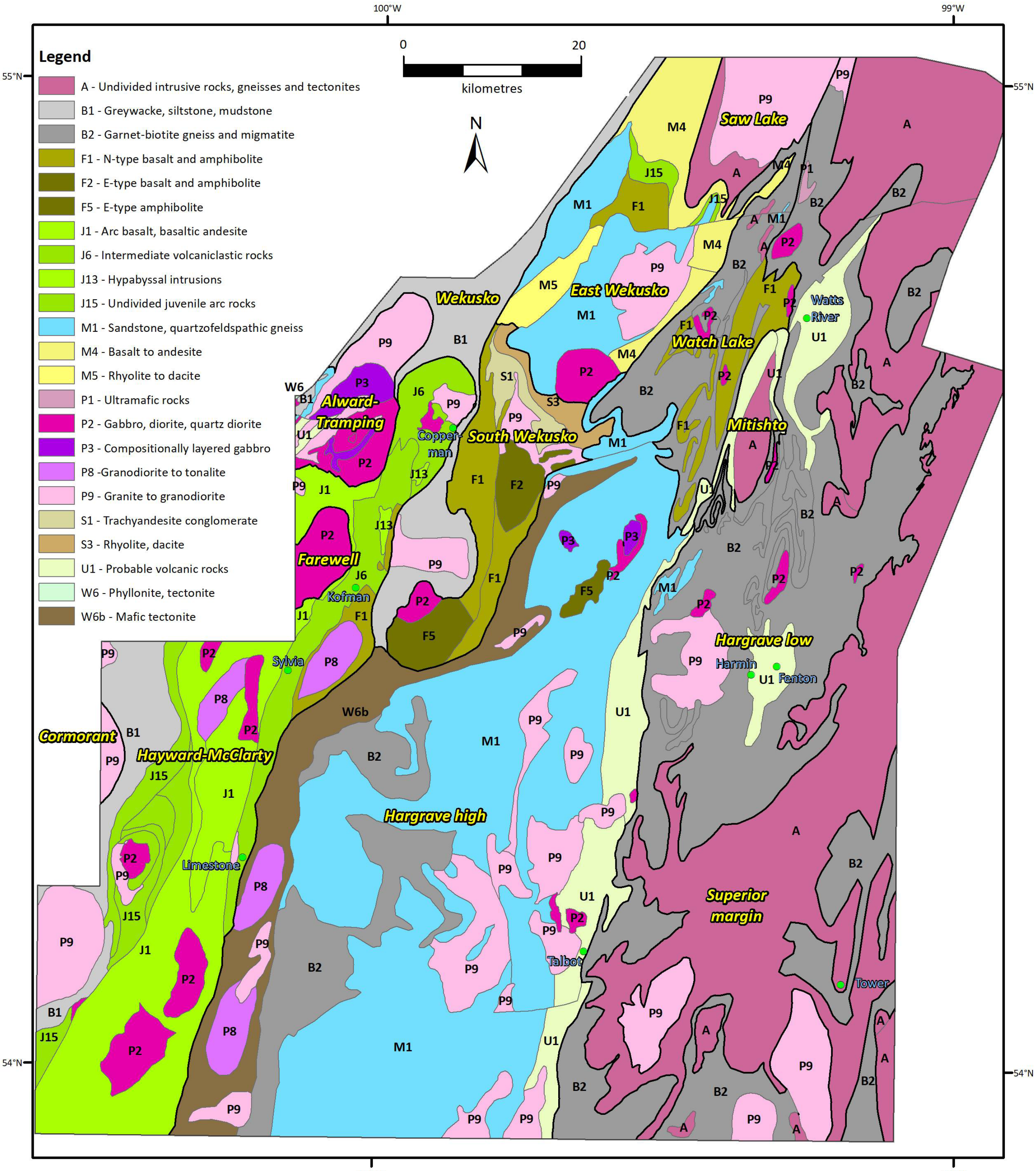

Figure GS2022-8-4: Lithological subdivision map based on the proposed aeromagnetic domains. The legend is adapted from the NATMAP Shield Margin project (NATMAP Shield Margin Project Working Group, 1998). Green dots show locations of known mineral deposits.

