

Preliminary analysis of the sequence stratigraphy and geochemistry of the Portrait Lake Formation at Macmillan Pass, Yukon, Canada

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Abstract

The Upper Devonian Earn Group is a clastic-dominated, deep-water succession that is intersected in outcrop and subsurface drill core throughout the Yukon. In east-central Yukon, the group is subdivided lithostratigraphically into the Portrait Lake and Prevost formations. The Portrait Lake Formation hosts significant lead-zinc ± silver (Pb-Zn ± Ag) mineralization in mudstone-dominated strata at three significant deposits in the Macmillan Pass region. The Portrait Lake Formation is well defined lithostratigraphically; however, a sequence stratigraphic approach to mapping the unit would allow for a better understanding of the evolution of the basin in relation to sedimentation and mineralization phases. By mapping the strata using this approach, it is possible to predict the distribution and extent of ore bodies in relation to the 3D variability of systems tracts and will allow for the prediction of where other ore bodies may exist in the Macmillan Pass district or in other areas of the Selwyn basin. This study presents the initial results of the core logging, x-ray fluorescence (XRF), and organic carbon isotope ($\delta^{13}\text{C}$) analyses that were conducted on four cores that were drilled at the Boundary, Jason and Tom properties.

Three major depositional processes have been identified, which include hemipelagic sedimentation, mass transport deposits (grainflow, mudflow, slump) and turbidites (high and low-density). Where coarser grained material that forms the grainflows, slumps and turbidite deposits are present, it is easier to identify stratigraphic horizons that separate depositional processes. This is due to distinct lithological and sedimentological contrasts between the strata above and below the contact. The mudstone-dominated units require additional geochemistry to identify subtle stratigraphic horizons and changes in depositional trends to facilitate regional correlations.

During the Late Devonian, the structural context of deposition shifted from that of a passive margin to an extensional setting. As extension occurs, coarse material is transported to the deep basin and accumulates in topographic lows of graben complexes. This causes the lateral and rapid juxtaposition of coarse-grained material with finer-grained material, complicating stratigraphic correlations in the region.

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Plain language summary

This publication includes the initial geochemical dataset and descriptions for rocks that are between 388 and 359 million years old. The rocks that were studied for this dataset were deposited in deep water (water depths generally exceeding 1 km or more) where sediment (e.g., mud) settles to the ocean floor. Coarser grained material (sand and pebbles) is not typically expected to be found in deep-water deposits. When it is, it was generally brought to deeper water depths from underwater landslides (debris flows) or gravity-driven currents. This understanding is important when we try to interpret the paleogeography of a region and where economic deposits might be located. In the study area, critical minerals are found in the muddier sediment and generally contain lead-zinc \pm silver (Pb-Zn \pm Ag)-bearing minerals, such as sphalerite and galena that were formed as the mudstone was deposited, or shortly thereafter. These minerals are critical to Canada's drive for a green economy as they are used in the energy sector to build batteries and maintain wind turbines. This study aims to demonstrate where minerals occur in relation to the mudstone and sandstone intervals that were deposited hundreds of millions of years ago. It is challenging to see features in mudstone due to the fine-grained nature of these types of rocks. The geochemical study will inform us of subtle changes in the composition of the rocks, which will in turn allow us to map throughout the study area even in the finer grained units of rocks.

Introduction

The Yukon Geological Survey completed an initial study of Upper Devonian core that was drilled in the Macmillan Pass lead-zinc district. This study comprises a proposed four-year mapping project across east-central Yukon to create a high-resolution account of the sedimentology, stratigraphy and geochemistry of the Earn Group across the Selwyn basin region. The results of the project will be a sequence stratigraphic framework for the Earn Group using the 4-systems tract nomenclature (*sensu* Catuneanu et al., 2011). Herein, we present the initial results of our first year of data collection along with the objectives and goals for subsequent mapping years.

Location

The Earn Group was logged at Fireweed Metals' exploration property at Macmillan Pass during the summer of 2024. Macmillan Pass is located in east-central Yukon along the border with the Northwest Territories (Fig. 1). The site is accessible by driving the North Canol Road in the summer months when the barge at Ross River is operational.

The Macmillan Pass region hosts lead-zinc \pm silver (Pb-Zn \pm Ag) mineralization within mudstone-dominated intervals of the Late Devonian. The main deposits at Tom, Jason and Boundary are historical deposits that have received renewed interest when the property was acquired by Fireweed Metals. The company has been drilling seasonally and using the camp in the area since 2017.

Previous work – basin analysis and tectonism

From the Cambrian to Middle Devonian, rocks in the region were deposited in Selwyn basin, which was a deep-water depocenter along the northwestern margin of Laurentia (Figs. 2, 3; Gabrielse, 1967; Gordey and Anderson, 1993). Selwyn basin occurs basinward of the Mackenzie platform that is preserved to the northeast in outcrop belts of the Mackenzie Mountains. At Macmillan Pass, the Ordovician to Middle Devonian strata of the Road River Group comprise deposits that record basinal deep-water deposition. The Middle Devonian is marked by a volcanic suite known as the Macmillan Pass volcanics that separates the underlying Road River Group from the overlying Earn Group. The Earn Group is subdivided into the Portrait Lake Formation (Niddery Lake, Macmillan Pass and Fuller Lake members) and the Prevost Formation (Fig. 2).

The Devonian deposits logged in outcrop and core have been described lithostratigraphically in the literature for the Selwyn basin region (Carne, 1976; Gordey and Anderson, 1993; Cecile, 2000; Abbott, 2013). Fault-bound basins create the compartmentalization of sedimentary facies which results in rapid changes in the distribution of deep-water depositional environments over a relatively short distance. As a result, the naming conventions used to describe Devonian strata vary over relatively short distances within the Selwyn basin. For the present study, the nomenclature outlined in Abbott (2013) is adopted for the Macmillan Pass region (Figs. 1 and 2).

