

Lithogeochemistry and isotopic analyses of rocks from the Halfway Lake area, Thompson nickel belt, central Manitoba (parts of NTS 6301, 2)

by C.G. Couëslan

In Brief:

- Supracrustal rocks at Halfway Lake are geochemically and stratigraphically similar to the Ospwagan group
- Whole-rock Nd-model ages of Pipe-Setting formations clastic rocks are anomalously young for Ospwagan group rocks
- Many ultramafic bodies in the Halfway Lake area occur at the Thompson formation-Pipe formation boundary, which correlates to the mine horizons at the Pipe and Birchtree mines

Citation:

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Summary

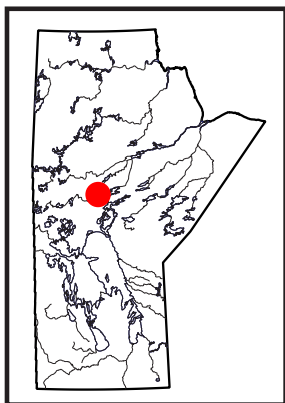
A mapping project, initiated at Halfway Lake in 2022, continued with the examination of lithogeochemical and isotopic analyses of outcrop and drillcore samples collected during the 2022–2025 field seasons. Mafic volcanic rocks collected from south-central Halfway Lake share a geochemical affinity with mid-ocean–ridge basalts and are likely correlative with the Bah Lake assemblage of the Ospwagan group. Amphibolite layers contained within the sedimentary rocks at Halfway Lake likely represent mafic dikes or sills and have a mid-ocean–ridge to back-arc–basalt affinity. They are assumed to be correlative with mafic intrusions of the ca. 1880 Ma Molson dike swarm. A monzonitic pluton located along the southeastern shore of Halfway Lake has a high-K calcalkaline affinity and is geochemically and isotopically similar to the ca. 1835 Ma Bucko pluton south of Wabowden. A garnet-bearing granite–tonalite pluton that occurs in western Halfway Lake shares an affinity with FII felsic rocks and was likely derived by melting of shallow- to mid-level crust in an extensional environment. The garnet-bearing pluton could be contemporaneous with Bah Lake assemblage or Molson swarm mafic–ultramafic magmatism.

The sedimentary stratigraphy at Halfway Lake appears to be correlative with the Ospwagan group and is similar to the Thompson mine sequence. Clastic rocks from the upper part of the sequence (P3 member of the Pipe formation and Setting formation) are geochemically similar to Pipe formation pelite; however, Nd-model ages are anomalously young for Ospwagan group rocks. Detrital zircon recovered from the upper sequence yield dominant age-nodes that coincide with metamorphism in the adjacent Pikwitonei domain of the Superior craton. Calcareous semipelite of the Thompson formation may be correlative to the T2 member, but shares geochemical similarities with Paint sequence rocks. A Nd-model age calculated for the calcareous semipelite is considered typical for Ospwagan group rocks.

Ultramafic rocks at Halfway Lake are frequently emplaced near sulphidic horizons at the boundary between the Thompson and Pipe formations, which coincides with the ore horizons at the Pipe and Birchtree mines. Although whole-rock Sm–Nd isotope geochemistry has been proposed as an exploration tool for differentiating rock units in the northern Thompson nickel belt, the presence of anomalously young Nd-model ages for upper sequence Ospwagan group rocks at Halfway Lake suggests a cautious approach should be taken. The FII felsic rock affinity of the garnet-bearing pluton could suggest a notional potential for volcanogenic massive-sulphide or epithermal mineralization.

Introduction

A mapping project at Halfway Lake in the Thompson nickel belt (TNB) was initiated in the summer of 2022 with shoreline mapping (Figure GS2025-4-1). Significant discrepancies were found between previous mapping and the 2022 results, which led to the logging of archival and recent drillcore from the area in 2023, 2024 and 2025 (Couëslan, 2022a, 2023). The drillcore data suggests a correlation between the metasedimentary rocks at Halfway Lake and the Ospwagan group, with close similarities to the stratigraphic sequence at the Thompson mine (cf. Bleeker, 1990; Couëslan, 2023). Samples of metasedimentary rocks, along with all of the major rock units at Halfway Lake, were submitted for lithogeochemical and isotopic analyses to better characterize and strengthen this correlation with the Ospwagan group. The main focus of this report is the analytical results for mafic, metasedimentary and granitoid rocks. The geochemical results and analytical methods can be found in Couëslan and Janssens (2025b) and in Data Repository Item DRI2025029 (Couëslan and Janssens, 2025c)¹. The



¹ MGS Data Repository Item DRI2025029, containing the data or other information sources used to compile this report, is available online to download free of charge at <https://manitoba.ca/iem/info/library/downloads/index.html>, or on request from minesinfo@gov.mb.ca, or by contacting the Resource Centre, Manitoba Business, Mining, Trade and Job Creation, 360-1395 Ellice Avenue, Winnipeg, Manitoba R3G 3P2, Canada.

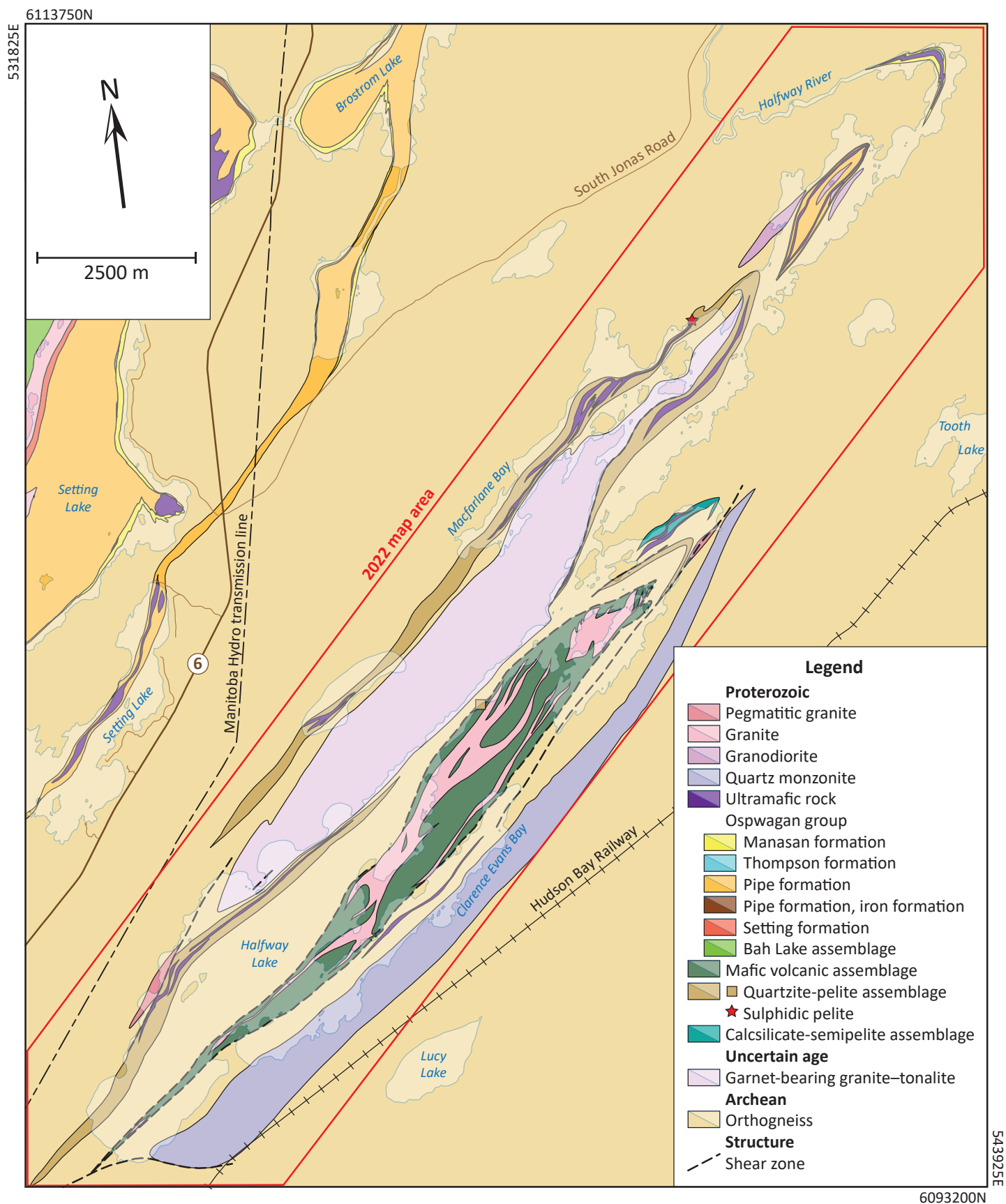


Figure GS2025-4-1: Bedrock geology of the Halfway Lake area, central Manitoba (modified from Couëslan, 2022a). Lighter shade of colour indicates a body of water. Geology outside of the 2022 map area is from Macek et al. (2006). All co-ordinates are in UTM Zone 14, NAD83.

