New geological mapping, geochemical, Sm-Nd isotopic and U-Pb age data for the eastern sub-Phanerozoic Flin Flon Belt, west-central Manitoba

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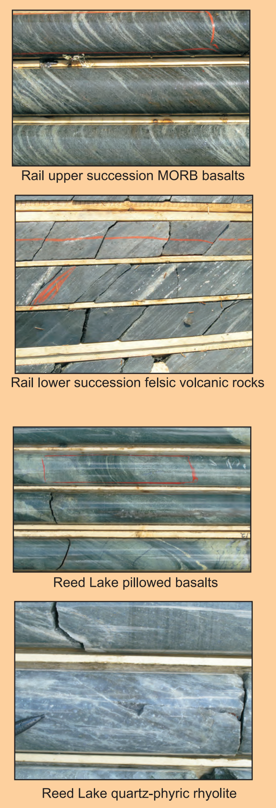
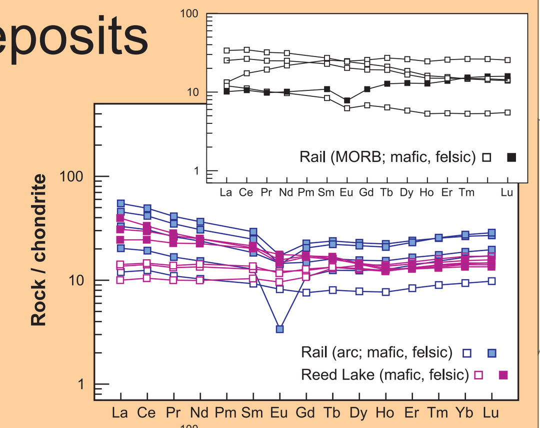
Rail and Reed Lake deposits



Rail deposit

The Rail deposit host stratigraphy consists of two faulted successions of variably altered, intercalated aphyric basalt and quartz-plagioclase–phyric rhyolite, separated by a 2–7 m wide fault zone. The lower succession, which host the copper-zinc-rich mineralization, is intruded by a medium-grained, pinkish grey granodiorite sheet, just below the main mineralized interval.

The lower succession (mineralized) is the product of tholeiitic subduction-related processes in an oceanic-arc environment (flat REE patterns and pronounced negative Nb-Ti anomalies), whereas the upper succession (barren) is the product of mid-ocean-ridge (MORB) magmatism (flat REE pattern, depletion in strongly incompatible elements, no significant negative anomalies in Nb and Ti).

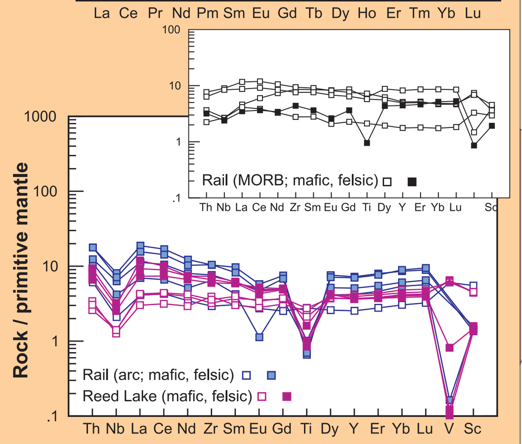


Reed Lake deposit

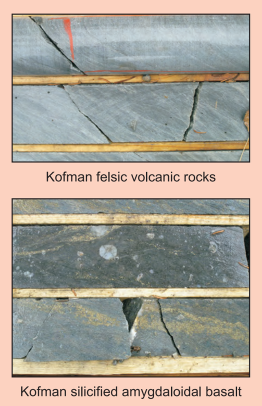
(Rockcliff Resources Inc.)

The Reed Lake deposit host stratigraphy consists of intercalated well-preserved aphyric basalt and quartz- and quartz-plagioclase–phyric rhyolites. Basalt forms thick successions (>150 m) of variably altered, massive to pillowed flows with minor mafic breccia intervals. The rhyolites form thick (>300 m), massive to brecciated units. Quartz-epidote patches are common throughout the mafic rocks. The rhyolites are variably altered (purplish hematization, silicification, sericitization).

This succession is the product of tholeiitic subduction-related processes in an oceanic-arc environment (flat REE patterns and pronounced negative Nb-Ti anomalies).