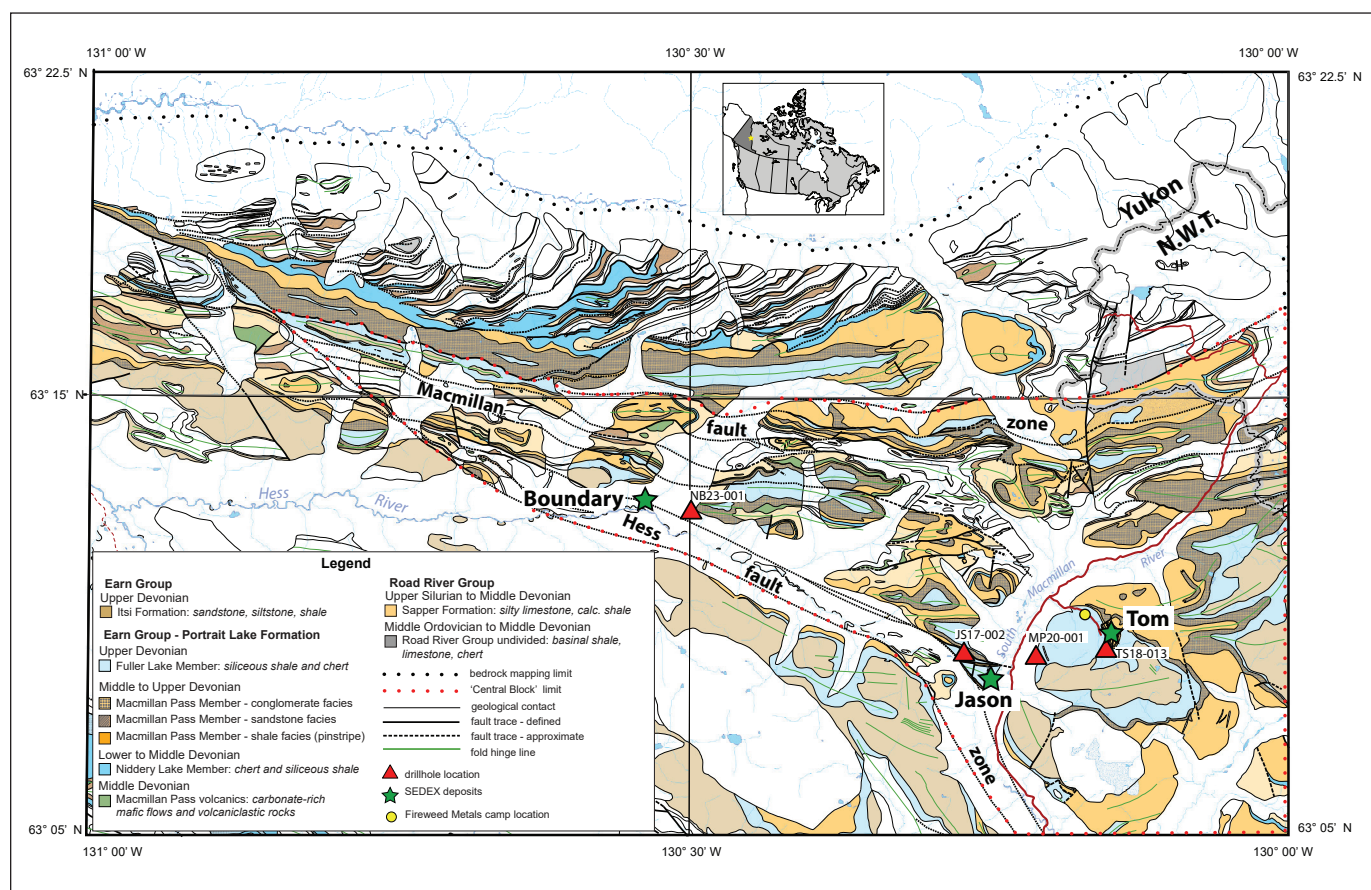


Figure 1. Geological map of the Macmillan Pass region (after Abbott, 2013; modified from Fraser et al., 2021). Locations of the lead-zinc deposits and cores that were logged and sampled for this study are presented herein.

During the deposition of the Late Devonian Portrait Lake Formation, the basin transitioned to an active convergent margin and the Macmillan Pass region experienced extensional events that were marked by the reactivation of normal faults in the region (Abbott and Turner, 1991; Nelson et al., 2006; Fraser et al., 2021). The syn-depositional fault reactivation creates horst and graben features in the region which localizes the deposition of coarse clastic material into the basin (Abbott and Turner, 1991; Fraser et al., 2021). The sub-seafloor replacement of barite by sphalerite and galena is inferred to have occurred syn and post-depositionally which resulted in the deposits at Tom, Jason and Boundary (Magnall et al., 2020; 2021; Grema et al., 2024). The strata at Macmillan Pass were later incorporated into the Mesozoic fold and thrust belt, complicating the correlation of stratigraphic units. It is inferred that major tectonic features mapped in the region (Fig. 1; Abbott, 2013) reflect pre-existing Devonian rift structures and divide the area into three distinct tectonic domains which include the North, Central and South blocks (Fig. 1; Abbott, 1983; Abbott and Turner, 1991).

Sequence stratigraphy

Sequence stratigraphy is a methodology of correlating stratal units based on the stacking patterns that develop in the sedimentary succession (Catuneanu et al., 2011). Changes in stratal stacking patterns are controlled by changes in accommodation and sedimentation in relation to fluctuations in relative sea level. Sequence stratigraphically significant surfaces mark changes in the observed stratal stacking patterns and can be traced regionally along depositional strike and down depositional dip. High-resolution sequence stratigraphic correlations require detailed facies analyses and a characterization of surfaces that mark changes in stratal stacking patterns to reconstruct the 3D variability of the sedimentary systems (Zecchin and Catuneanu, 2013; Catuneanu, 2019a,b). This is done to ensure that the deposits have been correctly assigned to their respective systems tracts and depositional systems to map the paleoshoreline and basin evolution (Ainsworth et al., 2017; Zecchin and Catuneanu, 2017).

