GS2018-4

Sub-Phanerozoic basement geology from drillcore observations in the Watts, Mitishto and Hargrave rivers area, eastern Flin Flon belt, west-central Manitoba (parts of NTS 63J5, 6, 11, 12, 13, 14)

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In Brief:

- Drillcore observation and geophysics define a new geological interpretation of the sub-Phanerozoic basement southeast of Wekusko Lake
- Previously unrecognized mafic to felsic volcanic rocks, typical of the Flin Flon belt, occur in the study area and significantly expand the exploration space for base-metal deposits

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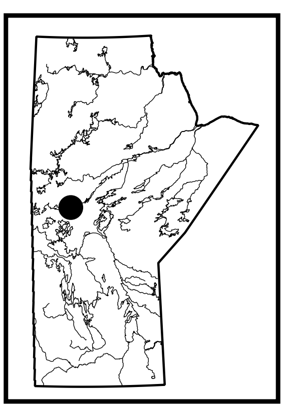

Summary

The Manitoba Geological Survey (MGS) is in the process of refining the geology of the Precambrian Flin Flon belt where it extends to the south beneath Phanerozoic cover rocks. New 1:50 000 scale geological maps are being developed from industry and government aeromagnetic, drillhole geochemistry and lithological log data. Domains with similar aeromagnetic signatures were investigated by examining drillcore from 31 holes during a three-week period in the summer of 2018.

Highlights of the summer's investigations include a new geological interpretation of the study area that encompasses metamorphosed sandstone and conglomerate, pelite and psammopelite, mafic to felsic volcanic rocks, and a variety of intrusive rocks from granite to gabbro. Middle- to upper-amphibolite facies peak metamorphic assemblages occur in pelitic rocks; a shift from sillimanite-bearing to migmatitic indicates a southeastward increase of the metamorphic grade. The recognition of volcanic rocks broadens the potential area for volcanogenic massive-sulphide (VMS) exploration in the region.

Introduction

The Flin Flon belt (FFB) is one of a series of volcanic-sedimentary belts that make up the internal Reindeer zone of the Paleoproterozoic Trans-Hudson orogen (Lewry and Collerson, 1990). Geological mapping of the exposed portion of the FFB demonstrates that a belt-wide stratigraphy is applicable from Flin Flon to Snow Lake. This stratigraphy involves ca. 1.9–1.8 Ga oceanic volcanic assemblages that include juvenile island-arc, juvenile ocean-floor/back-arc, and ocean-island basalts (Syme et al., 1999), which were tectonically accreted during closure of the Proterozoic Manikewan Ocean (e.g., Stauffer, 1984; Syme and Bailes, 1993). Postdating the accretion of the oceanic volcanic assemblages is the emplacement of 'successor'-arc plutons and the deposition of local subaerial volcanic rocks (1.87–1.83 Ga; e.g., Connors et al., 1999; Whalen et al., 1999). In addition, fluvial-alluvial sandstone and conglomerate of the Missi group (1.85–1.83 Ga) unconformably overlie older volcanic rocks and, in some cases, are intimately associated with 'successor'-arc volcanic rocks (e.g., Ansdell et al., 1992; Connors et al., 1999; Syme et al., 1999). Burntwood group (1.85–1.84 Ga) greywacke and argillite represent the deeper water lateral facies equivalents to the Missi group (e.g., Ansdell et al., 1995).

The FFB is one of the most well-endowed VMS camps in the world, with the majority of deposits hosted by juvenile-arc and arc-rift volcanic sequences (Syme et al., 1999). The development of deep-penetrating airborne geophysical surveys has expanded exploration in the FFB from the exposed areas to its sub-Phanerozoic extension to the south, and has resulted in the discovery of several VMS deposits since the mid-1990s (e.g., Watts River, Harmin, Fenton and Talbot). Several of the sub-Phanerozoic Cu-Zn massive-sulphide discoveries at the eastern end of the FFB are located on existing geological maps within Burntwood group sedimentary rocks (see Figure GS2017-7-1; Reid, 2017). This raises two important questions:

- Does the region contain volcanic rocks not previously identified?
- Alternatively, are these a new class of VMS deposit in the belt associated with dominantly sedimentary rocks?