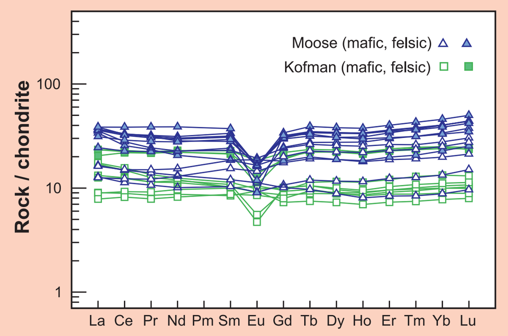
Kofman and Moose deposits



Kofman deposit

The Kofman deposit host stratigraphy consists of well-preserved aphyric basalt 'underlain' by a thick package of massive to brecciated aphyric rhyolite and massive silicified (light grey) amygdaloidal basalt, which is in turn 'underlain' by aphyric basalt. Silicification related to the mineralization is very intense and concentrated in the massive, light grey, amygdaloidal basalt.

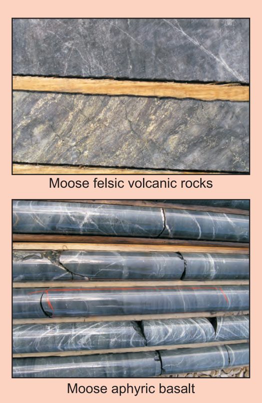
This succession is the product of tholeiitic subduction-related processes in an oceanic-arc environment (flat REE patterns and pronounced negative Nb-Ti anomalies).

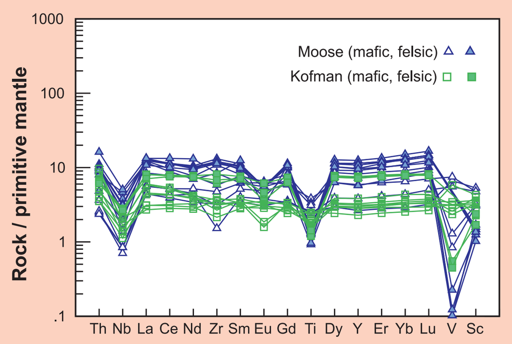


Moose deposit

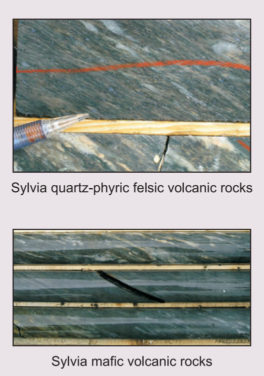
The Moose deposit host stratigraphy consists of well-preserved aphyric basalt is 'underlain' by massive to brecciated (lapilli tuff), aphyric, plagioclase-phyric and quartz-phyric rhyolite, and crosscut by several plagioclase-phyric mafic dikes <3 m thick. Basalt is weakly to moderately chloritized and rhyolite is commonly sericitized and/or silicified. Late brittle faults that commonly display strong carbonatization were observed both above and below the mineralization.

This succession is the product of tholeiitic subduction-related processes in an oceanic-arc environment (flat REE patterns and pronounced negative Nb-Ti anomalies). Yielded juvenile $\varepsilon_{Nd(1850Ma)}$ values of +4.0 to +4.5.





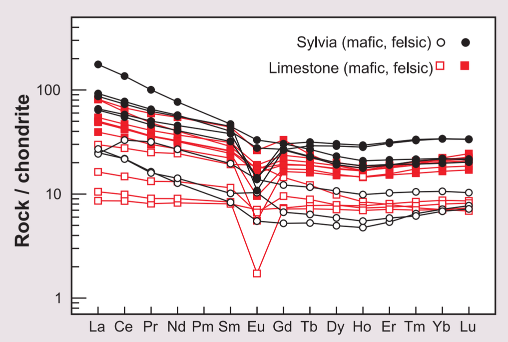
Limestone and Sylvia deposits



Sylvia deposit

The Sylvia deposit host stratigraphy consists of intercalated, strongly foliated mafic (basalt) and felsic (rhyolite) rocks 'underlain' by graphitic argillite. The volcanic stratigraphy consists of a thick succession of aphyric and plagioclase-phyric basalt and mafic volcaniclastic rocks intercalated with generally thinner, aphyric and quartz±plagioclase-phyric rhyolite. The entire volcanic sequence has been extensively sericitized and/or chloritized.