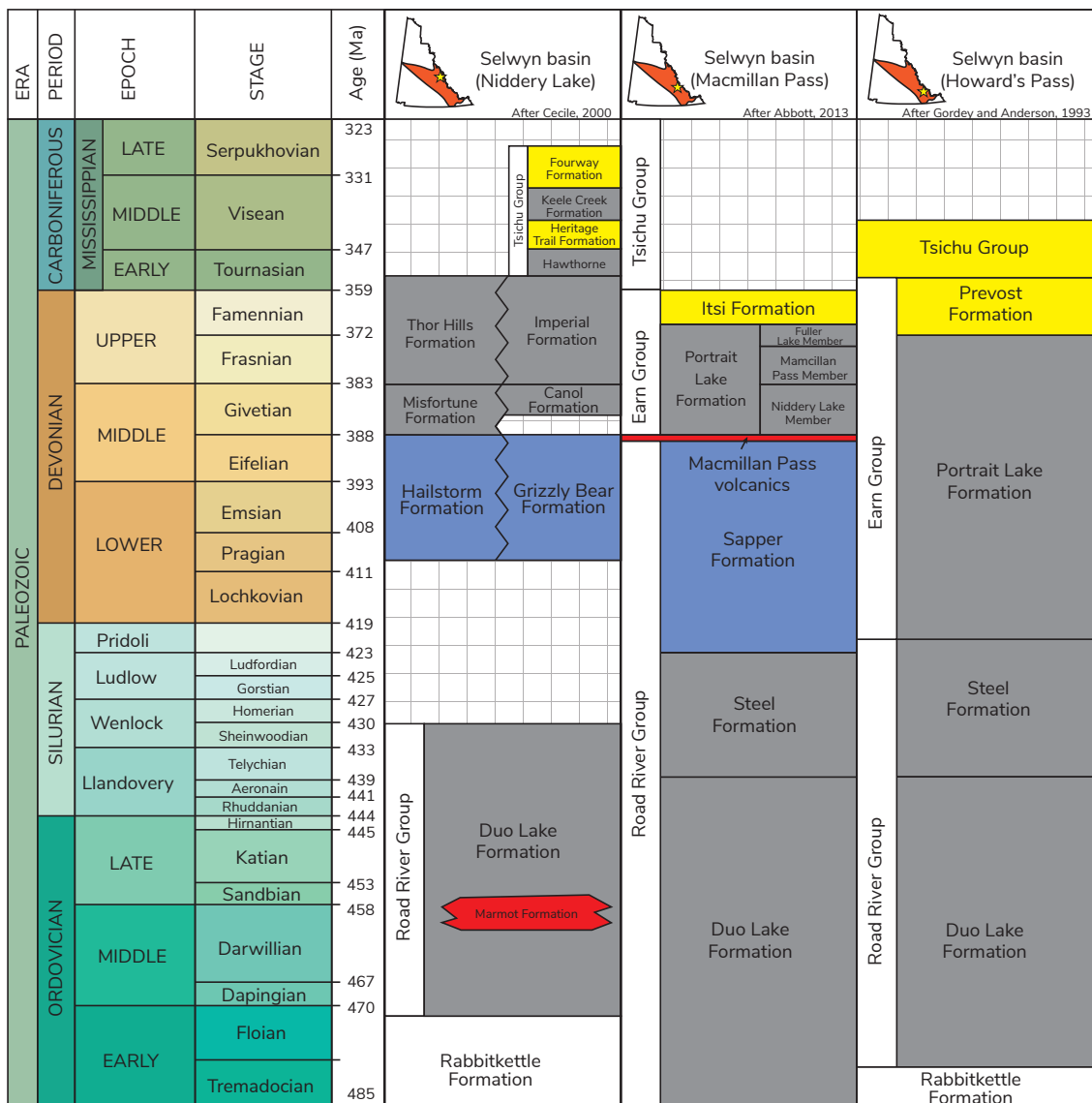


Figure 2. Table of formations for the Macmillan Pass region (modified from Gordey and Anderson, 1993; Abbott, 2013). The colours on the table represent the following lithologies: yellow – sandstone; grey – shale; blue – limestone; red – volcanic rocks.

This study follows the 4-systems tract nomenclature (Fig. 4; c.f. Catuneanu et al., 2011), which separates systems tracts into the highstand systems tract (HST; normal regression that follows a transgression); the falling-stage systems tract (FSST; forced regression); the lowstand systems tract (LST; normal regression that follows a forced regression); and the transgressive systems tract (TST). The sequence boundary selected for this study is the maximum flooding surface (MFS), which separates the underlying TST deposits from the overlying HST deposits (Fig. 4). This boundary was selected for the following reasons: it is readily identifiable through geochemical and sedimentological

trends; it reflects trends of basin accommodation and subsidence (Galloway, 1989); and it can be used reliably to define cyclicity in the study area.

Sequence stratigraphy in deep-water settings

Deep-water settings are complex depositional systems to model due to the interplay between multiple allogenic and autogenic processes active during deposition; the co-existence of multiple sediment sources into a basin; and the mode of sediment transport into the basin (turbidity flows vs. mass-transport deposits; Catuneanu, 2022). As a result, depositional systems

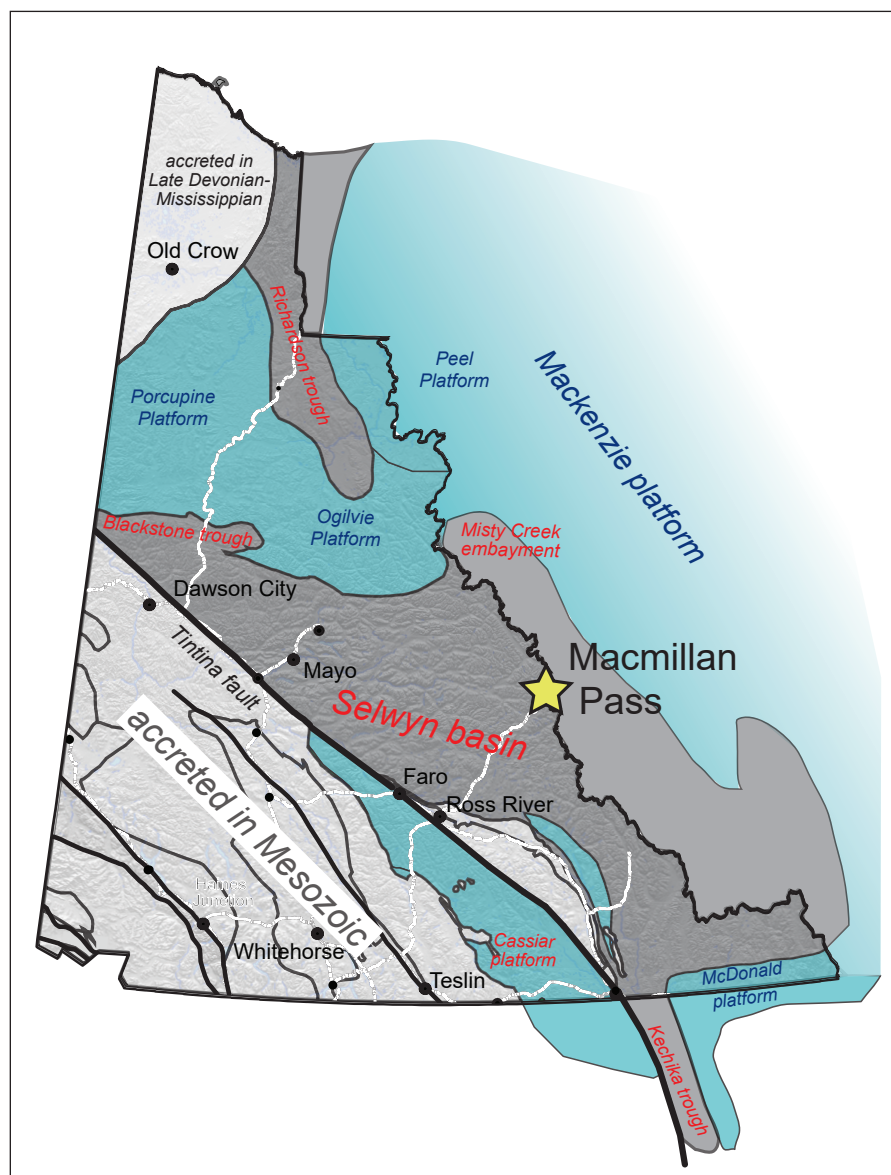


Figure 3. Distribution of platforms and basins (after Nelson et al., 2006).

may exhibit a high degree of variability along strike and down dip over a relatively short distance. In the absence of a sediment source, mud may accumulate in significant thicknesses through hemipelagic sedimentation, juxtaposing thick mudstone-dominated successions adjacent to sand-rich turbidites and mass transport deposits (Fig. 5).

Frameworks for the deep basin were developed initially for units that accumulated along a passive margin and were leveraged through the integration of 2D seismic datasets (Vail, 1987). In these models, turbidites can prograde significant distances into the deep basin and have well-developed lobe geometries

with levee complexes (Fig. 4). Much of the literature for the deep basin has focused on creating stratigraphic frameworks and facies models for mapping passive margin depositional systems (e.g., Vail et al., 1977; Vail, 1987; Galloway, 1989; Posamentier and Allan, 1999).

Sequence stratigraphy in extensional settings

Sedimentary basins that form in active tectonic settings typically have tectonism outpacing the influence of sea level changes on stratigraphic cyclicity (Catuneanu, 2022). The resulting stratigraphic architectures are typically asymmetrical sequences with distinct variability in the distribution of sedimentary successions. Basin margins typically display higher rates of subsidence, particularly in fault-bound basins, due to the increase in the level of tectonic activity (Catuneanu, 2022). Clinoforms that develop in these settings are typically confined to graben features, and therefore significant lobe features do not develop well into the basin. Instead, the frequent tectonism promotes the collapse of unstable slopes and leads to the development of ramps that redirect sedimentation patterns (Catuneanu, 2022).