Aeromagnetic domains

Figure GS2022-8-3 shows the project area divided into 13 aeromagnetic domains that broadly correlate with the Clearwater, Eastern Kisseynew and Southern Kisseynew lithotectonic domains of Leclair et al. (1997). The Hayward-McClarty, Alward-Tramping, Farewell, East Wekusko and South Wekusko aeromagnetic domains are broadly correlative with the Clearwater domain, whereas the Watch Lake, Hargrave high and Hargrave low aeromagnetic domains largely correspond to the Eastern Kisseynew domain (Figures GS2022-8-2 and -3). The Cormorant domain corresponds with the Cormorant batholith as defined by Leclair et al. (1997). The Wekusko domain is associated with the Southern Kisseynew domain. Note, however, that the preliminary interpretation in this report places less emphasis on attempting to identify aeromagnetic domains within the Clearwater or Kisseynew domains, and more emphasis on identifying aeromagnetic domains in the Flin Flon domain. A brief description of the 13 aeromagnetic domains is given below. Figure GS2022-8-4 shows smaller lithological subdivisions; these are based on a number of features, such as TMI, structural pattern, and apparent discontinuities and conductivity (see Table GS2018-4-1 in Reid, 2018 for list of aeromagnetic characteristics of rocks in the eastern Flin Flon domain). Where possible, drillcore data have been incorporated into the interpretation.

Alward-Tramping

This partially exposed aeromagnetic domain is composed of granite and quartz diorite successor-arc plutons and contains subordinate supracrustal rocks (Syme et al., 1995; David et al., 1996). The Wekusko Lake pluton (unit P9; Figure GS2022-8-4) in the northern part of this domain has a very low magnetic signature with almost no internal complexity, and the transition with the Wekusko domain to the northeast is very subtle (Figure GS2022-8-4). The Alward quartz diorite pluton has layered internal complexity and moderate magnetic intensity; its southern extent appears to truncate north-northeast-trending aeromagnetic features in the Hayward-McClarty domain (Figure GS2022-8-3). Although this domain is largely considered to be plutonic, subordinate volcanic and sedimentary rocks are present along its northwest side (units M1, U1; Figure GS2022-8-4).

Wekusko

The Wekusko aeromagnetic domain is a north-south-trending magnetic low; it has varying width and low internal complexity but does contain subtle north-northeast-trending magnetic features and moderate conductivity (EM and TAU; not shown on any figure). The exposed area is mainly composed of mudstone and greywacke that belongs to the Burntwood group at Wekusko Lake (Bailes and Galley, 1992; Gilbert and Bailes, 2005). Moving southward, the Wekusko domain is traced several kilometres under the subsurface via aeromagnetic and drillcore data (Figure GS2022-8-3; Reid, 2017). The Wekusko domain is bounded by the Alward-Tramping domain to the west, the Hayward-McClarty domain to the south and the South Wekusko dome to the east (Figure GS2022-8-3).

Hayward-McClarty

The Hayward-McClarty aeromagnetic domain is broadly analogous to the Clearwater lithotectonic domain identified by Leclair et al. (1997; Figure GS2022-8-2). It is characterized by low to intermediate magnetic intensity and is visible as a series of corrugated north-northeast-trending magnetic fabrics (Figure GS2022-8-3). Irregular to ovoid magnetic lows and highs are interpreted as felsic (unit P9; Figure GS2022-8-4) and mafic (units P2 and P3; Figure GS2022-8-4) intrusive bodies, respectively. In the southwest portion of this domain, macroscopic S-folds flanked by magnetic lows are interpreted as greywacke and mudstone (unit B1; Figure GS2022-8-4), similar to those observed in the Wekusko domain. The eastern portion of the domain hosts the Copper-man, Kofman, Sylvia and Limestone VMS deposits (Figure GS2022-8-3; Simard et al., 2010; Reid, 2017).

Farewell

The Farewell magnetic domain is a prominent north-northeast-trending magnetic high within the Hayward-McClarty domain; it has distinct low and high magnetic corrugations (Figure GS2022-8-3). Two drillholes, WEK-93-13 and WEK-93-14 intersecting massive medium-grained gabbro, test this magnetic high. The corrugated magnetic signature is interpreted to represent a layered mafic intrusion (unit P2; Figure GS2022-8-4) with an approximate 12 km strike length and 9 km width. The 3:2 aspect ratio of this layered intrusion might suggest a much larger intrusion at depth.

Cormorant

A small expression of the Cormorant Lake batholith occurs along the western margin of the project area and has a relatively even, moderately magnetic signature (Figure GS2022-8-3). Work by Leclair et al. (1997) outlined an approximately 60 by 25 km granite intrusion (Figure GS2022-8-2) with an age of 1831 +5/-4 Ma (Stern et al., 1993).