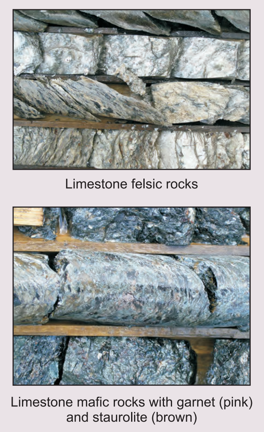
This succession is the product of tholeiitic to transitional subduction-related processes in an oceanic-arc environment (light LREE-enrichment on REE patterns and pronounced negative Nb-Ti anomalies).

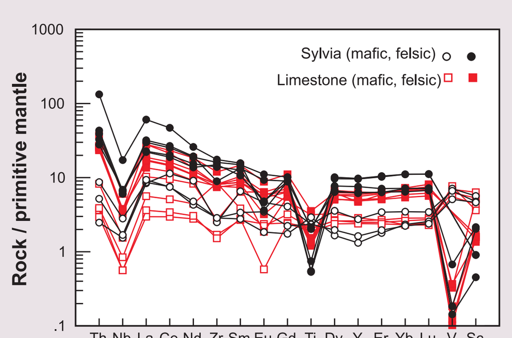


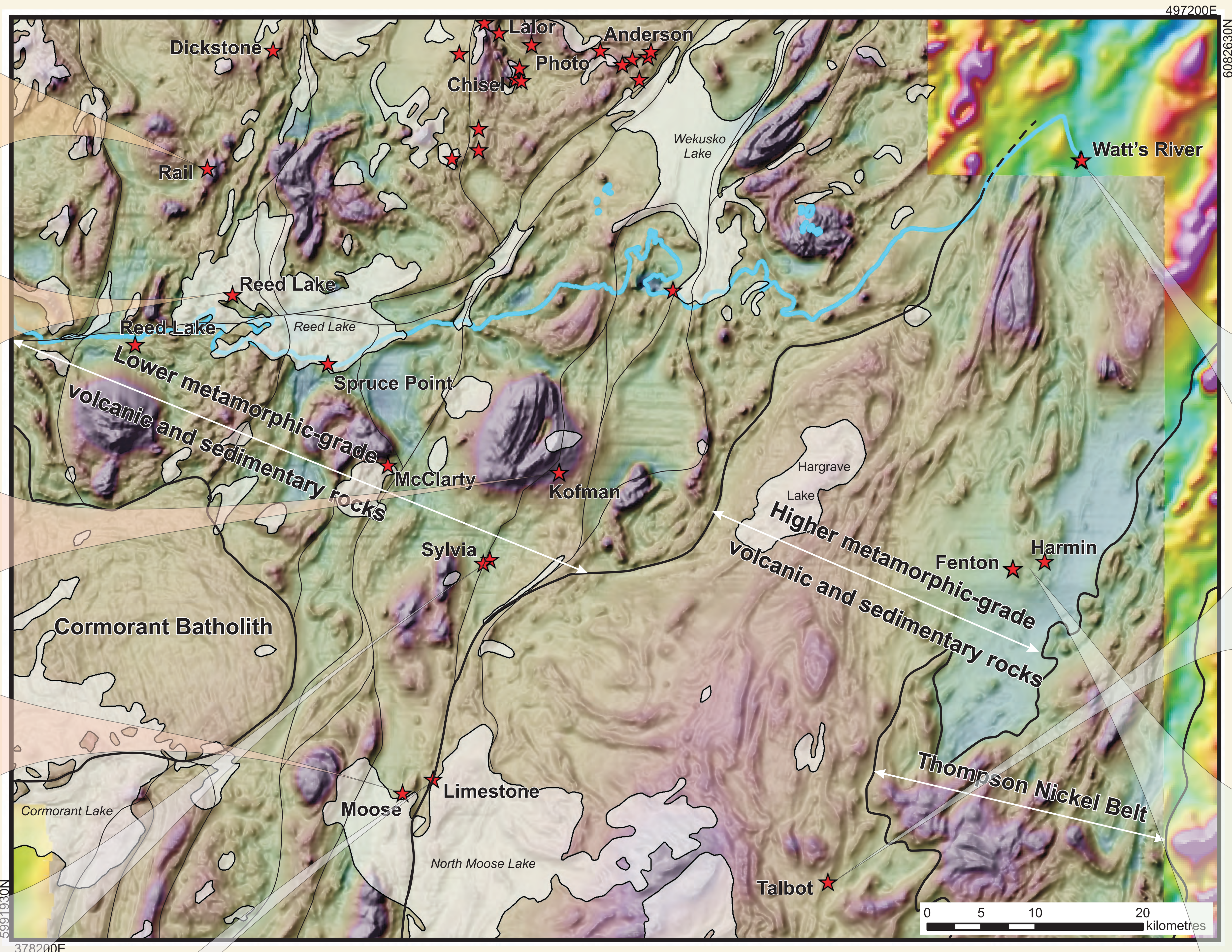
Limestone deposit

The Limestone deposit host stratigraphy consists of highly deformed mafic (chlorite-biotite-garnet-quartz±staurolite) and felsic (sericite-quartz-biotite-chlorite±staurolite±garnet) schists, crosscut by less deformed, 3–15 m thick, fine-grained, hornblende-rich mafic rock interpreted as younger mafic dikes. The overall stratigraphy of the deposit consists of mafic schist (no staurolite) 'underlain' by intercalated, variably mineralized, mafic and felsic schist (with staurolite), in turn 'underlain' by mafic schist (no staurolite). The premetamorphic nature of these rocks is unclear. A chlorite-biotite-garnet-staurolite-quartz metamorphic mineral assemblage is commonly observed in pelitic rocks, but a similar assemblage has also been documented in altered mafic volcanic rocks in the footwall of VMS deposits of the Snow Lake area.

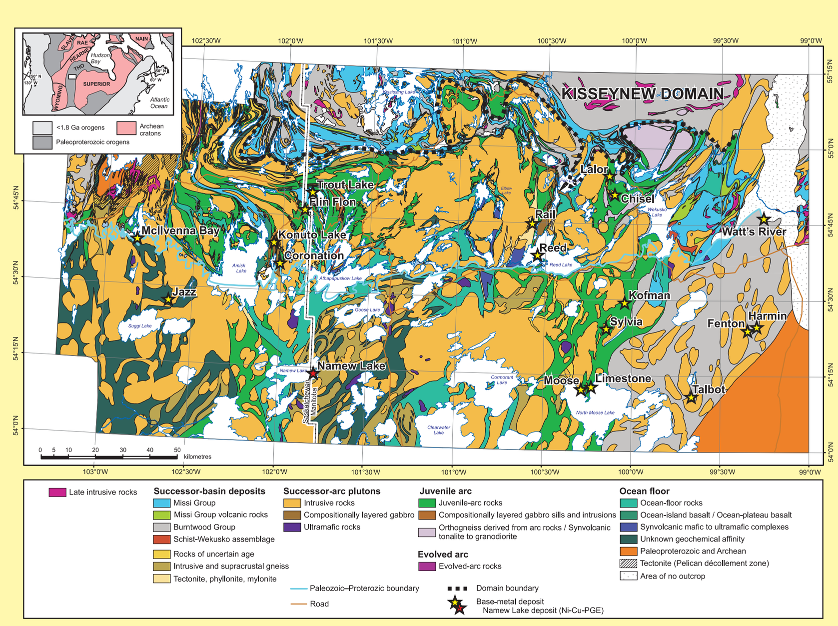
This succession is the product of tholeiitic to transitional subduction-related processes in an oceanic-arc environment (light LREE-enrichment on REE patterns and pronounced negative Nb-Ti anomalies).