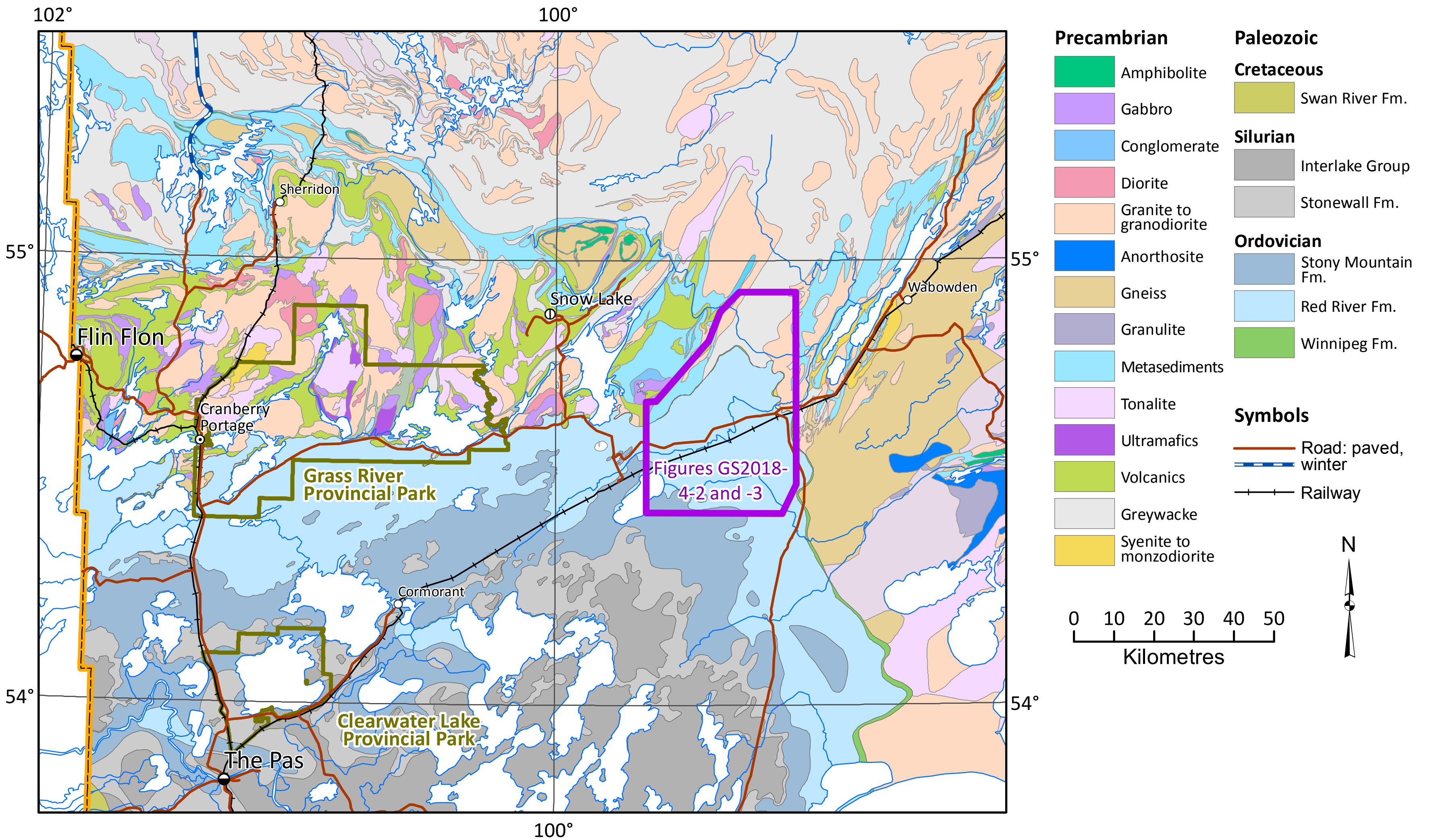

Figure GS2018-4-1: *Geology of the Flin Flon belt in west-central Manitoba, with the Watts, Mitishto and Hargrave rivers study area outlined in purple. Note the extent of Phanerozoic cover rocks. The rocks in the northern portion of the study area are poorly exposed.*

A better understanding of the sub-Phanerozoic geology of the eastern FFB is required, and part of this involves updating and refining geological maps for this region.

Previous work

Early geological work in the exposed FFB to the north of study area was completed by the Geological Survey of Canada and later by the MGS in the form of mapping in exposed areas to the northeast and north (e.g., Stockwell, 1937; Bailes, 1985). More recently, Leclair et al. (1997) subdivided the eastern sub-Phanerozoic portion of the FFB into three domains based on geophysical and drillcore data: the Cormorant batholith, the Clearwater domain and the East Kisseynew domain (see Figure GS2017-7-1; Reid, 2017). The increased metamorphic grade of the East Kisseynew domain complicates interpretation of protoliths; therefore, this area was only subdivided into two rock types: granitoids and pelites (Burntwood group). Reid (2017) reviewed drillcores from holes KUS356, KUS367 and KUS368 in 2017 but did not attempt to place these rocks into a new regional geological framework. Data from these drillholes, however, aided the geological interpretation given below.

Aeromagnetic data

Figure GS2018-4-2 shows a simplified geological interpretation based on compilation of drillcore and aeromagnetic data. Keating et al. (2012) compiled and leveled high-resolution government and industry aeromagnetic data for the Flin Flon–Snow Lake region and produced total magnetic intensity (TMI) and first vertical derivative (1st VD) maps of the magnetic field that are reduced to pole. The TMI provides the basis for defining domains of similar magnetic intensity, potentially identifying areas with similar rock types. A semitransparent hillshade directed from 290º adds depth to northeast-trending features in the TMI (Figure GS2018-4-3). In contrast, the 1st VD tends to define magnetic lineaments that help to delineate structures and internal complexity, and to better resolve contacts. Table GS2018-4-1 contains a summary of aeromagnetic signatures from stratigraphically constrained rocks in the exposed eastern FFB. The linework from Figure GS2018-4-2 is included on the TMI map in Figure GS2018-4-3 to aid interpretation.

Drillcore observations

The following summary of the drillcore observations makes it possible to test the interpretations made from geophysics. Middle-amphibolite facies and higher metamorphism affected all rocks in the study area, so the prefix 'meta' has been dropped for the sake of brevity. Industry drill logs refer to the rocks mainly as gneisses; however, not all rocks are gneissic in character and locally retain some primary textures. The preservation of primary textures depends largely on the extent of hydration, which is higher in hydrous pelitic rocks than in mature quartz-rich sandstone or unaltered rhyolite. More information regarding drillhole locations and associated assessment files can be found at https://web33.gov.mb.ca/mapgallery/mgm-md.html.