U-Pb zircon data can be found in Couëslan (2025). For a review of the project objectives, as well as the regional and local geology, the reader is referred to Couëslan (2022a). All rocks reported in this study were subjected to amphibolite-facies metamorphism; however, the ‘meta-’ prefix is not used for rock names in an effort to simplify the text.

Whole-rock lithogeochemistry and Sm-Nd isotope geochemistry

Mafic rocks

Heterogeneous amphibolites, interpreted as volcanic rocks, form a large continuous unit in south-central Halfway Lake and are believed to be correlative with the Bah Lake assemblage (Figure GS2025-4-1). They are characterized by intermediate Mg# values (molar $\text{Mg}/[\text{Fe}^{2+}+\text{Mg}]$; 0.41–0.62). Silica contents range from 46.58 to 52.16 wt. %, total alkalis ($\text{Na}_2\text{O}+\text{K}_2\text{O}$) range from 2.20 to 4.02 wt. % and molar $\text{K}_2\text{O}/\text{Na}_2\text{O}$ ratios range from 0.11 to 0.23. Chondrite-normalized rare-earth element (REE) profiles are relatively flat ($[\text{La}/\text{Yb}]_N = 0.87\text{--}1.88$), with the exception of a single sample ($[\text{La}/\text{Yb}]_N = 3.60$; Figure GS2025-4-2a). Primitive mantle-normalized multi-element profiles are relatively smooth, with variable enrichment at Th and variable depletion at Nb (Figure GS2025-4-2b). No spatial pattern is associated with the variations in Nb anomalies; however, the two most enriched samples are both located toward the southern end of the heterogeneous amphibolite package.

Layers of garnet amphibolite occur within the clastic rocks of the upper sequence (Pipe and Setting formations) of the Ospwagan group. The amphibolites are interpreted as mafic dikes or sills that intruded the sedimentary sequence. The Mg# values range from 0.28 to 0.64, with SiO_2 contents of 45.51–53.89 wt. %. Total alkali content is generally low (0.95–1.97 wt. %), except for one sample that contains 3.40 wt. %. Molar $\text{K}_2\text{O}/\text{Na}_2\text{O}$ ratios range from 0.12 to 1.50. Chondrite-normalized REE profiles are relatively flat ($[\text{La}/\text{Yb}]_N = 1.00\text{--}1.90$), and primitive mantle-normalized profiles are characterized by variable to no enrichment at Th and variable anomalies at Nb (Figure GS2025-4-2c, d).

Layers of homogeneous amphibolite occur within the Archean orthogneiss and Ospwagan group, and are interpreted as Paleoproterozoic mafic dikes or sills. The Mg# values range from 0.38 to 0.65, with SiO_2 contents of 48.01–52.13 wt. %. Total alkali content ranges from 1.72 to 4.00 wt. %, with molar $\text{K}_2\text{O}/\text{Na}_2\text{O}$ ratios of 0.16 to 0.58. Chondrite-normalized REE profiles are relatively flat ($[\text{La}/\text{Yb}]_N = 1.14\text{--}1.67$), with one sample displaying a more negative slope ($[\text{La}/\text{Yb}]_N = 2.52$; Figure GS2025-4-2e). Primitive mantle-normalized profiles show minor to no enrichment at Th and minor to no depletion at Nb (Figure GS2025-4-2f).

Granitoids

A variety of granitoids are present in the Halfway Lake area, ranging from pegmatitic granite dikes that are present in almost

all outcrops, to kilometre-scale bodies of monzonite and granite–granodiorite. Only more substantial intrusions were investigated for geochemistry.

A monzonite pluton roughly 13 km long occurs along the southeastern shore of Halfway Lake (Figure GS2025-4-1). Samples of monzonite have Mg# values of 0.64–0.66, and contain 59.71–61.23 wt. % SiO_2 , 180–200 ppm Cr and 90–110 ppm Ni. The monzonite is metaluminous (alumina saturation index, $\text{ASI} = 0.77\text{--}0.78$; Figure GS2025-4-3), contains 7.13–7.33 wt. % total alkalis, with $\text{K}_2\text{O}/\text{Na}_2\text{O}$ ratios of 0.61–0.70, and is enriched in other large-ion lithophile-elements (LILEs; 2396–2417 ppm Ba, 1031–1064 ppm Sr). Chondrite-normalized REE profiles have steep negative slopes ($[\text{La}/\text{Yb}]_N = 46.3\text{--}60.5$) and primitive mantle-normalized profiles are characterized by enrichment in LILEs and light rare-earth elements (LREEs), and relatively depleted in high-field strength elements (HFSEs; Figure GS2025-4-4a, b). A sample of monzonite yielded an initial ϵ_{Nd} value of -1.77 , assuming a crystallization age of ca. 1835 Ma (see Discussion) and a depleted-mantle Nd-model age (T_{DM}) of ca. 2.34 Ga (Table GS2025-4-1).

A garnet-bearing pluton at least 12 km long occurs along the western shore of Halfway Lake and ranges from granitic in the south to tonalitic in the north (Figure GS2025-4-1). The age of intrusion is not well constrained. It is characterized by a weak gneissosity and previous mapping suggests that it is intruded by mafic dikes of the ca. 1880 Ma Molson swarm (Macek et al., 2006; Heaman et al., 2009). The pluton becomes increasingly ferruginous from tonalite (Mg# = 0.19–0.25) to granite (Mg# = 0.11–0.12). Similar trends are observed with many of the LILEs, with the total alkalis increasing from the tonalite (3.86–4.13 wt. %) to the granite (6.98–7.08 wt. %), as the pluton becomes more enriched in potassium ($\text{K}_2\text{O}/\text{Na}_2\text{O} = 0.08\text{--}0.15$ and 1.05–1.09, respectively) and Ba increasing from 179–229 ppm to 1488–1664 ppm, respectively. Alumina saturation also increases from the tonalite ($\text{ASI} = 0.85\text{--}0.94$) to the granite ($\text{ASI} = 1.03\text{--}1.08$; Figure GS2025-4-3). However, no trend is observed related to the SiO_2 content, which varies from 71.95 to 75.64 wt. %, and Sr concentrations are relatively uniform from tonalite to granite (159–264 ppm). Chondrite-normalized REE profiles are characterized by negative-sloping LREEs ($[\text{La}/\text{Sm}]_N = 2.40\text{--}4.12$) and relatively flat heavy rare-earth elements (HREEs; $[\text{Gd}/\text{Yb}]_N = 0.89\text{--}1.11$; Figure GS2025-4-4c). Primitive mantle-normalized multi-element profiles are characterized by depletion at Nb, P, Ti and V (Figure GS2025-4-4d). Both tonalitic and granitic profiles are relatively enriched in Th; however, granitic and granodioritic profiles are also enriched in Ba and K.

A folded pluton or series of granodioritic to granitic intrusions with a combined length of at least 2.5 km underlies a series of points, islands and reefs in northern Halfway Lake (Figure GS2025-4-1). The pluton grades from biotite-bearing to hornblende-bearing. The Mg# values range from 0.27 to 0.33, with 69.97–70.55 wt. % SiO_2 . The rocks are weakly peraluminous ($\text{ASI} = 1.00\text{--}1.05$; Figure GS2025-4-3) with 8.56–8.87 wt. % total