Extensional basins generally are subject to rapid changes in sedimentation rates and variations in accommodation. This variability may lead to the suppression of certain systems tracts forming, complicating the creation of a stratigraphic framework. In extensional basins with horst and graben features, the reactivation of fault-bounded features can lead to episodic sedimentation (Catuneanu, 2022), which can impose higher-frequency sequences of deposition (e.g., mass transport deposits and turbidites) into topographic lows in the basin (Fig. 5). Following the rapid creation of accommodation, periods of tectonic quiescence allow for sedimentation to infill topographic lows through hemipelagic sedimentation or through the deposition of mud-dominated turbidites (Fig. 5).

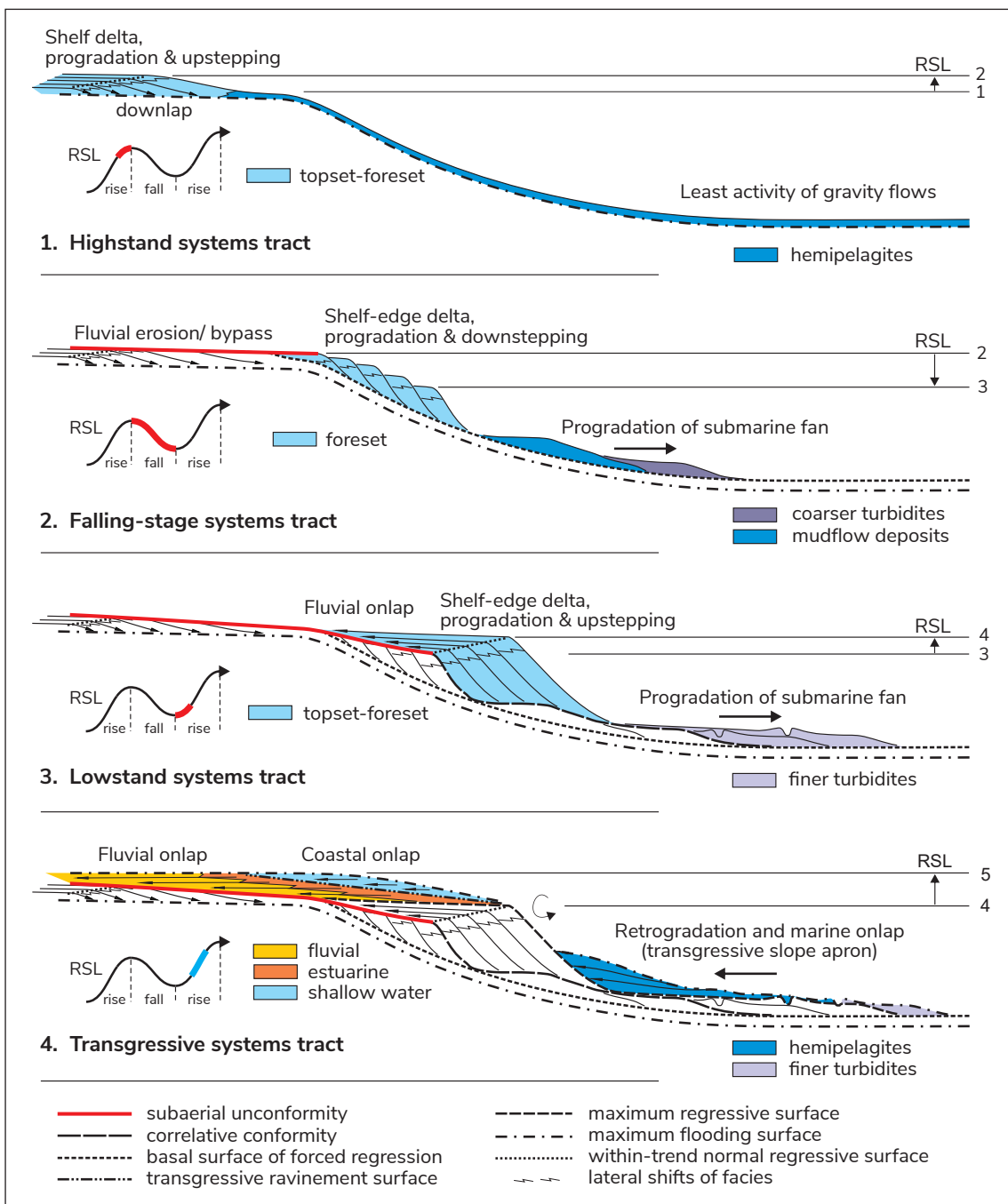


Figure 4. Trends of sedimentation patterns that occur in siliciclastic passive margin settings (from Catuneanu, 2022). Departures in the expected trends are the result of allogenic and autogenic controls that are active during deposition and affect the accommodation and sedimentation conditions of the basin. RSL – relative sea level.