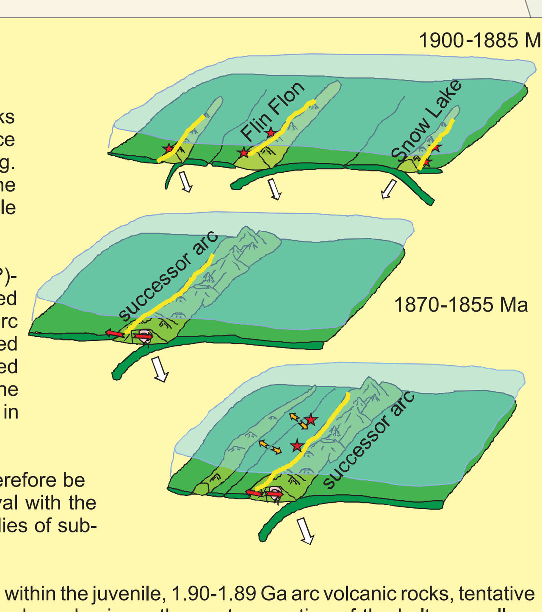


Economic Considerations



All the VMS deposits of the "lower metamorphic grade volcanic and sedimentary rocks" domain are hosted in rocks that formed in a bimodal tholeiitic to transitional oceanic arc setting, and were derived from a juvenile magma source with little to no involvement of continental crust in the magma genesis, which is similar to the Flin Flon deposit setting. At this stage of the project, additional geochronological data is needed/underway to more fully assess whether the volcanic successions that were later juxtaposed in multiple distinct fault panels represent one or multiple dismembered tholeiitic to transitional arc system(s).

Compared to "the lower metamorphic grade domain rocks", tentative data for the four studied base-metal (VMS?)-host successions from the "higher metamorphic grade volcanic and sedimentary rocks" domain suggest they formed in a slightly different tectonic setting. All the collected data so far suggest that these deposits formed in a rifting arc and/or at the onset of back-arc magmatism. The maturity or width of the "rifted basin" in which these deposits formed may have varied slightly from one to the other, as suggested by the varying amounts of subduction-related contamination in the source mantle. Zircon U-Pb age data for the Fenton deposit host rock suggests that part of the rifting arc formed around 1865 Ma, which could represent an age estimate for volcanism and VMS mineralization in this area.



If this age does represent the age of the magmatism/mineralization for this area, these VMS deposits would therefore be younger than the ones found in Flin Flon or Snow Lake arc assemblages (~1.90-1.89 Ga) and would be coeval with the "successor-arc" magmatism (~1.88-1.83 Ga). Similar ages have been obtained in recent geochronological studies of sub-Phanerozoic VMS deposits in the Saskatchewan portion of the Flin Flon – Glennie domains (Morelli et al. in prep.).

In conclusion, although all VMS deposits found to date in the exposed portion of the Flin Flon Belt are solely located within the juvenile, 1.90-1.89 Ga arc volcanic rocks, tentative data presented here provides evidence for a younger, prospective, ~1.87 Ga "successor arc" age spreading back-arc basin on the eastern portion of the belt, as well as prospective tholeiitic to transitional oceanic arc environments further west.

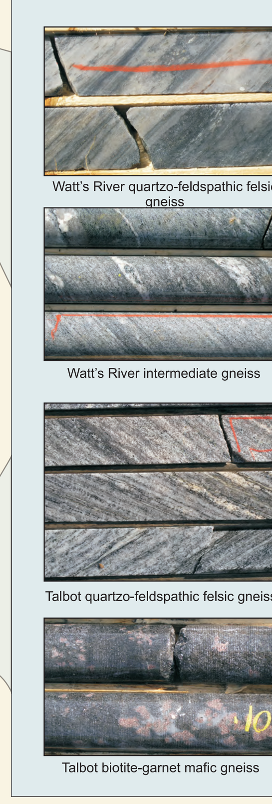
Higher grade metamorphic volcanic and sedimentary rocks

East of the lower metamorphic-grade rocks, a north-northeast-trending belt of 'higher metamorphic-grade volcanic and sedimentary rocks' is characterized by curvilinear to tightly folded magnetic patterns and extends from east of Hargrave and North Moose lakes to the Thompson Nickel Belt. These higher grade rocks, which underwent peak metamorphism at upper-amphibolite to lower-granulite facies, are typically migmatitic gneiss with varying proportions of younger plutonic veins and sheets. These rocks host the Talbot, Harmin, Fenton and Watt's River VMS deposits.

'Higher metamorphic-grade volcanic and sedimentary rocks' have been metamorphosed at upper-amphibolite to lower-granulite facies, resulting in variable amounts of melt (anatectic texture and felsic intrusive veins/sheets); thus, no primary textures are preserved and protoliths are difficult to ascertain.