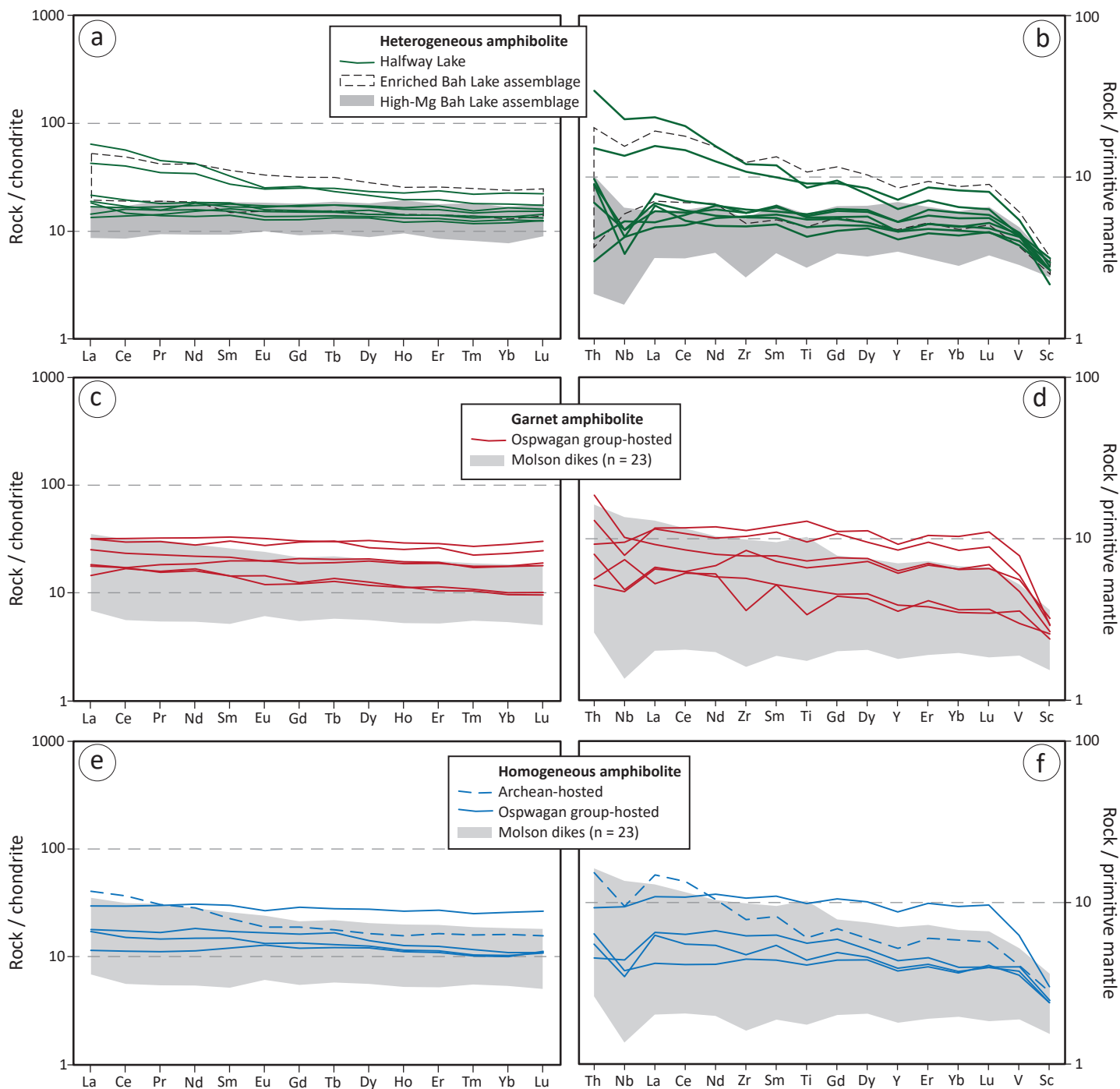


Figure GS2025-4-2: Chondrite-normalized rare-earth element profiles (left column) and primitive mantle-normalized multi-element profiles (right column) for mafic rocks from the Halfway Lake area: **a), b)** heterogeneous amphibolite; **c), d)** garnet amphibolite; **e), f)** homogeneous amphibolite. Normalizing values for chondrite and primitive mantle are from McDonough and Sun (1995). Reference values for Bah Lake assemblage area are from Zwanzig (2005). Reference values for Molson dikes are for analyses with $1 < (La/Yb)_N < 3$ and are sourced from Burnham et al. (2009), Heaman et al. (2009), Ciborowski et al. (2017) and Couëslan (2016, 2021a, b; unpublished data, 2014).

alkalis, K_2O/Na_2O ratios of 0.45–0.56, and high concentrations of Sr and Ba (1857–2306 ppm and 4381–5266 ppm, respectively). Chondrite-normalized REE profiles have negative slopes ($[La/Yb]_N = 16.8–45.8$), with variable enrichment of Eu ($[Eu/Eu^*]_N = 0.88–1.66$; Figure GS2025-4-4e). Primitive mantle-normalized profiles display relative enrichments at Ba, K, Sr and Zr, and relative depletions at Nb, P, Ti and V (Figure GS2025-4-4f).

A granite–granodiorite pluton or series of intrusions is intercalated with rocks of the Bah Lake assemblage in south-central Halfway Lake. The Mg# values range from 0.26 to 0.33, with 70.89–72.91 wt. % SiO_2 . The rocks are weakly peraluminous ($ASI = 1.00–1.02$; Figure GS2025-4-3) with 8.12–8.42 wt. % total alkalis and K_2O/Na_2O ratios of 0.29–0.64. Barium concentrations are enriched but vary considerably from 1606 to 4110 ppm,

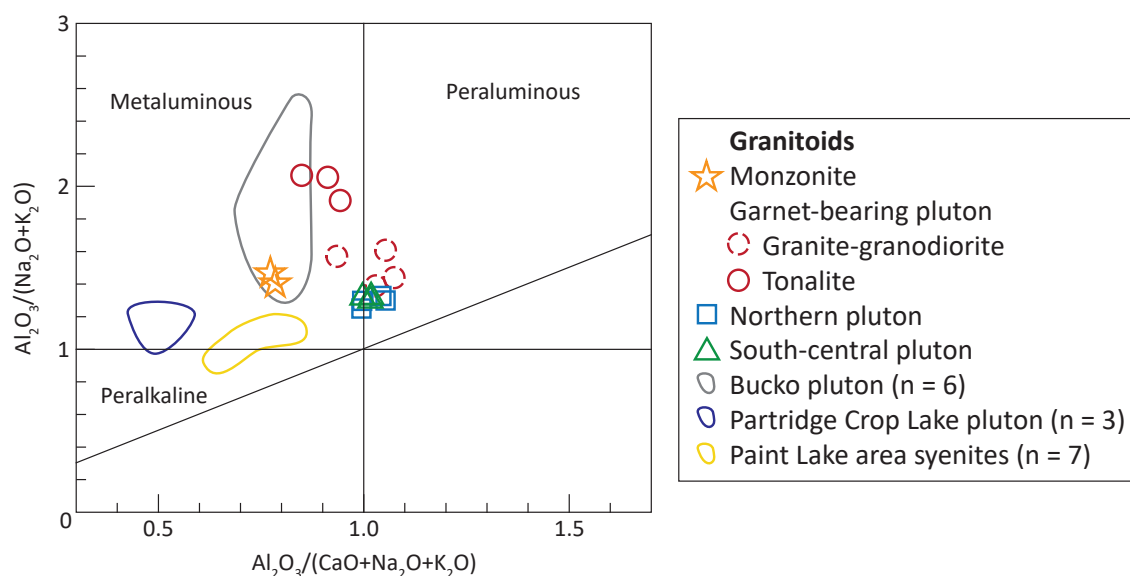


Figure GS2025-4-3: Granitoids from the Halfway Lake area and syenitic to monzonitic rocks from the Thompson nickel belt plotted on the alumina saturation-index diagram (Maniar and Piccoli, 1989). Reference values for the Bucko pluton are from Burnham et al. (2009) and H.V. Zwanzig (unpublished data, 2003). Reference values for the Partridge Crop Lake pluton are from Couëslan and Janssens (2025a) and C.G. Couëslan (unpublished data, 2014). Reference values for the Paint Lake area syenites are from Couëslan (2016).

whereas Sr is more consistent at 1104–1302 ppm. Chondrite-normalized REE profiles have negative slopes ($[La/Yb]_N = 3.60\text{--}18.3$), with variable enrichment or depletion at Eu ($[Eu/Eu^*]_N = 0.55\text{--}1.65$; Figure GS2025-4-4g). Primitive mantle-normalized profiles are characterized by relative enrichments at Ba, K, Sr and Zr, and relative depletions at Nb, P, Ti and V (Figure GS2025-4-4h).

Sedimentary rocks

The Setting formation of the Oswagan group is defined as the clastic sedimentary rocks deposited above the uppermost iron formation of the P3 member of the Pipe formation (Zwanzig et al., 2007). The stratigraphy of the P3 member of the Pipe formation at Halfway Lake is similar to that of the Thompson mine and consists largely of interbedded quartzite, wacke and pelite, with only local iron formation. This makes differentiating Setting formation from Pipe formation clastic rocks difficult. Therefore, clastic rocks of the P3 member and Setting formation will be referred to simply as ‘upper sequence’ rocks in this report. Multi-element profiles normalized to the average P2 member pelite (Zwanzig et al., 2007) are relatively flat for upper sequence pelites, with minor variability for Th, K and LREEs (Figure GS2025-4-5a, b). The P2 pelite-normalized profiles of upper sequence wacke are typically flat; however, one sample is notably depleted in Th and LREEs and enriched in HREEs (Figure GS2025-4-5c, d). Two wacke samples from the upper sequence yielded T_{DM} ages of ca. 2.46 Ga and 2.71 Ga (Table GS2025-4-1).

The lower Thompson formation at Halfway Lake consists largely of calcareous semipelite, locally interlayered with calcsilicate (Couëslan, 2023). The semipelite is similar to the T2 member as described by Bleeker (1990) and Zwanzig et al. (2007), which

occurs as a relatively thin (1–4 m) unit at the Thompson mine. This suggests that unlike elsewhere in the TNB, the T2 member could make up a significant portion of Thompson formation stratigraphy in the Halfway Lake area. The P2 pelite-normalized profiles of the calcareous semipelite are flat to weakly negative sloping, with relative depletions at K, Zr and Ti, and strong enrichment at Sr and P (Figure GS2025-4-5e, f). A sample of Thompson formation calcareous semipelite yielded a T_{DM} of ca. 2.94 Ga (Table GS2025-4-1).