South Wekusko

Rocks of the exposed South Wekusko magnetic domain contain basalt and trachyandesite conglomerate that are structurally juxtaposed against rocks of the Wekusko domain along the Crowduck Bay fault (Gilbert and Bailes, 2005; Reid, 2019). Overall, aeromagnetic response of these rocks is moderate, with minor internal folding and an irregularly folded eastern contact with the East Wekusko and Hargrave high domains. The western half of the South Wekusko domain contains north-south-oriented lows interpreted to represent north-south fault splays running parallel to the Crowduck Bay fault (see Figure GS2022-8-2 for approximate location of the Crowduck Bay fault). An ovoid magnetic feature, in part interpreted to represent a zoned intrusion with intermediate to mafic composition (unit F5; Figure GS2022-8-4), truncates the southern end of this magnetic domain.

East Wekusko

The East Wekusko magnetic domain covers an area of poorly exposed bedrock east of Wekusko Lake (Figures GS2022-8-1 and -3). Overall TMI signatures that are moderate to high correspond to dominantly Missi group sandstone, conglomerate, felsic–intermediate volcanic, and intermediate intrusive rocks (units M1, M4, M5, P2, P9; Figure GS2022-8-4; NATMAP Shield Margin Project Working Group, 1998; Ansdell et al., 1999; Reid, 2021). Tight to isoclinal folding, recorded by alternating magnetic highs and lows, distinguishes the stratified character of the rocks. The exceptions to the strongly magnetic rocks are ocean-floor basalt and late granite intrusive rocks in the northeast portion of the domain (units F1 and J5; NATMAP Shield Margin Project Working Group, 1998).

Hargrave high

Hargrave high is the largest magnetic domain in the study area; it is a broad magnetic high with variable internal geometry (Figure GS2022-8-3). The contact between the Hayward-McClarty and this domain roughly aligns with the transition to the Eastern Kisseynew domain of Leclair et al. (1997). Similar to Leclair's findings, drillcore from this domain yielded gneissose textures with abundant felsic intrusive sheets. Complexly folded stratigraphy is apparent from magnetic fabrics along the western side of the Hargrave high domain: these resemble interlayered heavy-mineral-rich feldspathic sandstone and conglomerate of the Missi group (unit M1; Figure GS2022-8-4) found in the East Wekusko domain (Figure GS2022-8-3). Drillcore observations support this interpretation; small windows of feldspathic arenite (unit M1; Figure GS2022-8-4) in drillhole HAR077 have a detrital zircon age distribution (Reid, unpublished data) similar to that of Missi group sandstone (e.g., Ansdell et al., 1992, 1999).

Magnetic fabrics along the eastern side of the Hargrave high have been transposed into a north-south orientation; this area hosts the Talbot VMS deposit and may contain intercalated volcanic rocks. Truncation of these north-south magnetic fabrics are considered to be the result of intrusive bodies, possibly granite to granodiorite (unit P9; Figure GS2022-8-4).

Hargrave low

Bordering the Hargrave high domain to the east is a parallel north-northeast-trending magnetic low extending from the very north of the project area to its southern boundary. In contrast to the rocks of the Hargrave high, this domain is characterized by much more subtle magnetic responses (Figure GS2022-8-3). Work by Reid (2020) indicates that a significant amount of rock associated with this broad low aeromagnetic response corresponds with garnet-biotite gneiss that is interpreted to have a sedimentary protolith (unit B2; Figure GS2022-8-4). Similar to rocks in the Hargrave high domain, evidence of in situ melting is often present, with the formation of melanosome and leucosome (Reid, 2018, 2020). Although primary textures are largely absent, Simard et al. (2010) suggested VMS mineralization that occurs in this domain formed in a 'rifted basin' with a mixture of sedimentary and volcanic rocks of younger age (ca. 1865 Ma). Within the broad magnetic lows are areas with subtle increased magnetic response that often coincide with VMS mineralization (e.g., Watts River, Harmin, Fenton deposits; Figure GS2022-8-3); these are considered areas with probable volcanic rocks (Figure GS2022-8-4).

Rocks of the Hargrave low domain have a complexly folded contact with rocks of the Superior margin domain. In the northern part of the domain, a small arrowhead-shaped magnetic high feature (Figure GS2022-8-3) suggests a modified type-2 fold interference. To the south, subtle magnetic features have ovoid patterns, more indicative of type-1 fold interference (Figure GS2022-8-3). Ovoid areas of low aeromagnetic response that are isolated within the Superior margin domain are considered part of the Hargrave low.