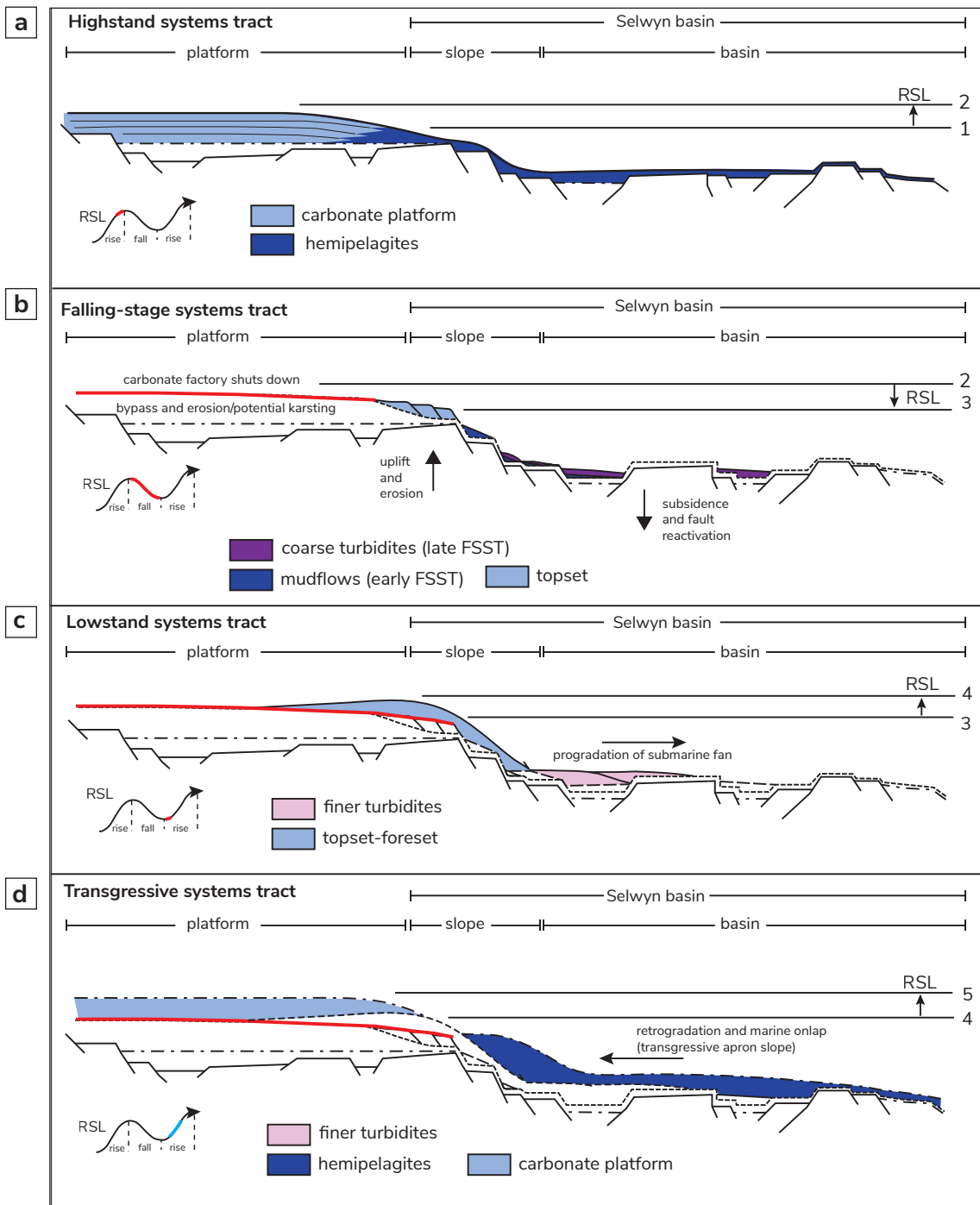


Figure 5. Fault-bound basin sequence stratigraphic model (RSL – relative sea level). Refer to Figure 4 for the legend of the sequence stratigraphic surfaces. **(a)** Highstand systems tract (HST). During the deposition of the HST, carbonate platforms build out in a basinward direction in relation to sedimentation outpacing the rise RSL. In the deep basin, hemipelagic sedimentation is the predominant depositional process that occurs. Turbidites may accumulate; however, most continentally derived material is being deposited along the continental shelf. **(b)** Falling-stage systems tract (FSST). During the FSST, an extensional event occurs that creates a fall in RSL, causing horst and graben features to form or become reactivated in the deep basin. In the continental realm, the carbonate factory shuts down with the fall in sea level; bypass and erosion occur along the shelf. Coarse-grained material is deposited along the shelf to slope transition as shorelines and deltas downstep away from the previous landward position. During early stages of FSST, the slope becomes destabilized, which may result in mudflows being deposited in the deep basin. During the late stages of FSST, the

coarse-grained turbidites form spill and fill patterns of sedimentation. The material is deposited in successive topographic lows until accommodation is filled and the material spills over to the next horst and graben feature. **(c)** Lowstand systems tract (LST). Following the drop in RSL, there is a rise which generates the deposition of the LST. This documents the farthest extent of deposition into the basin during this sequence of deposition. During this time, the continental slope builds in a basinward direction creating a wedge of material. In the deep basin, finer-grained turbidites infill the graben features, which results in localized deposition of sediment and atypical fan architecture. **(d)** Transgressive systems tract (TST). During the rise in RSL, hemipelagic sedimentation and the deposition of finer-grained turbidites occurs. In early TST, a healing-phase wedge may form in which hemipelagic sedimentation infills any remaining topographic lows in the region. With continued sea level rise, the slope may become destabilized, which results in slumps and mudflows of the slope into the deep basin. As sea level rises, deposition of the carbonate platform may resume. Note: figure is not to scale.

Systems tracts in extensional settings

During the deposition of the HST, paleoshorelines and shallow-water systems prograde, along with the aggradation of continental topsets. At this time, sedimentation outpaces the rise in relative sea level, generating normal regressive stacking patterns. Slopes prograde in carbonate settings (i.e., 'carbonate shedding'), but less so in siliciclastic settings, where sediment supply to deep water diminishes as a result of topset aggradation. In the deep basin, hemipelagic sedimentation is a predominant depositional process, resulting in thick mudstone-dominated units. Turbidites may accumulate as mudstone-dominated heterolithic units, as most of the coarse-grained continentally derived material is being retained within the continental realm. The HST deposits in the deep basin overlie the maximum flooding surface (MFS) and are typically overlain by the basal surface of forced regression (BSFR) that develops at the base of the FSST deposits.

The deposition of the FSST occurs during the drop in relative sea level. In extensional settings, relative sea-level changes are commonly driven by tectonism. In carbonate realms, the carbonate factory shuts down with progressive subaerial exposure which results in sediment bypass and erosion along the shelf, potentially associated with karst features. In siliciclastic settings, coarse-grained material commonly bypasses the shelf as shorelines and deltas prograde and downstep toward the shelf edge. During early stages of FSST, mudflows and slumps are typically dominant in the deep basin, whereas late stages of FSST are conducive to coarser gravity flows such as turbidity currents and grainflows. The coarse-grained material is deposited in successive topographic lows down the slope until accommodation is filled and the material spills over to the next graben feature. Turbidite units that are deposited during the FSST may not have well-developed fan architectures and may be restricted to local depocenters such as half grabens. The FSST deposits overlie the BSFR and are overlain by a correlative conformity (CC), if an LST develops, or by a maximum regressive surface (MRS). The BSFR is identifiable as an erosional surface at the base of mudflow deposits or slumps, marking a stark change in the sedimentation patterns (Catuneanu, 2022). The CC in deep water is typically marked by a sharp decrease in grain size from the coarser FSST sediments below to the finer LST sediments above, due to the retention of coarser sediments on the shelf within the LST topset. In contrast, the MRS is more cryptic, within a gradational trend of decrease in the sediment grain size from LST into the TST (Catuneanu, 2022).

The subsequent rise in relative sea level leads to the deposition of the LST if the rates of sedimentation exceed the rates of relative sea-level rise at the shoreline. This documents the farthest extent of deposition into the basin during this sequence of deposition and likely reflects tectonic quiescence. During this time, the continental slope progrades, creating a 'lowstand wedge' of sediment clinofolds along the slope. In the deep basin, finer-grained turbidites infill the graben features, which results in localized deposition of sediment and atypical fan architecture. It is noted though that a significant development of the LST may be impeded by the rapid increase in accommodation that may accompany the reactivation of faults in extensional settings, making the development and/or identification of this systems tract challenging. The LST deposits overlie the CC, which are subsequently overlain by the MRS.

When the rise in relative sea level outpaces the rates of sedimentation at the shoreline, the deposition of the TST is initiated. During the rise in relative sea level, hemipelagic sedimentation and the deposition of finer grained turbidites occurs. During TST, a healing-phase wedge may form in which hemipelagic sedimentation infills any remaining topographic lows in the region. With continued sea level rise, the slope may become destabilized, which results in slumps and mudflows into the deep basin. A MFS overlies the TST and is often preserved as a cryptic gradational contact within a potentially condensed section.