Detrital zircon U-Pb geochronology

Two samples of upper sequence clastic rocks were submitted for detrital zircon U-Pb isotope analyses. The results and description of the methods can be found in Couëslan (2025). For this report, analyses were filtered to results of detrital-core analyses (no rims or mixed core-rim analyses) that are <5% discordant, with $^{207}\text{Pb}/^{206}\text{Pb}$ age errors <100 Ma (2σ). Sample 108-22-118 consists dominantly of arkose and was collected from a point in southwestern Halfway Lake. The outcrop is composed of interlayered arkose and arkosic wacke, with local pegmatite dikes and boudinaged layers of plagioclase amphibolite. The sample yielded zircon grains of variable size and morphology. Most grains consist of rounded to subrounded, equant to elongate crystals and crystal fragments. A total of 112 analyses were made on detrital zircon grains with 90 analyses considered after filtering. A probability-density distribution (PDD) curve of the $^{207}\text{Pb}/^{206}\text{Pb}$ ages defines a dominant node at ca. 2640 Ma, with minor Paleoproterozoic nodes older than ca. 2215 Ma and minor Meso- to Paleoproterozoic nodes as old as ca. 3480 Ma (Figure GS2025-4-6a). A cumulative distribution curve of the detrital zircon ages yields

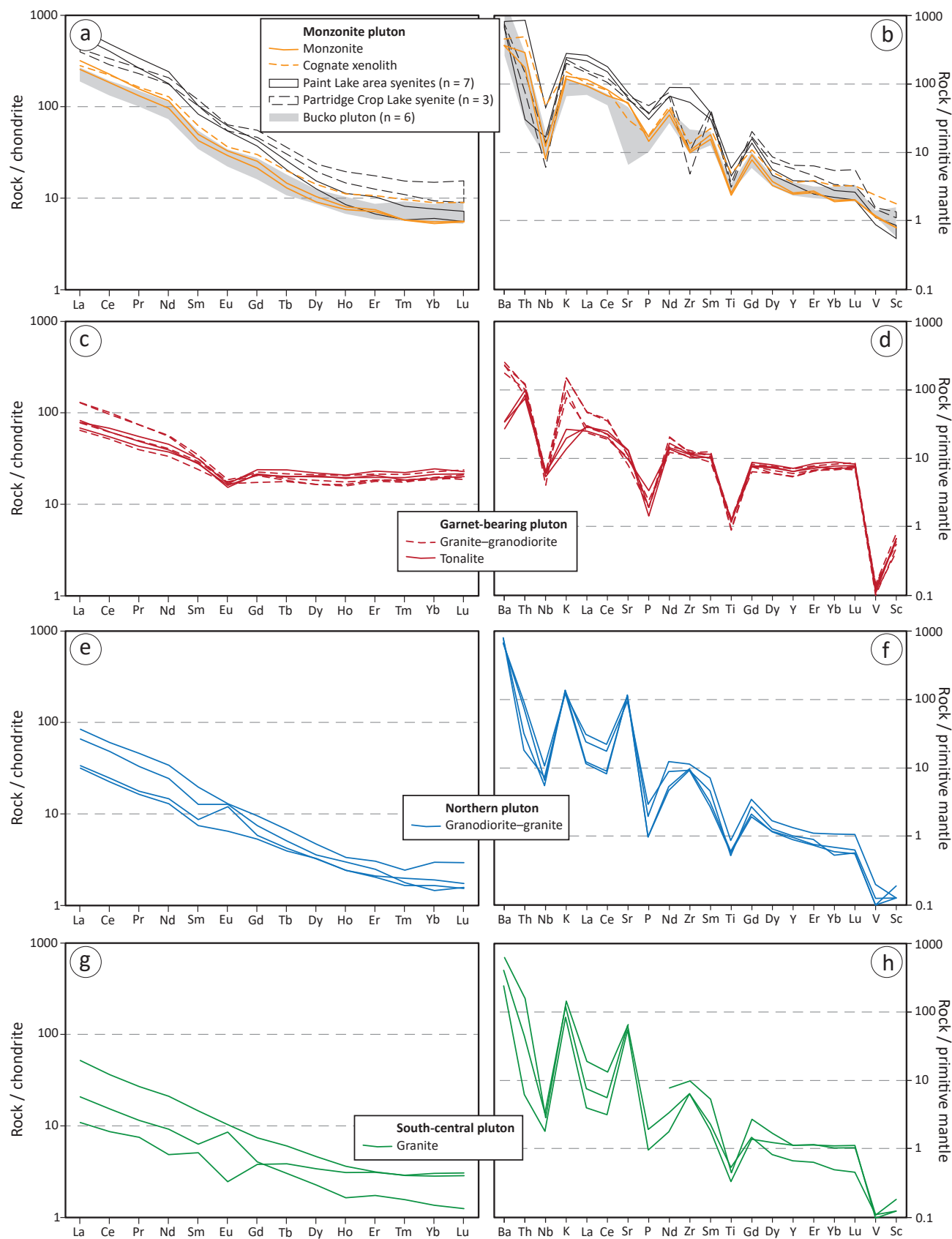


Figure GS2025-4-4: Chondrite-normalized rare-earth element profiles (left column) and primitive mantle-normalized multi-element profiles (right column) for granitoids from the Halfway Lake area: **a), b)** monzonite compared with syenites from the Paint Lake and Partridge Crop Lake areas and the Bucko pluton; **c), d)** garnet-bearing pluton; **e), f)** granodiorite-granite from northern Halfway Lake; **g), h)** granite from south-central Halfway Lake. Data sources: Bucko pluton, Burnham et al. (2009) and H.V. Zwanzig (unpublished data, 2003); Paint Lake area syenites, Couëslan (2016); Partridge Crop Lake syenite, Couëslan and Janssens (2025a) and C.G. Couëslan (unpublished data, 2014).

Table GS2025-4-1: Summary of Sm-Nd isotopic data for selected samples from the Halfway Lake area.

Sample number	Rock type	Sm (ppm)	Nd (ppm)	$^{147}\text{Sm}/^{144}\text{Nd}^1$	$^{143}\text{Nd}/^{144}\text{Nd}^2$	2 σ abs. uncert.	T _{DM} ³ (Ga)	ϵ_{Nd}^4
108-22-039	Archean Bt-Hbl gneiss	2.00	10.92	0.11108	0.511025	0.000010	3.12	-1.64
108-22-097	Monzonite	6.52	41.28	0.0954	0.511325	0.000010	2.34	-1.77
108-22-111	Thompson formation calcareous semi-pelite	4.86	32.17	0.0913	0.510766	0.000010	2.94	
108-22-118	Ospwagan group, upper sequence arkose	5.30	31.47	0.1018	0.511328	0.000010	2.46	
108-22-157A	Ospwagan group, upper sequence arkosic wacke	1.50	10.08	0.0898	0.510928	0.000010	2.71	

¹ Estimated error is better than 1.0%

² Presented relative to $^{143}\text{Nd}/^{144}\text{Nd} = 0.512095$ for the JNdi-1 standard

³ Depleted-mantle Nd-model ages (T_{DM}) calculated according to the linear model of Goldstein et al. (1984)

⁴ ϵ_{Nd} values at 2700 Ma for 108-22-039 and 1835 Ma for 108-22-097, calculated using present-day chondritic ratios of $^{143}\text{Nd}/^{144}\text{Nd} = 0.512638$ and $^{147}\text{Sm}/^{144}\text{Nd} = 0.1967$

Sample locations can be found in Couëslan and Janssens (2025b)

Abbreviations: abs., absolute; uncert., uncertainty

an interquartile range (middle 50% of data) of 2600–2700 Ma (Figure GS2025-4-6b).

Sample 108-22-157A consists of interbedded arkosic wacke and arkose. It was collected from an island in central Halfway Lake. The outcrop consists of arkosic quartzite with interbeds of arkosic wacke and local boudins of plagioclase amphibolite. Local veins of pseudotachylite cut the compositional layering at a low-angle. A total of 118 detrital zircon grains were analyzed with 96 analyses considered after filtering. A PDD curve of the $^{207}\text{Pb}/^{206}\text{Pb}$ ages defines a dominant node at ca. 2650 Ma, with minor Paleoproterozoic nodes as young as ca. 1940 Ma and Mesoarchean nodes as old as ca. 2955 Ma (Figure GS2025-4-6c). The interquartile range of the detrital zircon ages is relatively narrow (2623–2692 Ma; Figure GS2025-4-6d).