Historically, the high-grade rocks were logged as metasedimentary rocks such as pelite (>50% biotite), greywacke (<30% biotite), pebbly greywacke and siltstone/quartzite (<10% biotite). More recently, they have been logged according to their mineral composition and fabric as 'mafic' biotite-rich quartzofeldspathic gneiss (>35% biotite), 'intermediate' quartzofeldspathic gneiss (15–35% biotite) and 'felsic' quartzofeldspathic gneiss (<15% biotite). However, in view of the recent discoveries of stratabound VMS-like mineralization in these rocks, the possibility has arisen that they are of volcanic origin (quartzite / felsic quartzofeldspathic gneiss = metamorphosed rhyolite and felsic tuff; biotite-rich quartzofeldspathic gneiss/greywacke = metamorphosed basalt or andesite), but this hypothesis remains to be tested.

Watt's River and Talbot Lake deposit

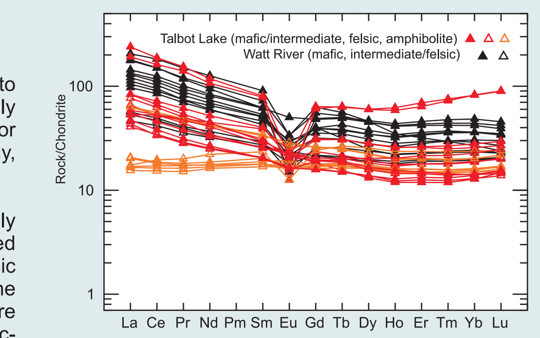


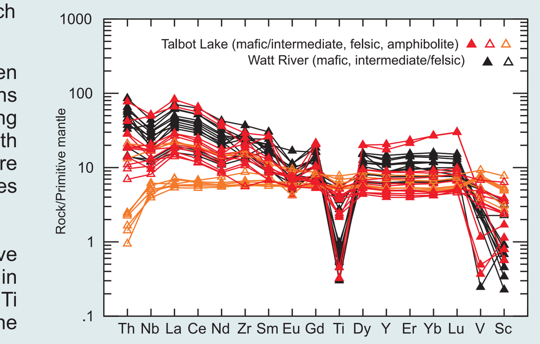
The **Watt's River deposit** consists of several thin (30–70 m), mafic to felsic quartzofeldspathic gneissic successions, which are locally crosscut by younger, fine-grained, massive amphibolite dikes. Minor brittle fault zones, which do not seem to affect the stratigraphy, commonly display carbonatization and sericitization.

The **Talbot deposit** comprises several 100–300 m thick, mainly mafic and intermediate gneiss sequences with well-foliated garnetiferous amphibolite intervals. Thinner (<15 m) intervals of felsic quartzofeldspathic gneiss are found toward the top of the intermediate gneiss intervals. The mafic gneisses are much more abundant in this deposit compared to other 'higher metamorphic-grade' deposits in the area. The mafic gneisses are very biotite rich (60–70%) and usually garnetiferous.

The mafic gneisses of the Watt's River and Talbot deposits, when compared to primitive mantle, have trace-element and REE patterns enriched in incompatible elements, which is typical of E-MORB, along with slightly negative Nb and Ti anomalies commonly associated with subduction-related processes. This suggests an E-MORB signature for these rocks with some contamination from subduction processes (contaminated mantle).

The well-foliated amphibolite intervals of the Talbot Lake deposit have flat to very slightly LREE-depleted REE patterns and are depleted in strongly incompatible trace elements with no significant Nb or Ti anomalies, typical of N-MORB, which suggests that they were the product of mid-ocean-ridge magmatism.





The intermediate to felsic gneisses of all the studied high metamorphic grade deposits have slight LREE enrichment, flat HREE patterns and pronounced negative Nb and Ti anomalies, which suggest that they are either products of subduction-related processes in a tholeiitic to transitionaloceanic-arc environment (felsic volcanic/volcaniclastic rocks) or siliciclastic rocks derived from an evolved continental source.