Geochemistry

X-ray fluorescence (XRF) has proven to be a valuable tool when mapping sequences stratigraphically in mudstone-dominated successions (Sano et al., 2013; LaGrange et al., 2020; 2025; Harris et al., 2021). Commonly, these successions display subtle variabilities in their composition, lithology and sedimentology that is observable on a microscopic scale, or less commonly, a macroscopic scale. To accurately assess the subtle variabilities of mudstone in deep basins, geochemical analyses are becoming a common tool used to delineate changes in mudstone-dominated successions through whole rock geochemistry, x-ray fluorescence, x-ray diffraction (XRD), or total organic carbon (TOC). The geochemical dataset that is collected from mudstone-dominated intervals can be used to calculate proxies for terrestrial input, carbonate content in relation to distance from the continental shelf, grain size, marine anoxia, and basin restriction (LaGrange et al., 2020, 2025; Fraser et al., 2021).

Methods

Core logging

At Macmillan Pass, four cores were logged in July and August 2024 (Fig., 1; Table 1). Cores were selected based on vintage (younger than 2017 drilling programs), availability, length, as well as intersections including intervals of interest. One core was selected from each deposit in order to demonstrate the abrupt along-strike variations in sedimentation patterns that occur in the region. Core was logged onsite at the Tom property where the material is stored.

X-ray fluorescence (XRF) study

Results for the XRF study on the core from Macmillan Pass were completed in December 2024. In this study, 625 samples were collected from four cored intervals at a 2 m spacing and sent to Spectrum Geosciences Ltd. for analysis. The raw dataset for these cores is provided in Appendix A.

Samples were prepped for analysis by lightly washing the area before analysis to remove dust, mud or debris that could potentially influence the measurements. The sample points were collected using a portable XRF Bruker Tracer 5g model that is placed directly on the core surface. At the start of each analysis day, the XRF device analyzed a check standard to ensure all instrumentation was operating correctly. The data was quality checked and calibrated upon the completion of analysis of each core.

Samples were placed directly on the XRF analyzer window and were run using a 40 kV high-energy beam for 20 seconds to detect heavier elements, and with a 15 kV low-energy beam for 20 seconds to detect light elements. Samples in this study were run under air instead of vacuum purge or helium. This was done to increase accuracy for lighter elements such as silica (Si) and aluminum (Al). The drawback of running the sample under air is a lower detection value for sodium (Na; ~5% error margin).

Facies that contained conglomerate, breccia or significant mineralization were avoided in the sampling process. The clasts of the conglomerate contain reworked clasts in a mudstone to sandstone matrix. Given that each conglomerate facies is variable across the property, it was decided that the conglomerate would be excluded. Additionally, the mineralization was not sampled to avoid flooding the XRF results with an enrichment in iron (Fe), lead (Pb) and zinc (Zn) values.

Proxies

The geochemical data used in this study builds upon the work that was previously started at the Yukon Geological Survey by Fraser et al. (2021). In that study, values for terrigenous input, carbonate content and enrichment factors were calculated from whole-rock geochemistry from three cores at the Tom deposit. In this study, we also include a spectral gamma ray log. Additional proxies for basin restriction, anoxia, flooding surface markers and grain size will be calculated in subsequent studies once a larger dataset can be

Table 1. Summary of the core data analyzed in 2024.

Location	Hole #	Deposit	Location (Lat, Long)	Interval	Stratigraphic units	
					Formation	Members
Macmillan Pass	NB23-001	Boundary	63.214955°, -130.545624°	12–460 m	Portrait Lake	Fuller Lake, Macmillan Pass, Niddery Lake
					Sapper	Macmillan Pass volcanics
Macmillan Pass	TS18-103	Tom	63.160225°, -130.143376°	39–368 m	Portrait Lake	Fuller Lake, Macmillan Pass
Macmillan Pass	MP20-001	Jason South	63.151897°, -130.216625°	18–632 m	Portrait Lake	Fuller Lake, Macmillan Pass, Niddery Lake
Macmillan Pass	JS17-002	Jason	63.146910°, -130.252275°	9–197 m	Portrait Lake	Macmillan Pass

collected from the property to more accurately assess their utility as a correlation marker. The proxy trends are summarized in Table 2.

Terrigenous input (TIP)

The values for terrigenous input are calculated by the sum of weight percent oxides of Al_2O_3 , TiO_2 , Fe_2O_3 , and K_2O (Ratcliffe et al., 2012). The calculated value is then plotted with the TiO_2 values to determine if the titanium is shelf-derived (e.g., rutile). If the values are determined to be terrestrially derived, an increase in the TIP (%) would relate to a change in the point source of deposition, which could reflect closer proximity of basinal deposition to the continental shelf. A decrease in this value could indicate that the distance away from shelf-derived material is increasing, which is expected during transgressive phases.

Carbonate content CaO (wt%) and MgO (wt%)

The carbonate content proxy is used to indicate the proximity to a carbonate sediment source. The farther distance from the continental shelf (i.e., carbonate source), the lower the values in CaO and MgO will be. These values increase when the units were deposited closer to the shelf.

Enrichment factor of molybdenum and vanadium

The enrichment values in elements like molybdenum and vanadium have typically been used to estimate redox conditions of bottom waters and have been used as a proxy for total organic carbon (TOC; Tribovillard et al., 2006). The enrichment factor for elements is calculated by normalizing the aluminum in the sample to the aluminum value calculated for the average shale (values provided in Tribovillard et al., 2006). This may

be used as a proxy to estimate basin restriction at the time of deposition.

Spectral gamma ray log

A spectral gamma ray log is calculated from the XRF values to reflect fluctuations in lithology and to be used in stratigraphic correlations. Sedimentary rocks, and in particular shale, have distinct radioactive signatures that allows for the differentiation of lithological units. The gamma ray (GR) value is calculated as follows: $GR = 8(U_{ppm}) + 4(Th_{ppm}) + 16(K_2O_{\%})$. Low values of gamma ray indicate a sandier or siltier deposit. High values of gamma ray generally indicate a muddier or shalier deposit.

Organic carbon isotopes ($\delta^{13}C$)

Organic carbon isotopes are used in this study as potential marker horizons that can be correlated on a basin-wide or a global scale. The ratio of $^{13}C/^{12}C$ in oceans has fluctuated throughout time and significant markers that record negative and positive excursions of the isotope values are well documented in the rock record (Saltzman and Thomas, 2012). This study aims to use this marker on a local scale to add a broad chronostratigraphic component to the stratigraphic sections.

Select samples from the MP20-001 and NB23-001 cores were sent for organic carbon isotopes at the Saskatchewan Isotope Laboratory at the University of Saskatchewan. Samples were initially run at a 10 m interval spacing to determine if this type of analysis would be useful in creating local stratigraphic correlations. The first run was successful, and the remaining samples collected from MP20-001 and NB23-001 have been sent to infill the stratigraphic spacing to a 2 m interval.

Table 2. Proxy indicators for the x-ray fluorescence (XRF) study.

Proxy indicator	Trends in transgression	Trends in regression
CaO and MgO (wt%)	Decrease in values. Reflects a further distance away from the shelf and slope.	Increase in values. Reflects proximity to the continental shelf and slope.
Terrigenous input (TIP) $TIP = Al_2O_3 + TiO_2 + K_2O + Na_2O$	Lower values indicate less input from terrigenous sources. Titanium is heavier and less likely to travel far distances into the basin.	Higher values indicate more input from terrigenous sources.
Molybdenum enrichment (ppm) and vanadium enrichment (ppm)	Can become enriched in euxinic, anoxic or suboxic environments. Values possibly higher.	Values possibly lower in regressive packages that may reflect deposition in suboxic to oxic settings.