Discussion

Mafic rocks

The volcanic rocks from Halfway Lake all plot within the ocean-floor field in the Zr-Ti-Y diagram (Figure GS2025-4-7a); however, the normalized profiles appear to define two trends. One trend is relatively flat, whereas the other is more enriched and negative sloping (Figure GS2025-4-2a, b). Two trends are also evident in the Zr-Nb-Y and La-Y-Nb discrimination diagrams, with the majority of samples plotting within the normal mid-ocean-ridge basalt (N-MORB) field and back-arc-basalt fields, and two samples trending toward increasing enrichment into the enriched mid-ocean-ridge basalt (E-MORB) and continental basalt fields (Figure GS2025-4-7b, c). Previous work on the Bah Lake assemblage of the Ospwagan group by Zwanzig (2005) subdivided the volcanic rocks into an N-MORB-like high-Mg suite and an E-MORB-like enriched suite (Figure GS2025-4-2a, b). The profiles of the two suites are similar to the two trends defined by

the mafic volcanic rocks at Halfway Lake and support the interpretation that they could be correlative with the Bah Lake assemblage.

The normalized profiles of the garnet-bearing mafic dikes are relatively flat and suggestive of a MORB affinity (Figure GS2025-4-2c, d), and are similar to the profiles of homogeneous amphibolite samples hosted in Ospwagan group rocks (Figure GS2025-4-2e, f). Variable anomalies at Th and Nb could indicate interaction with more evolved crust. Samples of garnet amphibolite and homogeneous amphibolite plot within the ocean-floor-basalt and MORB fields of the discrimination diagrams of Pearce and Cann (1973) and Meschede (1986), and overlap with the back-arc-basalt field of Cabanis and Lecolle (1989; Figure GS2025-4-7a–c). The normalized profiles and results from discrimination diagrams are similar to those of mafic dikes of the Molson swarm, which have been interpreted as the result of a mantle plume, passive mantle upwelling or back-arc magmatism (Figure GS2025-4-2c–f; Figure GS2025-4-7a–c; Heaman et al., 2009; Ciborowski et al., 2017). The main difference between the garnet amphibolite and the homogeneous amphibolite appears to be related to alkali content. The garnet amphibolite typically contains <2 wt. % total alkalis with a K₂O/Na₂O ratio typically >0.3, whereas the homogeneous amphibolite typically contains >2 wt. % total alkalis with a K₂O/Na₂O ratio <0.2.

The homogeneous appearance of the Archean-hosted amphibolite suggests that it is likely of Paleoproterozoic age. The normalized profiles of the samples have notably steeper negative slopes than the other amphibolite samples ([La/Yb]_N = 2.5 vs. 1.14–1.66), as well as negative anomalies at Nb and Ti, which could suggest an arc affinity (Figure GS2025-4-2e, f). However, the Archean-hosted sample is also characterized by a relatively flat normalized HREE profile ([Gd/Yb]_N = 1.16), which is similar to the other homogeneous amphibolite and garnet amphibolite

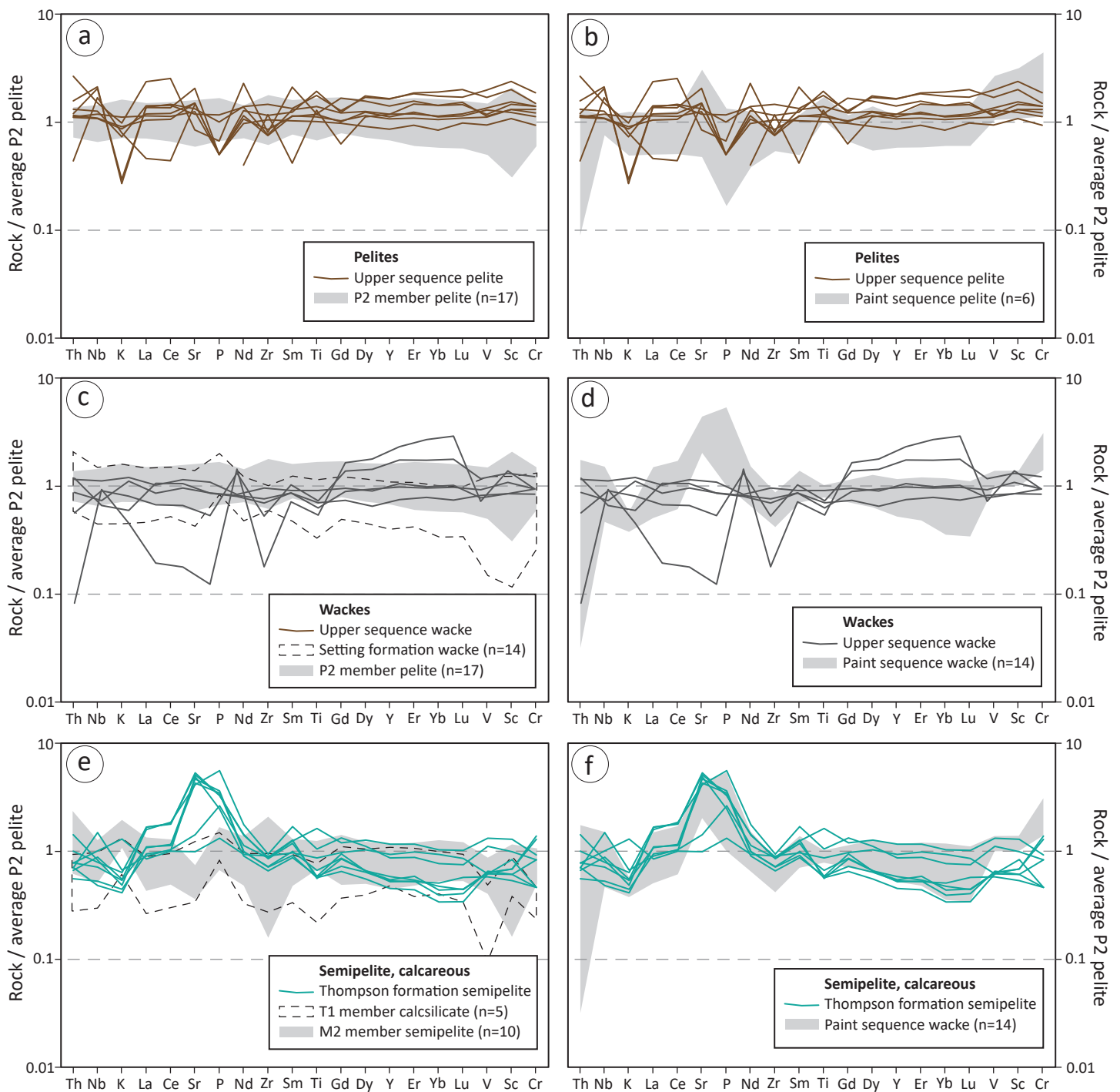


Figure GS2025-4-5: Average P2 member pelite-normalized multi-element profiles for sedimentary rocks from the Halfway Lake area compared with other sedimentary rocks from the Thompson nickel belt: **a)** upper sequence pelite and P2 member pelite; **b)** upper sequence pelite and Paint sequence pelite; **c)** upper sequence wacke, Setting formation wacke and P2 member pelite; **d)** upper sequence wacke and Paint sequence wacke; **e)** Thompson formation semipelite, calcsilicate and M2 member semipelite; **f)** Thompson formation semipelite and Paint sequence wacke. Normalizing values are from Zwanzig et al. (2007). Reference values for pelite from the P2 member of the Pipe formation, wacke from the Setting formation and semipelite from the M2 member of the Manasan formation are from Zwanzig et al. (2007) and Couëslan (2016). Reference values for the Paint sequence pelite and wacke are from Couëslan (2016) and Couëslan and Janssens (2025a). Reference values for the calcsilicate from the T1 member of the Thompson formation are from Couëslan (2003), Zwanzig et al. (2007) and Couëslan (2021b).