Sedimentary rocks

Psammite and conglomerate

Psammite and conglomerate occur in drillcores KUS342, KUS318, KUS378, and HAR195. These contain moderately to highly strained heterolithic (dominantly felsic rhyolite and minor granite) pebbles and cobbles within a quartz and feldspar sandstone matrix. Locally, millimetre- to centimetre-wide, weakly magnetic, dark layers are interpreted to represent heavy mineral–rich crossbeds (Figure GS2018-4-4a). Conglomeratic intervals in drillcore commonly display a striped appearance, with 2–10 mm of darker matrix between the flattened fragments. HAR195 contains a low-strain window where a subrounded rhyolitic cobble is present (Figure GS2018-4-4b). Sandstone and conglomerate in the northern half of the study area contain visible sillimanite as small white wisps in the matrix to the cobbles, whereas they contain abundant leucosome in the southwest. Magnetic susceptibility for these rocks is quite variable, ranging from 0.1 to 3 x 10^{-3} SI.

Pelite and psammopelite

Pelitic and psammopelitic rocks are recognized by their high biotite and garnet contents, which are generally above 30 and 10 modal percent in these rocks, respectively; changes in the amount of these minerals likely reflects minor compositional variations of the protolith. The magnetic susceptibility of these rocks in drillcore is typically less than 1 x 10^{-3} SI. Staurolite was not observed in these rocks; however, orange-brown staining around some garnets in KUS367 might reflect relict staurolite. Figure GS2018-4-2 shows the extent of biotite-garnet–bearing gneiss that contains visible wisps of sillimanite. Moving from west to east, sillimanite decreases or disappears and there is a notable increase of migmatite. Partial melting of pelite in HAR070 resulted in the development of quartzofeldspathic leucosome and biotite-garnet melanosome surrounded by paleosome (Figure GS2018-4-4c). Intervals 10–30 m wide containing graphite and sulphide (pyrrhotite and pyrite) were intersected

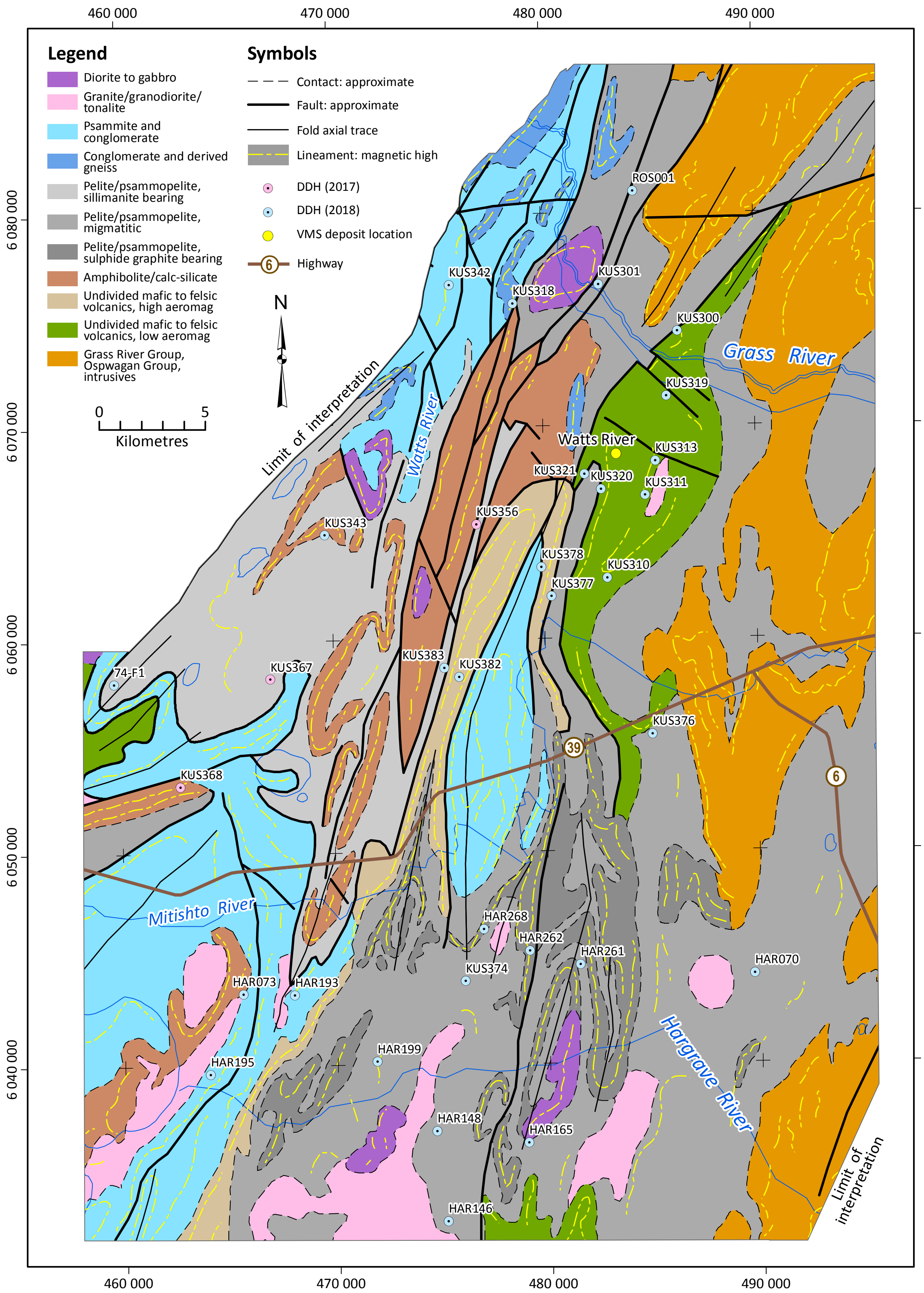

Figure GS2018-4-2: *Simple interpretation of the geology of the Watts, Mitishto and Hargrave rivers area from drillcore observations and aeromagnetic characteristics.*