Results

Facies and depositional processes

Facies have been documented and described from the cores that were logged in summer 2024. These descriptions are preliminary and will evolve when additional data is collected at the property. At present, 14 facies have been described and have been assigned to their corresponding depositional environments. The depositional environments have been grouped into the predominant depositional process that was active during deposition, which includes hemipelagic sedimentation, as well as turbidites and mass transport deposits. The facies are summarized in Figure 6 and Table 3.

XRF sequence stratigraphic surface classification

The geochemistry from the XRF study can be used to identify systems tracts and stratigraphic horizons. Additional data collected for this study in subsequent field seasons will follow and expand upon this identification criteria.

Maximum flooding surface (MFS)

The maximum flooding surface separates the underlying TST deposits from the overlying regressive deposits. The MFS is marked by the maximum decrease in the TIP values, a gradual increase in TOC above the surface, and the maximum decrease in carbonate



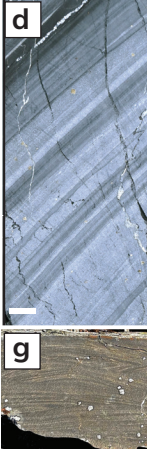
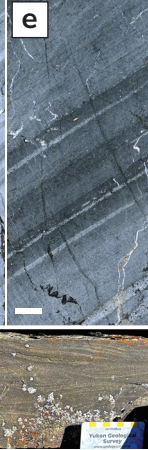



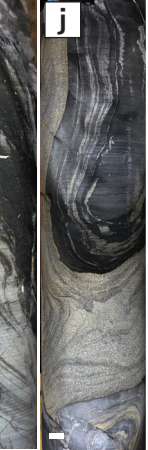
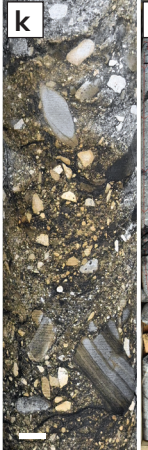

hemipelagic sedimentation		turbidites			mass transport deposits				
									
basinal plain		high-density turbidite	low-density turbidite		mudflow	slump		grainflow	
Characteristics: Mudstone-dominated succession that contains chert-rich intervals. Radiolarians are common. Deposition by suspension settling occurs in all 4 systems tracts.		Characteristics: Sand-dominated heterolithic deposit. Usually displays an overall coarsening upwards sequence. Normally graded beds are common.	Characteristics: Mud-dominated heterolithic deposit. Usually displays an overall coarsening upwards sequence. Normally graded beds are common.		Characteristics: Matrix-supported conglomerate succession that contains chert clasts. The matrix ranges from mudstone to sandstone-dominated.	Characteristics: Matrix-supported conglomerate succession that contains chert clasts. The matrix ranges from mudstone to sandstone-dominated.		Characteristics: Sandstone-dominated succession that contains matrix and clast-supported conglomerate. Clasts are variable in lithology.	
Systems tracts: FSST, LST, TST, HST		Systems tracts: FSST (late), LST	Systems tracts: LST, TST, HST		Systems tracts: FSST (early), TST (late)	Systems tracts: FSST, LST, TST		Systems tracts: FSST (late), LST	
Photos: a, b, c		Photos: d, g	Photos: e, f		Photos: h	Photos: i, j		Photos: k, l	

Figure 6. Facies associations from core in the region. (a–c) Hemipelagic sedimentation containing radiolarians (rad), barite nodules (ba), and pyrite (py), which are common in this interval ([a] – MP20-001 at 409.6 m; [b] – MP20-001 at 135.8 m; [c] – MP20-001 at 322.5 m; scale bar is 1 cm in each photo). (d–g) Turbidite deposits that are heterolithic. Finer grained expressions of turbidites are found in (d)–(f) and show variable proportions of sandstone to mudstone. Current ripple lamination in photo (g) is from outcrop of the Prevost Formation where sandier expressions of turbidite deposition are preserved ([d] – NB23-001 at 366.45 m; [e] – NB23-001 at 349.7 m; [f] – NB23-001 box 88). In (d) and (e) the scale bar is 1 cm and in (f) the length of the core box is 1 m. (h) Mudflow from the Fuller Lake member that has re-entrained larger clasts and sandier debris (MP20-001 at 394.7 m; scale bar is 1 cm). (i–j) Slump deposits from the Macmillan Pass member. Soft-sediment deformation is common in these deposits indicating that the remobilization of sediment occurred before the unit was fully lithified ([i] – TS18-013 at 76 m; [j] – TS18-013 at 250.6 m; scale bar is 1 cm). (k–l) Conglomerate that formed from grainflows. Clasts are composed of ripped-up turbidite material and chert-rich pebbles. ([k] – JS17-002 at 87.3 m; [l] – TS18-013 box 50 from 162 to 165.4 m). In (k) the scale bar is 1 cm and in (l) the length of the core box is 1 m.

Table 3. Initial summary descriptions of the facies associations and corresponding facies from core. BI – bioturbation index; vfgL – very fine grained lower; fgL – fine grained lower; mgL – medium grained lower; mgU – medium grained upper; vcgU – very coarse grained upper.