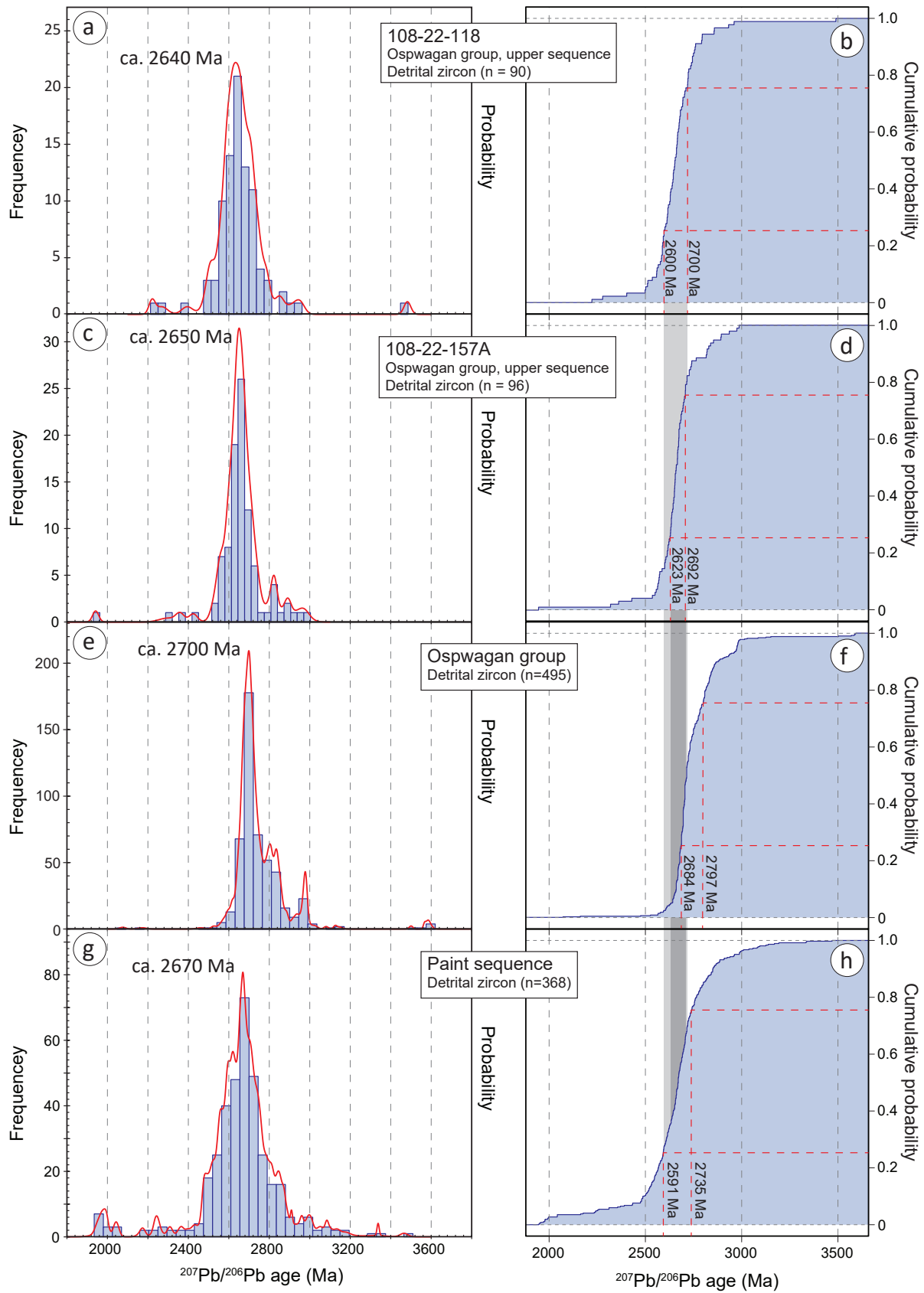


Figure GS2025-4-6: Combined frequency histogram and probability-density distribution curves (left column) and cumulative distribution curves (right column) of $^{207}\text{Pb}/^{206}\text{Pb}$ detrital zircon ages for sedimentary rocks from the Thompson nickel belt: **a), b)** Halfway Lake sample 108-22-118; **c), d)** Halfway Lake sample 108-22-157A; **e), f)** compilation of Ospwagan group rocks; **g), h)** compilation of Paint sequence rocks. Data sources: Ospwagan group, Rayner et al. (2006), Zwanzig et al. (2021), Couëslan (2022c); Paint sequence, Couëslan (2016, 2022b, 2025). The interquartile ranges of the Halfway Lake samples are projected in grey for comparison with the Ospwagan group and Paint sequence cumulative distribution curves.

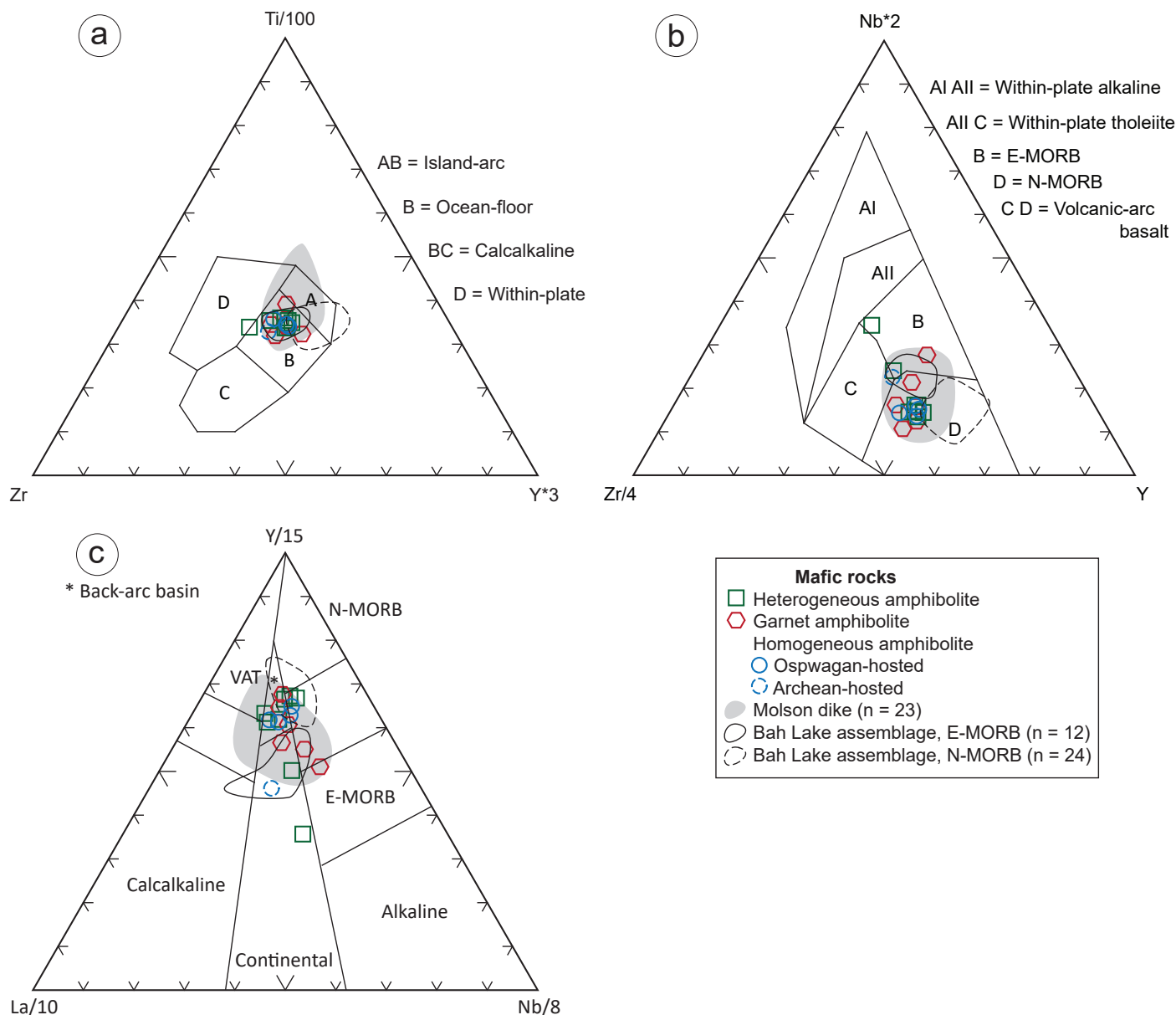


Figure GS2025-4-7: Geochemical discrimination diagrams for mafic rocks from Halfway Lake: **a)** Zr-Ti-Y diagram (after Pearce and Cann, 1973); **b)** Zr-Nb-Y diagram (after Meschede, 1986); **c)** La-Y-Nb diagram (after Cabanis and Lecolle, 1989). Reference values for Molson dikes are for analyses with $1 < (La/Yb)_N < 3$ and are sourced from Burnham et al. (2009), Heaman et al. (2009), Ciborowski et al. (2017), Couëslan (2016, 2021a, b; unpublished data, 2014). Reference values for Bah Lake assemblage area from Zwanzig (2005). Abbreviation: VAT, volcanic arc tholeiite.

samples ($[Gd/Yb]_N = 1.06\text{--}1.48$). The enrichment in LREEs and Th could be the result of crustal interaction/assimilation, possibly combined with a slightly more enriched mantle source, similar to the enriched Bah Lake assemblage sample discussed above. This interpretation is consistent with discrimination diagrams in which the Archean-hosted sample plots toward the E-MORB and continental basalt fields (Figure GS2025-4-7b, c).