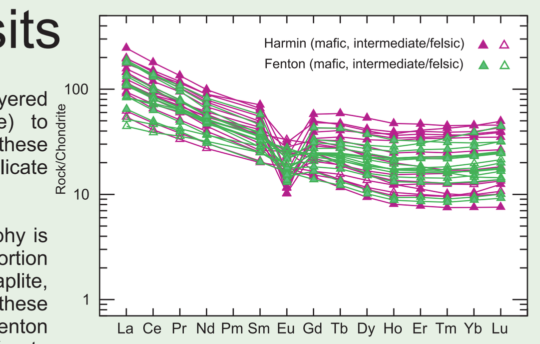
Fenton and Harmin deposits

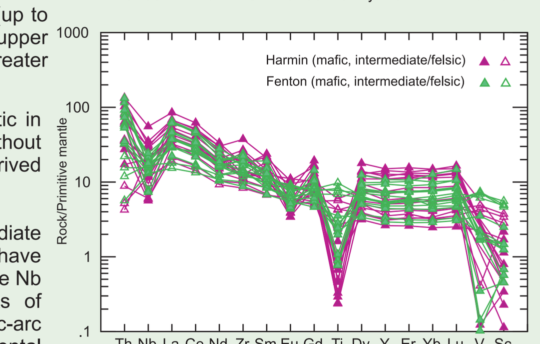
Both stratigraphies consist of 30 to 300 m thick successions of layered quartzo-feldspathic gneisses grading from mafic (>30% biotite) to intermediate (15-30 % biotite) to felsic (<15% biotite). Each of these successions displays variable degrees of green-purplish calc-silicate alteration (actinolite, diopside, calcite).

In the **Fenton deposit,** the upper portion of the observed stratigraphy is dominated by intermediate to mafic gneisses, whereas the lower portion consists mainly of felsic quartzofeldspathic gneiss. Abundant aplite, pegmatite, granodiorite, and leuco-granite randomly crosscut these gneisses. The **Harmin deposit** is very similar in every aspect to the Fenton deposit except for increased presence of late felsic intrusive rocks (up to 50%) cross-cutting the stratigraphy. The stratigraphy is dominantly an upper succession of mafic to intermediate gneisses and felsic gneisses at greater depths.

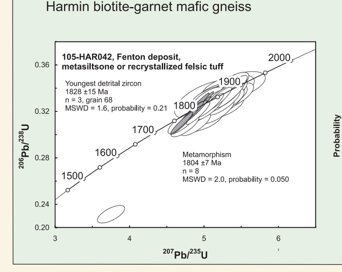
The mafic gneisses of the Fenton and Harmin deposits are basaltic in composition and have trace-element patterns typical of E-MORB without Nb and Ti anomalies. They most likely represent E-MORB basalts derived from an "uncontaminated" mantle.

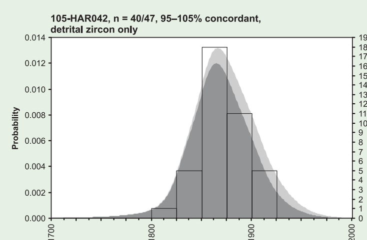
As mentioned in the Watt's River and Talbot section above, the intermediate to felsic gneisses of all the studied high metamorphic grade deposits have slight LREE enrichment, flat HREE patterns and pronounced negative Nb and Ti anomalies, which suggest that they are either products of subduction-related processes in a tholeiitic to transitional oceanic-arc environment or siliciclastic rocks derived from an evolved continental source.





Analyses of Sm-Nd isotopes from both mafic and intermediate/felsic rocks from the Fenton, Harmin, and Talbot Lake deposits yielded $\varepsilon_{Nd(1850Ma)}$ values of +2.7 to +3.2 , suggestive for a juvenile magma source with minimum to no involvement of continental crust in the magma genesis.





A sample of quartzofeldspathic gneiss of the Fenton deposit yielded abundant, small zircon grains. Fifty-five zircon grains were analysed by SHRIMP and yielded ages ranging from 1919 to 1790 Ma. The analyses yielded a unimodal age population centred at 1865 Ma, which is interpreted as the approximate age of a single detrital zircon source. The strong metamorphism at ~1.804 Ga obliterated all primary textures in the quartzofeldspathic gneiss, which renders it difficult to confidently interpret a volcanic or sedimentary protolith.

Assuming that the unimodal ~1.87 Ga zircon population is from a single igneous/volcanic source, it could represent an age estimate for volcanism and VMS mineralization in the Fenton deposit area.