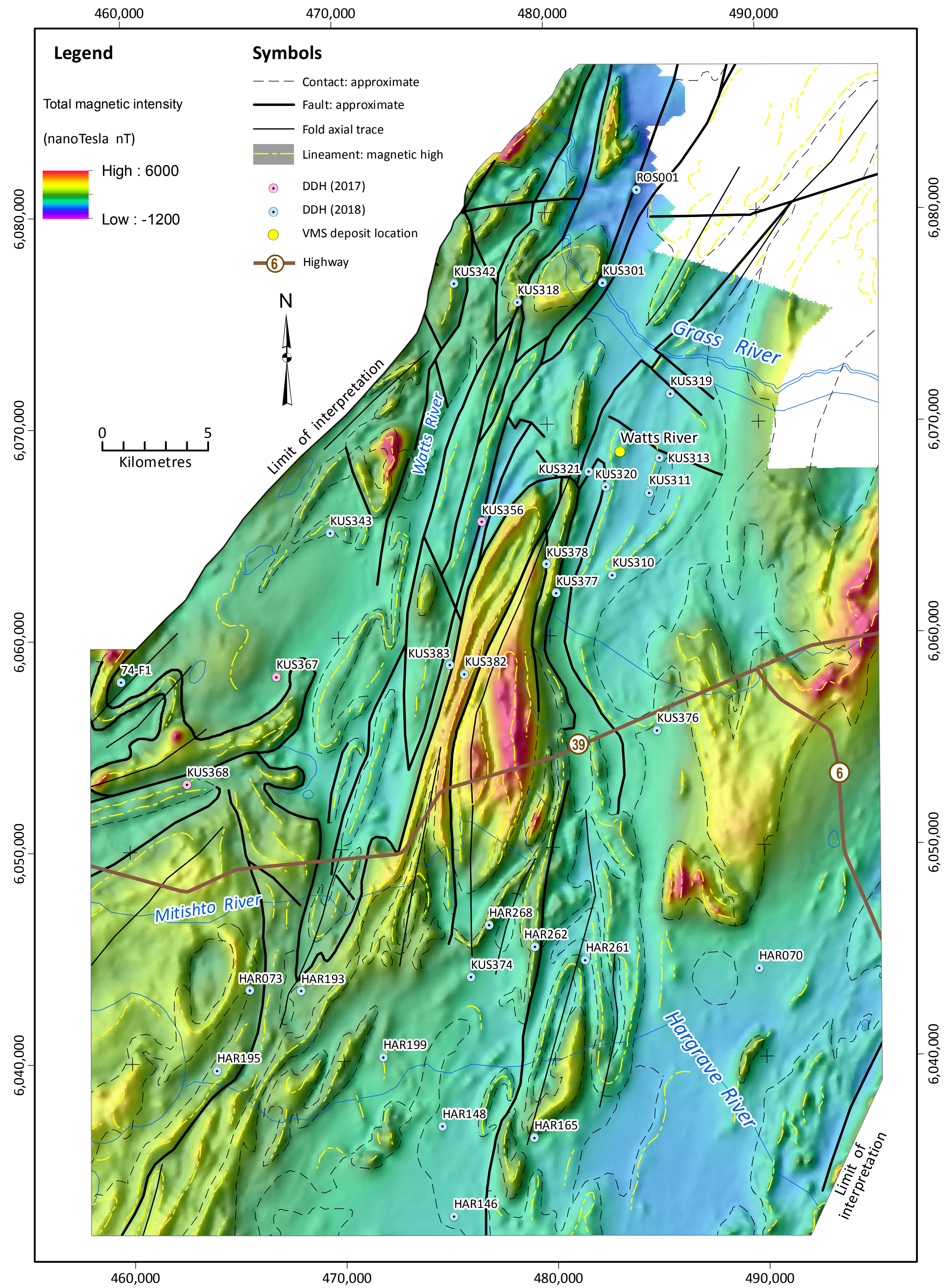

Figure GS2018-4-3: *Total magnetic intensity map of the Watts, Mitishto and Hargrave rivers study area, with a transparent hillshade (illuminated from 290°) and linework from Figure GS2018-4-2.*

Table GS2018-4-1: Aeromagnetic characteristics of stratigraphically constrained rocks in the exposed eastern Flin Flon belt.

	Rock type	Magnetic Intensity	Internal magnetic complexity	Electrical conductivity	Examples
'Successor-arc' intrusive rocks	Granite, granodiorite and tonalite	Low to moderate	Low complexity; circular to ovoid; cuts earlier fabrics	Low	Ham Lake and Wekusko Lake plutons
	Diorite and gabbro	Low to high, sill-like to layered complexes	Low complexity, circular to ovoid; earlier fabrics may be cut	Low	Rex Lake pluton, Rice Island gabbro
'Successor-arc' volcanic rocks	Basalt and andesite	Moderate to high	Moderately complex; contains folded stratigraphy	Low	Herb Lake arc-volcanic rocks
	Dacite and rhyolite	Low to moderate			
'Successor arc' basin deposits	Sandstone and conglomerate	High	Displays folding well, with magnetic highs and lows representing stratigraphy	Very low	Herb Lake sandstone and conglomereate
	Greywacke, mudstone and derived pelitic gneisses	Low	Monotonous with little complexity observed	Moderate to high	Wekusko Lake mudstone and siltstone
	Graphite-sulphide–bearing mudstone and pelite	Low to high (possibly dependent on metamorphic grade)	Prominent magnetic highs in broad magnetic lows; may or may not be complexly folded	High	
Ocean-floor basalt	Mainly mafic flows, pillows and minor tuff	Low-moderate to moderate	Variable; may contain magnetic highs due to sulphide- and oxide-facies iron formation	Moderate	Northeast Reed ocean-floor assemblage
Early arc-volcanic rocks	Mafic to felsic flows and volcanclastics with minor graphitic and sulphidic horizons	Low-moderate to moderate	Variable; may contain magnetic highs due to sulphide-facies iron formation	Low to high	Snow Lake juvenile-arc assemblage
Early arc-intrusive rocks	Gabbro to tonalite	Low-moderate to moderate	Lower complexity than surrounding volcanic rocks; may truncate stratigraphy	Low	Sneath and Richard plutons