Granitoids

The primitive mantle-normalized profiles of granitoids from the Halfway Lake area are typical of arc or crustal-derived melts (Figure GS2025-4-4b, d, f, h). The garnet-bearing granite-tonalite pluton is geochemically distinct from the other granitic to grano-

dioritic intrusions in that it defines a trend from tholeiitic to calcalkaline affinity on the $K_2O\text{--}SiO_2$ diagram (Figure GS2025-4-8a). All other granitoids plot in the calcalkaline field(s). The garnet-bearing pluton is also characterized by flat HREE profiles ($[Gd/Yb]_N = 0.89\text{--}1.11$ compared with >1.25 for other granitoids; Figure GS2025-4-4c). This is a characteristic of FII felsic rocks, which are interpreted to form from mid-level, high-temperature partial melting of crust in extensional environments (Figure GS2025-4-8b, c; Hart et al., 2004; Piercey, 2011). The garnet-bearing tonalite also shares some characteristics with FIII felsic rocks, including high SiO_2 content (>75 wt. %), and a tholeiitic affinity, which are characteristic of partial melts generated at higher crustal levels (Hart et al., 2004; Piercey, 2011). Partial melting in extensional environments is typically driven by mantle upwelling

and the emplacement of mafic to ultramafic magmas. Emplacement of the garnet-bearing pluton could therefore be contemporaneous with magmatism related to the Bah Lake assemblage or the Molson dike swarm. Samples were collected from drillcore for U–Pb zircon geochronology in June 2025 to test this theory.

A number of syenitic to monzonitic plutons occur within the TNB in the Paint Lake area, Bucko-Resting lakes area and at Partridge Crop Lake. The plutons in the Paint Lake area and at Partridge Crop Lake are typically more magnesian ($Mg\# = 0.65\text{--}0.76$), enriched in Cr (270–460 ppm), Ni (100–280 ppm) and LILEs ($Na_2O+K_2O = 7.32\text{--}9.99$ wt. %, 1166–1479 ppm Sr, 4299–5377 ppm Ba) than the Halfway Lake monzonite (Couëslan, 2016; Couëslan and Janssens, 2025a; C.G. Couëslan, unpublished data, 2014). The Paint Lake and Partridge Crop Lake plutons also have a lower peralkalinity index (molar $Al_2O_3/[Na_2O+K_2O] = 0.91\text{--}1.2$ compared with >1.4) and a more shoshonitic affinity (Figure GS2025-4-3; Figure GS2025-4-8a, d). The Paint Lake syenite yielded a U–Pb zircon age of 1883 ± 5 Ma, which is interpreted as a magmatic crystallization age (Couëslan, 2016). The plutons from the Paint Lake area and Partridge Crop Lake are characterized by strongly negative ϵNd values of -14.3 to -15.0 (calculated at 1880 Ma) and relatively old depleted-mantle Nd-model ages of ca. 3.09–3.36 Ga (Couëslan, 2016; unpublished data, 2017), which contrast with the much less evolved Sm–Nd isotope geochemistry of the Halfway Lake pluton (sample 108-22-097, Table GS2025-4-1).

The Bucko pluton is a relatively large monzodioritic to monzonitic pluton that stretches approximately 25 km from the Bucko Lake area in the north to the Manibridge mine area in the south. The Bucko pluton has a high-K calcalkaline affinity, and has $Mg\#$ values (0.57–0.62) and concentrations of Cr and Ni (90–141 ppm and 52–71 ppm, respectively) that are similar to the Halfway Lake pluton (Figure GS2025-4-8a, d). The Bucko pluton is also characterized by similar total alkali contents ($Na_2O+K_2O = 6.35\text{--}7.84$ wt. %) and ASI values (0.76–0.83) as the Halfway Lake pluton (Figure GS2025-4-3). The Bucko pluton has a magmatic crystallization age of ca. 1835 Ma (Bleeker et al., 1995), with an ϵNd value of -1.4 (calculated at ca. 1845 Ma) and a depleted-mantle Nd-model age of ca. 2.49 Ga (Percival et al., 2004). Given the similarities in geochemistry and Nd-model ages, a similar magmatic crystallization age could be assumed for the Halfway Lake pluton, which results in an ϵNd value of -1.77 (Table GS2025-4-1). An ϵNd value, calculated at 1835 Ma, of -1.77 Ga suggests a weakly evolved source or that the monzonite was derived from a juvenile magma that interacted with evolved crust.

Similarities were noted between the Bucko pluton and Archean sanukitoids (Percival et al., 2004); however, they also have characteristics that are transitional between the high-silica and low-silica adakites of Martin et al. (2005). Sanukatoid and adakite magmas are typically associated with subduction zone processes. This challenges current understanding of the subduction polarity at ca. 1835 Ma, which places the Superior craton as the under-riding plate (Bleeker, 1990; White et al., 2002).

Sedimentary rocks

One of the original intentions behind the mapping project at Halfway Lake was to investigate if Paint sequence rocks were present along strike from the Phillips–Paint lakes area (Couëslan, 2016, 2022b). A method using average P2 member pelite-normalized multi-element profiles to compare and contrast sedimentary rock units in the TNB was devised by Zwanzig et al. (2007). Average P2-normalized profiles of pelite from Halfway Lake are relatively flat and more similar to the profiles of pelite from the P2 member than pelite from the Paint sequence, which can be characterized by relative depletions at Th and P, and relative enrichments at Sr, V, Sc and Cr (Figure GS2025-4-5a, b). The majority of wacke samples from the upper sequence at Halfway Lake have similarly flat normalized multi-element profiles (Figure GS2025-4-5c). This contrasts with normalized profiles of the Paint sequence wacke, which can have negative slopes and be relatively depleted in Th and K, and is typically enriched in Sr, P and Cr (Figure GS2025-4-5d).

The calcareous semipelite of the Thompson formation at Halfway Lake is assumed to consist of a clastic component (likely siltstone or wacke) along with a calcareous component (sedimentary carbonate). A multi-element profile could therefore be expected with characteristics falling between those of the M2 member semipelite of the underlying Manasan formation and those of the Thompson formation calcsilicate (Figure GS2025-4-5e). Instead, the normalized profile of the calcareous semipelite can appear more similar to that of the Paint sequence wacke, with relative depletions in K and enrichments in Sr, P and, in some cases, Cr (Figure GS2025-4-5f). This could imply a similar clastic source is shared by Thompson formation rocks at Halfway Lake and the Paint sequence, whether or not it suggests a direct stratigraphic relationship (e.g., lateral facies change). However, it should also be noted that Thompson formation calcsilicates and marbles from the Halfway Lake area display similar relative enrichments in P, which could imply that P is part of the calcareous sedimentary component rather than the clastic component (Couëslan and Janssens, 2025b).

The T_{DM} of the Thompson formation calcareous semipelite (ca. 2.94 Ga) is typical for Ospwagan group rocks (ca. 2.82–3.16 Ga) and near the lower end for analyzed Paint sequence rocks (ca. 2.95–3.57 Ga; Figure GS2025-4-9). In contrast, the T_{DM} ages for the upper sequence wackes from Halfway Lake are significantly younger (ca. 2.46–2.71 Ga) than previous model ages determined for the Ospwagan group and overlap with model ages of the Burntwood group of the adjacent Kisseynew domain (ca. 2.13–2.62 Ga). The younger model ages for the upper sequence wacke suggest a less evolved (possibly younger) crustal component than observed elsewhere in the Ospwagan group. Recent work suggests that there may be a general younging of Paint sequence Nd-model ages toward the south (Figure GS2025-4-9; Couëslan, 2022b). Initial results suggest a similar relationship may exist in the Archean basement, with generally older model ages in the north (possibly coinciding with Hudson Bay terrain-