Watch Lake

This domain is similar to the Hargrave low in that it has a low magnetic response with subtle magnetic highs; some of these subtle highs appear to be doubly plunging and rootless folds, suggesting these rocks have undergone ductile flow with non-cylindrical folding (Figure GS2022-8-3). The broad magnetic low is assumed to correspond to psammopelite observed in drillcore that is interpreted to be equivalent to Burntwood group (e.g., drillholes KUS343, KUS356 and KUS367; Reid, 2020). However, north-northeast-trending magnetic highs in the very far northern portion of the domain have geochemical characteristics similar to those of Ospwagan group rocks (Reid, 2020), suggesting these rocks may be structurally interleaved.

Mitishto

The Mitishto magnetic domain is a prominent north-northeast-trending ovoid magnetic high with alternating internal complexity that is interpreted to have resulted from type-1 fold interference (Figure GS2022-8-3). Drillholes intersecting this high are limited, but detrital zircons from quartz-rich psammite along its eastern flank (drillhole KUS378) indicate that this unit has Archean provenance, similar to the Saw Lake protoquartzite (Bailes and Böhm, 2008; Reid, 2020). Alternatively, drillholes KUS382 and KUS383 along the western flank intersect calcsilicate-altered intermediate to mafic gneiss interpreted as possible volcanic rocks (Reid, 2020).

Saw Lake

The Saw Lake magnetic domain has low to intermediate magnetic intensity (Figure GS2022-8-3); internal fabrics show an ovoid centre area, whereas the contact between the East Wekusko and Saw Lake domains is tightly folded. Two main rock types make up the Saw Lake domain (e.g., Bailes, 1985; Bailes and Böhm, 2008); the southern half contains metasedimentary quartzite and subordinate pelite, and the northern half is the multiphase Saw Lake felsic pluton. Detrital zircons from the quartzite yielded only Archean ages, which to some extent overlap with those dominating the Ospwagan group (e.g., Rayner et al., 2006).

Superior margin

Work by Macek et al. (2006) and Zwanzig (1999) demonstrated that the exposed Superior margin stratigraphy extends into the eastern flank of the study area. Strongly magnetic rocks that occur along the eastern flank of the project area and that are in contact and complexly folded with rocks of the Hargrave low are part of the Superior margin domain (Figure GS2022-8-3). These include aspects of Archean orthogneiss and migmatite, and the Paleoproterozoic Ospwagan group passive-margin sedimentary rocks of the northwestern Superior province. The boundary between the Superior margin and the Hargrave low aeromagnetic domains is, in part, adopted from Macek et al. (2006).

Discussion

This report builds on the work of Leclair et al. (1997) by characterizing additional lithological subdivisions of the poorly exposed and sub-Phanerozoic basement rocks along the eastern flank of the Trans-Hudson orogen (Figures GS2022-8-1, -4). As an alternative to the previous subdivision of the studied region into the Clearwater and East Kisseynew lithotectonic domains, the current work divides this area into 13 aeromagnetic domains, each containing probable lithological subdivisions (Figure GS2022-8-4). The current interpretation highlights the following:

- The Hayward-McClarty domain contains arc volcanic and volcaniclastic rocks ranging in composition from basalt to rhyolite. These are, at least in part, an extension of the Hayward Creek juvenile arc volcanic assemblage exposed in the southwest portion of Wekusko Lake (e.g., Gilbert and Bailes, 2005; Reid, 2017).
- The Hargrave high, at least in part, is interpreted to be composed of feldspathic sandstone and conglomerate correlative to the Missi group in the exposed East Wekusko domain.
- The Hargrave low and Watch Lake domains dominantly consist of garnet-biotite gneiss interpreted to be equivalent of Burntwood group, but also contain intercalated intermediate to felsic volcanic rocks (e.g., Simard et al., 2010).
- The Mitishto and Saw Lake domains, although having differing aeromagnetic responses, have quartz-rich sediments with similar Archean provenance (see Bailes and Böhm, 2008; Reid, 2020).

Economic considerations

The poorly exposed and sub-Phanerozoic basement domains of the eastern flank of the Trans-Hudson orogen, particularly the areas east and south of Snow Lake, are well-endowed in a variety of mineral deposit types of economic significance. These include base-metal deposits such as VMS, which contain copper and zinc. Also of economic importance are orogenic structures in the region that are host to gold, and pegmatite dikes containing critical elements such as lithium (Silva et al., 2022). More recently, sulphide-graphite horizons have been recognized to contain elevated vanadium (Huzyk Creek; Couëslan, 2019). Thus, continued baseline documentation and interpretation of poorly exposed and sub-Phanerozoic basement rocks in the Snow Lake region are necessary for finding the critical minerals and elements needed for transitioning to a green electrified economy.

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