in drillcores HAR261, HAR262 and HAR268 (see Figure GS2018-4-4d); magnetic susceptibility up to 30 x 10^{-3} SI coincides with narrow magnetic highs (Figure GS2018-4-3) and is the basis for extrapolation of this unit to other parts of the study area (Figure GS2018-4-2). Many of the drillholes that contain a graphite-sulphide interval also have an adjacent minor intersection of intermediate to felsic rocks of uncertain origin and relationship.

Volcanic rocks

The primary basis for discerning volcanic rocks is their fine-grained character relative to intrusive and sedimentary rocks, and their lower contents of biotite-garnet (<10% garnet) and in situ melt relative to pelitic and psammopelitic rocks. Features such as subtle compositional layering, which may represent volcaniclastic tuff, resedimented volcanic material or possible flow banding, were locally noted.

Amphibolite and calcsilicate-altered mafic rocks

Dark to light green, fine- to medium-grained amphibolite that often has centimetre-scale layering occurs in drillcores KUS343, KUS318, KUS356, KUS383 and HAR073. These mafic rocks do not show much compositional variability and are usually in sharp (possibly fault) contact with sedimentary rocks or are intruded by granitoids. Light green, centimetre-scale layering represents calcsilicate-altered domains (diopside) that were transposed by regional deformation and often contain remnant calcite (Figure GS2018-4-5a). In drillcore, these rocks have magnetic susceptibility readings lower than 2 x 10^{-3} SI; they are characterized by subtle magnetic highs when compared to pelite and psammopelite (Figure GS2018-4-3, Table GS2018-4-1).

Undivided mafic to felsic volcanic rocks with low aeromagnetic signature

Fine- to medium-grained rocks with <10% garnet that are mainly intermediate to felsic in composition occur in the area of the Watts River VMS deposit (Figure GS2018-4-2) and have a low aeromagnetic signature. Compositional layering, at the millimetre- to centimetre-scale, of intermediate rocks in KUS311 possibly reflects primary tuffaceous layering or a reworked volcanic sand-