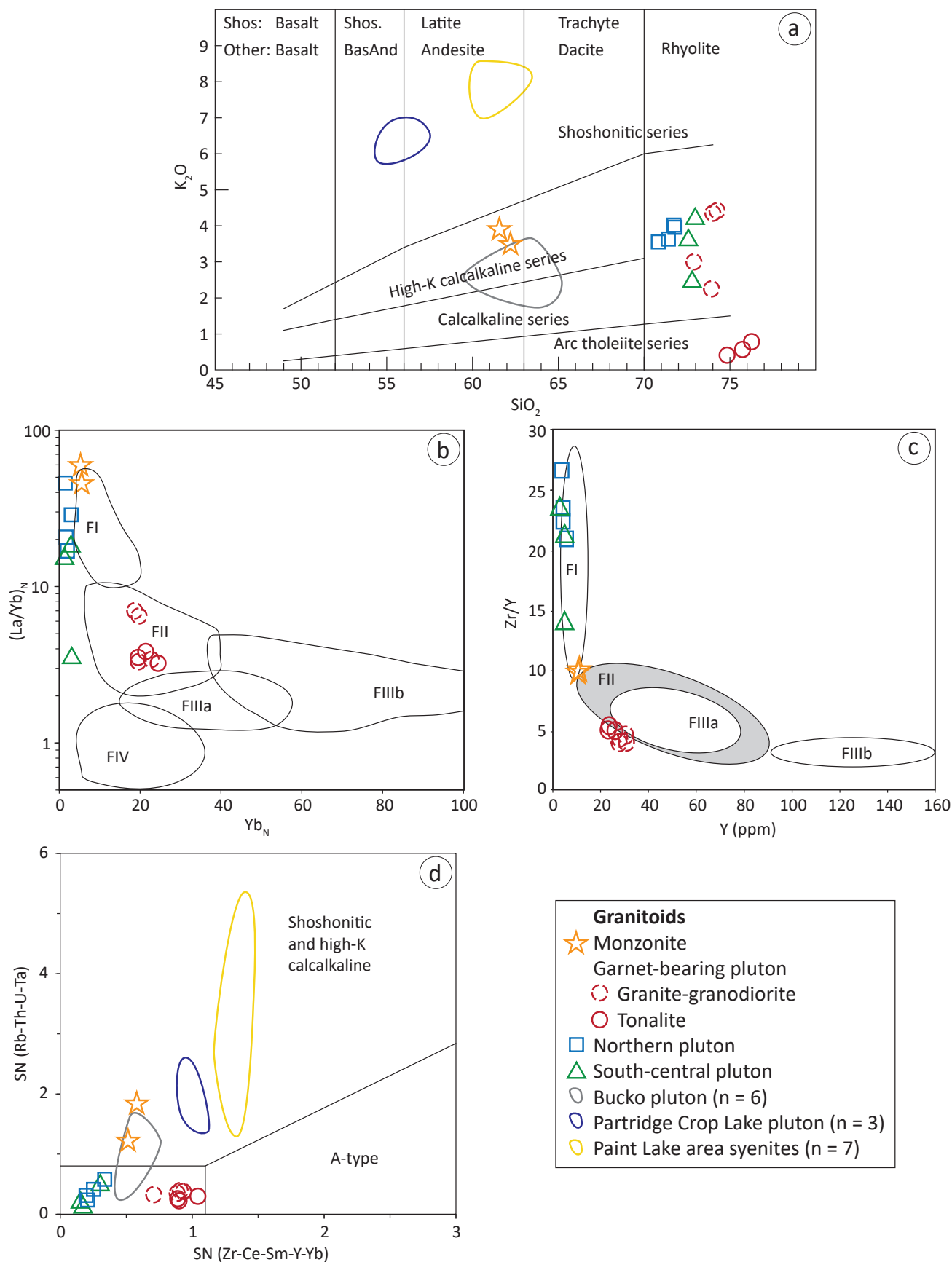


Figure GS2025-4-8: Geochemical discrimination diagrams for granitoid rocks from Halfway Lake: **a)** K_2O - SiO_2 diagram of Peccerillo and Taylor (1976); **b)** $(La/Yb)_N$ - Yb_N diagram of Hart et al. (2004; modified after Lesher et al., 1986); **c)** Zr/Y - Y diagram of Lesher et al. (1986); **d)** sliding normalization (SN) diagram of Liégeois et al. (1998). Abbreviations: BasAnd, basaltic andesite; Shos., shoshonite.

derived crust) and younger model ages in the south (possibly coinciding with North Caribou terrain-derived crust; Couëslan, 2021a, 2022b). It is possible that the same pattern could exist within the Ospwagan group, with older model ages in the north and younger model ages in the south; however, more sampling of all the rock suites in the south is required to provide a statistically robust dataset to confirm this hypothesis.

The dominant detrital zircon age nodes for the upper sequence wacke samples 108-22-118 and 108-22-157A are 2640 Ma and 2650 Ma, respectively (Figure GS2025-4-6a, c). These nodes coincide with U-Pb metamorphic zircon and monazite ages from the adjacent Pikwitonei granulite domain of the Superior craton (Heaman et al., 2011; Guevara et al., 2020; Couëslan, 2021a). This supports previous interpretations that the clastic detritus that formed the Ospwagan group was sourced mainly from the Superior craton (Bleeker, 1990; Bleeker and Hamilton, 2001; Rayner et al., 2006; Böhm et al., 2007; Zwanzig et al., 2007). However, these dominant age nodes are significantly younger than the dominant age node for a compilation of previously analyzed Ospwagan group detrital zircon (ca. 2700 Ma; Figure GS2025-4-6e). Although there is overlap of the interquartile ranges between the Ospwagan group compilation (2684–2797 Ma) and the upper sequence rocks of Halfway Lake (2600–2700 Ma and 2623–2692 Ma; Figure GS2025-4-6b, d, f), it is relatively minor. The dominant node and interquartile ranges of the Halfway Lake rocks are closer to those of the compilation of Paint sequence detrital zircon (Figure GS2025-4-6g, h).

Economic considerations

The stratigraphic relationships and lithogeochemistry of the supracrustal rocks at Halfway Lake suggest that they are correlative with the Ospwagan group rather than the Paint sequence (Couëslan, 2023; this study). Although not discussed in this study, many of the ultramafic bodies at Halfway Lake appear to be emplaced near sulphidic horizons at the boundary between the Thompson and Pipe formations, which coincides with the ore horizons at the Pipe and Birchtree mines (Couëslan, 2023). Conductors along this horizon, with or without significant ultramafic rock and that have been thickened along regional fold hinges, are prospective targets for Ni exploration (Bleeker, 1990; Lightfoot et al., 2017).

Böhm et al. (2007) demonstrated the use of Sm-Nd whole-rock geochemistry as an exploration tool for distinguishing Ospwagan group rocks from the less prospective Archean basement and Burntwood group in the northern TNB. However, the Nd-model age results from this study included two samples considerably younger than previous analyses from the Ospwagan group, one of which could be considered typical of the Burntwood group (Figure GS2025-4-9). These results underline the importance of collecting a suitable sample size. Further work is required to see if there could be a shift to younger Nd-model ages in Ospwagan group rocks toward the south in the TNB, which could restrict the use of Sm-Nd isotope geochemistry as an exploration tool to the northern portions of the TNB.

The garnet-bearing granite–tonalite pluton in western Halfway Lake shares a geochemical affinity with FII felsic rocks, which

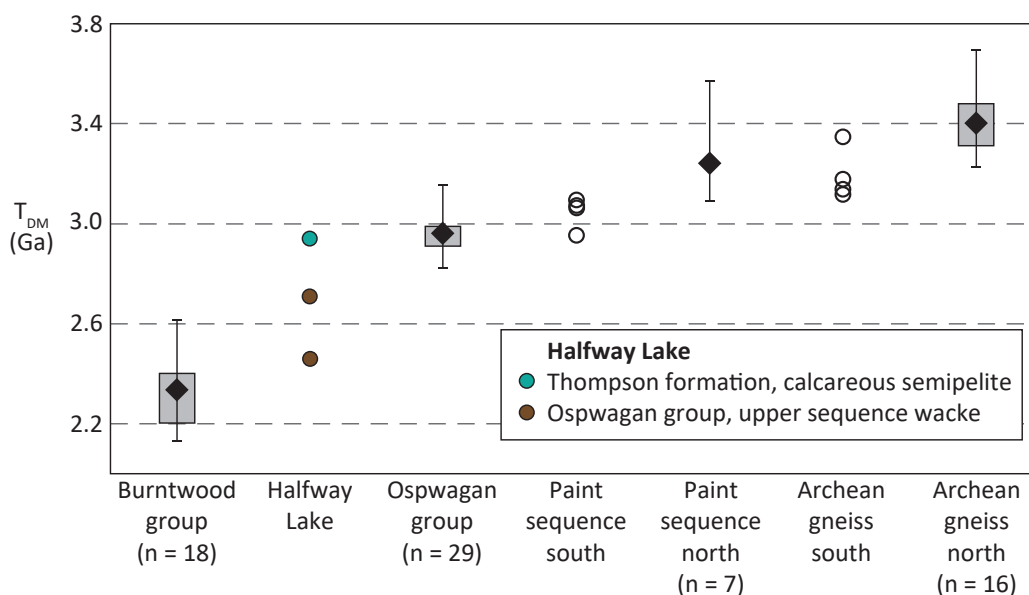


Figure GS2025-4-9: Range of crustal-residence Nd-model ages for rocks from the Thompson nickel belt and adjacent Kiseynew domain. Diamonds indicate median values, circles indicate individual model ages for units with limited datasets and grey bars indicate the interquartile range (middle 50% of the data). Data sources: Burntwood group, Böhm et al. (2007) and Murphy and Zwanzig (2021); Ospwagan group and Archean gneiss, Böhm et al. (2007) and Manitoba Geological Survey (2022); Paint sequence, Couëslan (2016, 2022b).

can be spatially associated with VMS systems. If the pluton was emplaced contemporaneously with the mafic-ultramafic magmatism of the Bah Lake volcanic assemblage, it would imply at least a notional potential for VMS mineralization. Outside of the submarine volcanic environment, FII felsic rocks can be found associated with epithermal deposits in extensional/rift environments (Hart et al., 2004). However, epithermal mineralization is considered to form at shallow crustal levels (<1000 m; Panteleyev, 1988), and would likely have poor preservation potential in the relatively high metamorphic-grade rocks of the TNB.

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