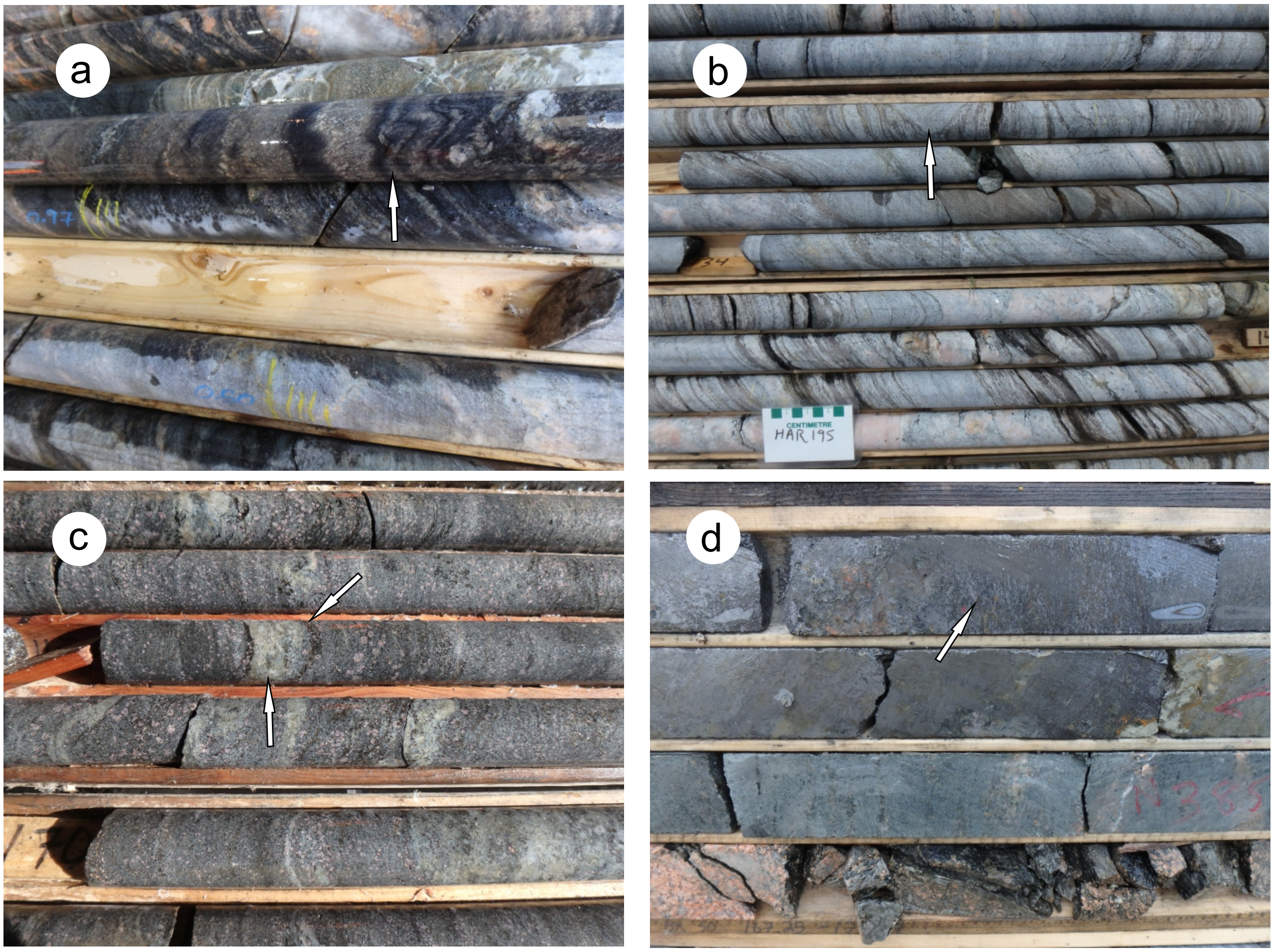

Figure GS2018-4-4: *Sedimentary rocks of the Watts, Mitishto and Hargrave rivers study area:* ***a)*** *dark, heavy-mineral layers (arrow) highlight primary bedding in a quartz-feldspar sandstone, drillcore KUS378;* ***b)*** *conglomerate interval with preserved subrounded felsic cobble (arrow), drillcore HAR195;* ***c)*** *biotite-garnet pelite with neosome (leucosome indicated by lower arrow and melanosome indicated by upper arrow) and paleosome, drillcore HAR070;* ***d)*** *graphite-sulphide–bearing interval in pelite (dull silvery wisps indicated by arrow are graphite), drillcore HAR261.*

stone (Figure GS2018-4-5b). Rare, subangular, lapilli-sized fragments are preserved; the example shown in Figure GS2018-4-5c contains local knots of sillimanite, suggesting possible hydrothermal alteration prior to metamorphism. A separate package of volcanic rocks with low aeromagnetic signature occurs along the western margin of the study area (immediately south of DDH 74-F1; Figure 2018-4-2), but no drillholes penetrate these rocks; instead they have been extrapolated from aeromagnetic data in the Wekusko Lake area, where they are interpreted as part of the Schist-Wekusko assemblage (Gilbert and Bailes, 2005).

Undivided mafic to felsic volcanic rocks with high aeromagnetic signature

These rocks have high TMI and display complex isoclinal folding (Figure GS2018-4-3) but lack textures characteristic of sandstone or conglomerate. Drillcore from hole KUS382 contains dark green, fine- to medium-grained amphibolite that contains scattered 4–10 mm garnet porphyroblasts and local calcsilicate alteration (Figure GS2018-4-5d); also present are lesser amounts of grey to light green, fine-grained intermediate rocks. What makes the amphibolite unit distinct, however, is its very high magnetic susceptibility (up to 161 x 10^{-3} SI), which is interpreted to correlate with the narrow pronounced aeromagnetic highs in the area (Figure GS2018-4-3). A potential analogue to this rock type could be strongly magnetic basalt flows and volcaniclastic rocks that occur to the northwest in the exposed Herb Lake volcanic block (e.g., Connors et al., 1999). Volcanic rocks of intermediate composition with moderate to high TMI are interpreted to occur in the southwestern portion of the study area; these have been extrapolated north from drillhole HAR253, the core from which was viewed in 2017 (see Figure GS2017-7-2 for the location of HAR253; Reid, 2017).

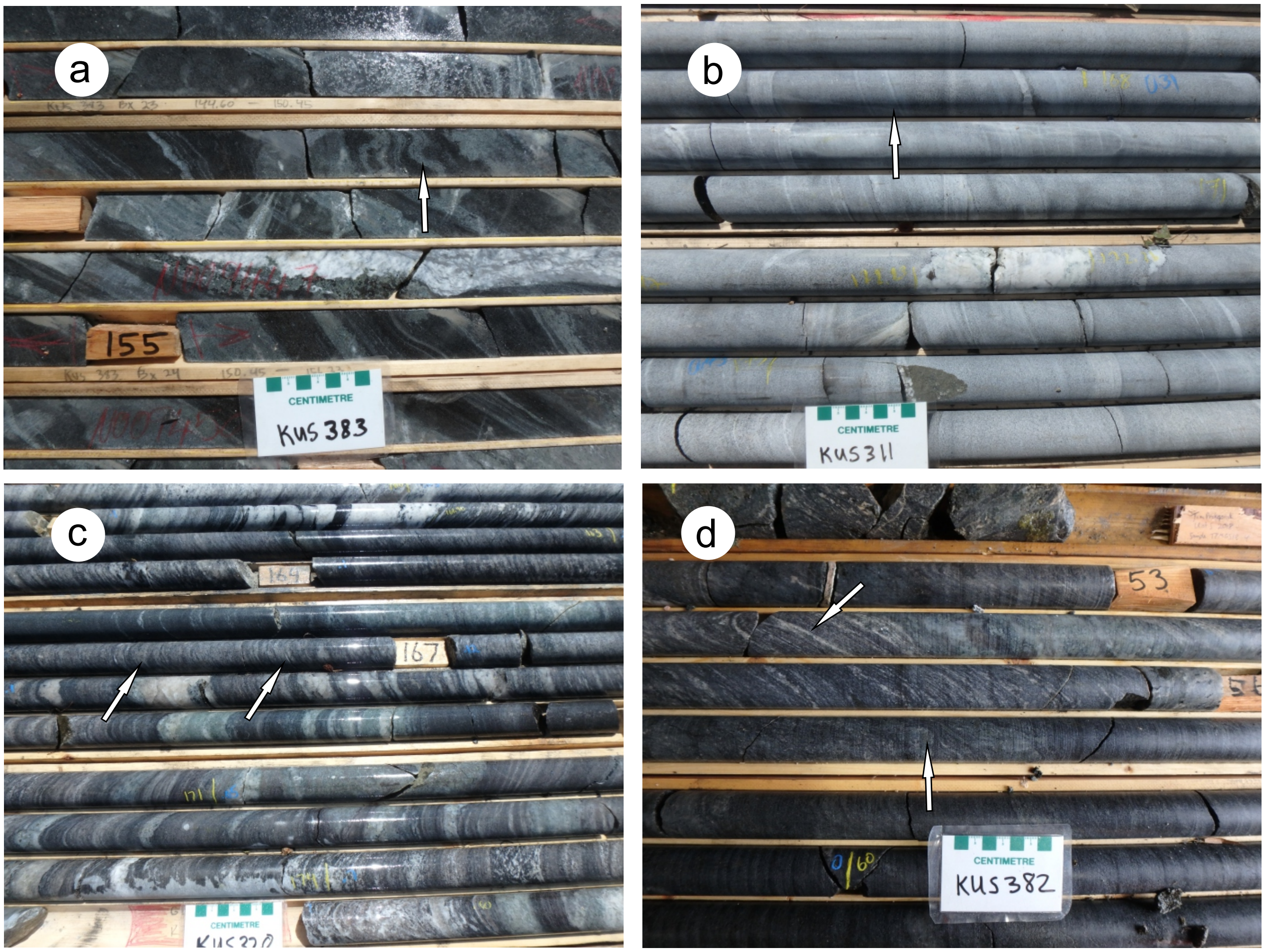

Figure GS2018-4-5*: Volcanic rocks of the Watts, Mitishto and Hargrave rivers study area:* ***a)*** *layered amphibolite with calcsilicate layer (arrow), drillcore KUS383;* ***b)*** *intermediate rock with centimetre-scale, subtle compositional layering (arrow), drillcore KUS311;* ***c)*** *light grey-green felsic rock with lapilli-sized fragments (left arrow) and local clots of sillimanite (right arrow), drillcore KUS320;* ***d)*** *highly magnetic carbonate- (upper arrow) and garnet-bearing (lower arrow) amphibolite, drillcore KUS382.*

Intrusive rocks

Pegmatite

Almost all drillcores examined contain numerous narrow (<3 m) intervals of leucocratic pegmatite; most of these have been affected to some extent by the latest stages of regional deformation, with contacts that parallel the foliation in the hostrock. Pegmatites typically have a relatively simple mineralogy, consisting of quartz, plagioclase, K-feldspar, minor biotite and occasionally muscovite. However, a noteworthy intersection occurs in drillcore KUS377 (continuous for 88 m, true width unknown) and multiple 3–5 m intervals are present in drillcore KUS310 (Figure GS2018-4-6a). These pegmatites both contain abundant macroscopic graphic textures that are interpreted to represent simultaneous crystallization and intergrowth of K-feldspar and quartz from a hydrous silicate melt (lower arrow in Figure GS2018-4-6a).

Granite, granodiorite and tonalite

Like pegmatite, granitoid rocks are present in nearly all drillholes and range from intersections of <1 m to most of the drillcore. Generally, the granitoid rocks are relatively homogeneous, leucocratic, medium to coarse grained and weakly to strongly foliated, and vary in colour from light grey to salmon pink (Figure GS2018-4-6a–c), depending largely on K-feldspar content. Contact relationships and primary features are mostly obliterated by ductile deformation (intrusive versus conformable), but the presence of what appear to be wallrock xenoliths indicates that granitoid rocks intruded the country rock (arrow in Figure GS2018-4-6b).

Diorite and gabbro

Mafic intrusive rocks are less abundant than felsic intrusives (see above). Mesocratic, dark green, massive

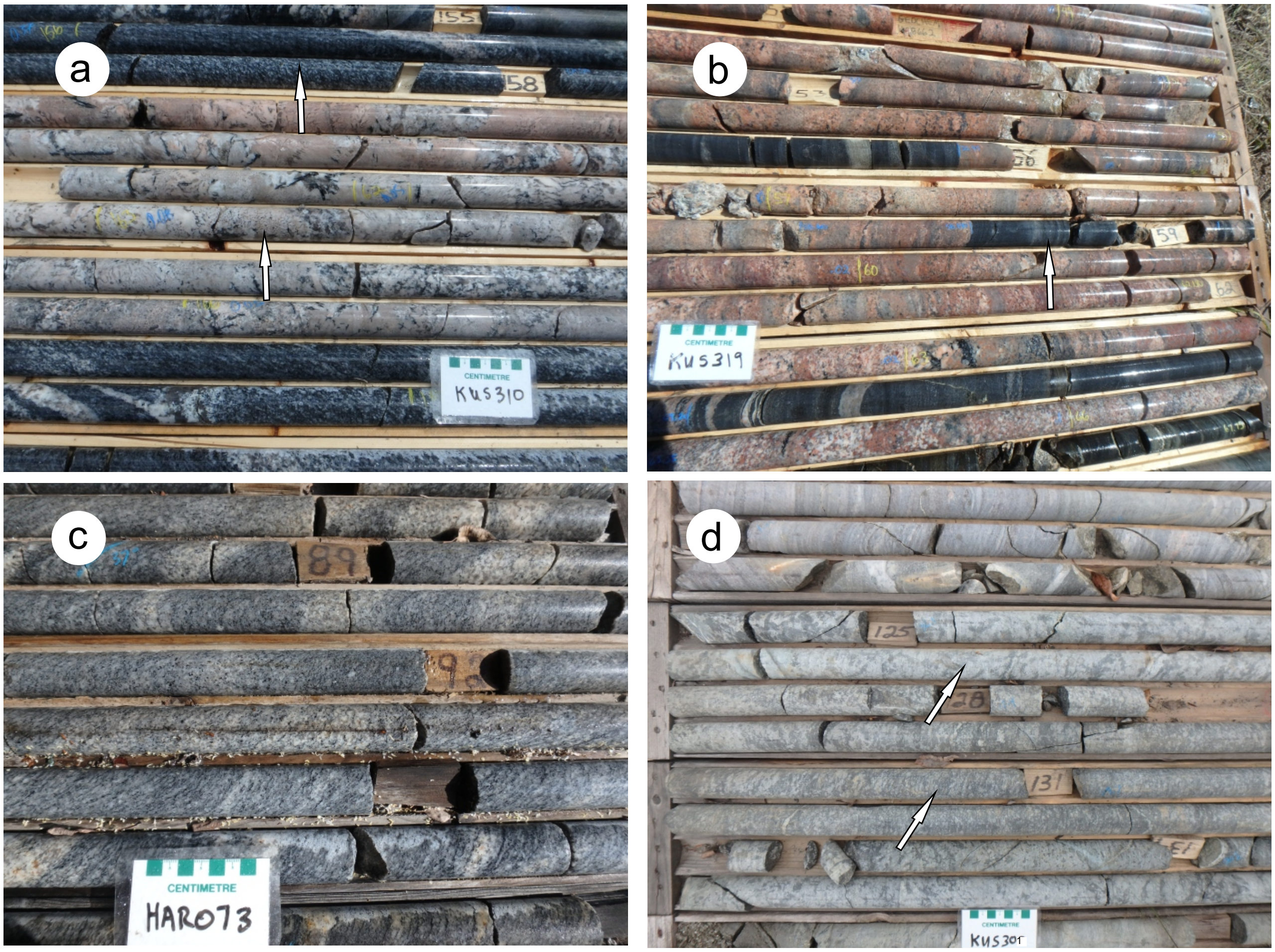

Figure GS2018-4-6: *Intrusive rocks of the Watts, Mitishto and Hargrave rivers study area:* ***a)*** *granodiorite (upper arrow) hosting significant interval of K-feldspar–rich pegmatite (graphic texture at lower arrow), drillcore KUS310;* ***b)*** *pink coarse-grained granite with xenoliths of intermediate volcanic rock (arrow), drillcore KUS319;* ***c)*** *well-foliated granite, drillcore HAR073;* ***d)*** *coarse-grained (lower arrow) to pegmatitic (upper arrow) gabbro, drillcore KUS301.*

to weakly foliated, coarse-grained to pegmatitic gabbro is present in drillcore KUS301 (Figure GS2018-4-6d). Its high magnetic susceptibility (~25 x 10^{-3} SI) is interpreted to correlate with the aeromagnetic high directly west of the drillhole location (Figure GS2018-4-3). A less conspicuous, melanocratic, moderately foliated, medium- to coarse-grained diorite occurs within volcanic rocks in drillcore KUS320. It should be noted that mafic intrusive rocks may be more abundant because fine- to medium-grained amphibolite and calcsilicate-altered amphibolite may represent high-level intrusions.

Grass River group, Ospwagan group and late intrusive rocks

Complexly folded rocks with high TMI near the intersection of Highways 39 and 6 (Figure GS2018-4-3) are surrounded by rocks with low aeromagnetic signature. These are interpreted to comprise undivided granitoid rocks; conglomerate and sandstone of the Grass River group; and pelite, calcsilicate, iron formation and volcanic rocks of the Ospwagan group. All of these rocks are surrounded by pelite and psammopelite of the Burntwood group. This interpretation rests largely on the fact that mapped examples are present in the Setting Lake area to the northeast (Zwanzig, 1999), where the Burntwood group is typically interpreted to be in thrust contact with rocks of the Ospwagan and Grass River groups (e.g., Zwanzig et al., 2007).

Metamorphic grade

Detailed petrographic studies have not been completed for rocks in the study area; tentative remarks, however, can be made based on macroscopic observations in pelitic and psammopelitic rocks. Biotite-garnet–bearing pelite underlying the Watts River area contains noticeable wisps of sillimanite, which is evidence that these rocks were subjected to upper-amphibolite facies during peak metamorphism. Pelite in the southeast half of the study area rarely contains visual sillimanite but is migmatitic; less or no sillimanite may be related to compositional changes linked to a higher degree of partial melting, indicating that metamorphic grade increases southeastward.

Economic considerations

The Watts River base-metal deposit, located in the north half of the study area, is interpreted to be a VMS deposit associated with felsic volcanic and sedimentary rocks (Bailes, 2015). The recognition of additional volcanic rocks in drillholes KUS319, KUS320 and KUS321 extends prospective stratigraphy to the north and east (Figure GS2018-4-2). Drillcores KUS308, KUS310, KUS340, KUS348 and KUS349 all contain intercepts of subeconomic base (Cu, Zn) and precious (Au, Ag) metals, indicating that prospective stratigraphy extends for more than a kilometre (Assessment File 74696, Manitoba Growth, Enterprise and Trade, Winnipeg). Drillcore KUS374 contains subeconomic Cu (<0.1%) and Zn (<0.3%) values over a 13 m interval that includes a 3.09% Zn assay over 0.2 m (Assessment File 63J1142); these sulphides are associated with minor felsic rocks and may represent a prospective horizon worthy of further work.

Future work

Further investigation will focus on using whole-rock lithogeochemistry to determine the affinity and character of the volcanic and intrusive rocks. Petrographic studies may detail the metamorphic history. A zircon U-Pb age from felsic rocks hosting the Watts River VMS deposit is pending—this should provide some insight on whether this deposit is associated with early juvenile-arc volcanism or successor-arc volcanism.

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