Depositional process	Facies	Sedimentology	Accessories / diagenesis	Trace fossils / fossils	Depositional environment
hemipelagic sedimentation	1 – carbonaceous mudstone/shale	<ul style="list-style-type: none"> planar parallel lamination to apparently massive bedding 	<ul style="list-style-type: none"> disseminated pyrite 	not observed	basinal plain
	2 – cherty mudstone/shale with interlaminated siltstone	<ul style="list-style-type: none"> weakly developed normally graded beds ranging from siltstone to mudstone planar parallel lamination to apparently massive bedding chert-rich intervals punctuated by interlaminated siltstone 	<ul style="list-style-type: none"> disseminated pyrite clay content may be high brecciation common in areas adjacent to faults 	<ul style="list-style-type: none"> radiolarians (can be locally replaced by pyrite) 	basinal plain
	3 – carbonaceous to cherty mudstone/shale	<ul style="list-style-type: none"> planar parallel lamination to apparently massive bedding 	<ul style="list-style-type: none"> disseminated pyrite (may concentrate on bedding planes) 	<ul style="list-style-type: none"> radiolarians (can be locally replaced by pyrite) 	basinal plain
turbidites	4 – pinstripe laminated mudstone/siltstone/sandstone with starved current ripple lamination	<ul style="list-style-type: none"> normally graded beds from laminated/bedded vfgL – fgL sandstone to mudstone starved current ripple lamination (less than 1 cm in crest height – lenticular bedding?) 	<ul style="list-style-type: none"> ankerite, siderite, quartz veins and sphalerite mineralization 	not observed	low-density turbidite
	5 – mudstone-dominated heterolithic with normally graded beds	<ul style="list-style-type: none"> normally graded beds from sandstone (vfgU – fgL) to mudstone current ripple-laminated beds range in thickness from 2 to 5 cm planar parallel lamination and apparently massive bedding in the mudstone and sandstone beds 	<ul style="list-style-type: none"> ankerite, siderite, and sphalerite mineralization brecciation common in areas adjacent to faults 	<ul style="list-style-type: none"> Planolites (uncommon) BI = 0; locally may be as high as 1 	low-density turbidite
	6 – heterolithic mudstone/sandstone with granules	<ul style="list-style-type: none"> heterolithic beds of sandstone (fgL – granule) interbedded with silty mudstone beds sandstone beds range in thickness from 10–25 cm and form bedsets that are >1 m mudstone interbeds are <20 cm thick 	<ul style="list-style-type: none"> ankerite, siderite, and sphalerite mineralization 	not observed	high-density turbidite
	7 – sandstone-dominated heterolithic with current ripple lamination	<ul style="list-style-type: none"> normally graded beds from sandstone (mgL – fgL) to siltstone current ripple lamination, low-angle planar parallel lamination and planar parallel lamination soft-sediment deformation 	<ul style="list-style-type: none"> carbonaceous debris mudstone interbeds may be mineralized 	not observed	high-density turbidite
	8 – apparently massive sandstone	<ul style="list-style-type: none"> apparently massive bedding in coarser sandstone beds (granule – mgU) 	<ul style="list-style-type: none"> rip-up clasts of mudstone 	not observed	channel complex
	9 – conglomerate with weakly developed imbrication	<ul style="list-style-type: none"> granule to clast-sized conglomerate fining upwards clasts may show subtle imbrication 	<ul style="list-style-type: none"> not observed 	not observed	channel complex
mass transport complex	10 – poorly sorted, clast-supported conglomerate	<ul style="list-style-type: none"> poorly sorted conglomerate (clasts are granule to clast-sized) matrix ranges from siltstone to sandstone (fgL – vcgU) appears structureless to massive clasts are subangular with low to moderate sphericity clasts are primarily chert 	<ul style="list-style-type: none"> matrix and clasts may be mineralized (pyrite, ankerite) 	not observed	grainflow
	11 – poorly sorted, matrix-supported conglomerate	<ul style="list-style-type: none"> poorly sorted conglomerate (clasts are granule to clast-sized) matrix ranges from mudstone to sandstone (vfgL – vcgU) clasts may be rip-up clasts of the turbidite facies (clasts retain original sedimentary fabric) 	<ul style="list-style-type: none"> matrix and clasts may be mineralized (pyrite, ankerite) 	not observed	grainflow
	12 – poorly sorted, matrix-supported conglomerate	<ul style="list-style-type: none"> mudstone to siltstone matrix larger granules and clasts are distributed randomly throughout clasts tend to be angular and chert-rich 	<ul style="list-style-type: none"> disseminated pyrite 	not observed	mudflow
	13 – syn-sedimentary deformed heterolithic mudstone	<ul style="list-style-type: none"> soft-sediment deformation, syn-sedimentary faulting, convolute bedding commonly are slumped deposits of the turbidite facies association 	<ul style="list-style-type: none"> disseminated pyrite, sandstone injectites 	not observed	slump
	14 – syn-sedimentary deformed mudstone	<ul style="list-style-type: none"> pyritized beds are deformed and may be inclined or overturned mudstone matrix (may be chert-rich) 	<ul style="list-style-type: none"> pyrite nodules, sandstone injectites 	not observed	slump

content. Above this horizon, the values in TIP, carbonate content and TOC increase. Additionally, the surface may be delineated by low values of the spectral gamma ray log (e.g., Fig. 7 at 260 m). Higher-frequency examples of the MFS follow similar geochemical trends.

Maximum regressive surface (MRS)

The maximum regressive surface separates the underlying regressive units from the overlying TST deposits. At this surface, there is an abrupt decrease in the TIP values, a decrease in the TOC above the surface, and an abrupt decrease in the carbonate content (e.g., Fig. 7 at 315 m). Below this surface, the values for TIP and carbonate content are generally high. The surface generally occurs within the fining-upward trends.

XRF geochemistry of systems tracts

Transgressive systems tract

The TST is marked by an overall decreasing trend in the TIP values, carbonate content and TOC values. In this study, the TST generally had TIP values that averaged around 10%, and carbonate content that averaged 2% MgO and 5% CaO. The TST trend generally indicates an overall decline in the terrigenous elements being delivered to the system.

Regressive systems tracts

This summary does not distinguish between which type of regression the mudstone units accumulated in, and it is noted that the mudstone accumulates in the HST, FSST and LST. The regressive systems tracts (HST, LST or FSST) are marked by an overall increasing trend in the TIP values, carbonate content and TOC values. Low values or declining trends for the enrichment of molybdenum (Mo) and vanadium (V) are observed in the deposits that accumulated in regression, which could indicate variable levels of redox that persisted throughout the deposition of the units.

X-ray fluorescence and organic carbon isotopes trends from core

Core NB23-001

The NB23-001 core contained syn and post-depositional mineralization throughout the mudstone-dominated successions and within the lobes of turbidites for the Niddery Lake and Macmillan Pass

members (Figs. 6 and 7). Values for Pb, Zn and barium (Ba) are considerably higher in this core than the others that were analyzed for this study. In zones where these elements peak, the enrichment values for Mo and V also peak, which could indicate euxinic or reducing conditions occurring syn-depositionally. The calculated spectral gamma ray values were significantly higher in this core when compared to core that contained a lesser degree of mineralization. High values for the spectral gamma are coincident with zones where Mo and V enrichment spiked. It is possible that mineralization is skewing values for this calculation through the enrichment of uranium (U).

Between 375 to 425 m there is a transgressive systems tract preserved. Associated with this TST are high values for Zn and the enrichment factors of Mo and V. The TIP shows an overall decreasing trend, while the carbonate content is low. This zone of hemipelagic sedimentation is associated with syn and post-depositional mineralization. Although care was taken to avoid heavily mineralized zones, it is possible that the enrichment of the Zn, Pb and Ba is flooding the results of the XRF.

Overlying the mineralized zone of the Niddery Lake member (from 240 to 375 m) is a mudstone-dominated package of sediment that was deposited during a low-frequency regression. Higher-frequency sequences of transgression and regression are denoted by the fluctuating values for carbonate content, TIP and TOC. A low-density turbidite is observed from 320 to 375 m, and hemipelagic sedimentation or very distal extents of turbidite deposition are observed from 240 to 320 m.

From 6 to 240 m, grainflows and slumps are observed in core. Samples were taken from the mudstone-dominated intervals of the grainflows to incorporate some geochemical data into these sections. The grainflows, turbidites and slumps are characterized by high TIP values, but low values for TOC and carbonate content. Molybdenum and V are enriched in mineralized zones, which correspond to high values for Pb, Ba and Zn. This regressive package of sediment overlies a BSFR, which is distinguishable through sedimentological features that places coarse-grained, matrix-supported conglomerate erosively over top of mudstone-dominated units.

The $\delta^{13}\text{C}$ values range from -32 to -24‰, and two positive excursions of the isotopes occur at 450 and 310 m. The excursion at 310 m is coincident with the increase in terrigenous input. By tightening the interval spacing of samples that were sent for analysis, it is

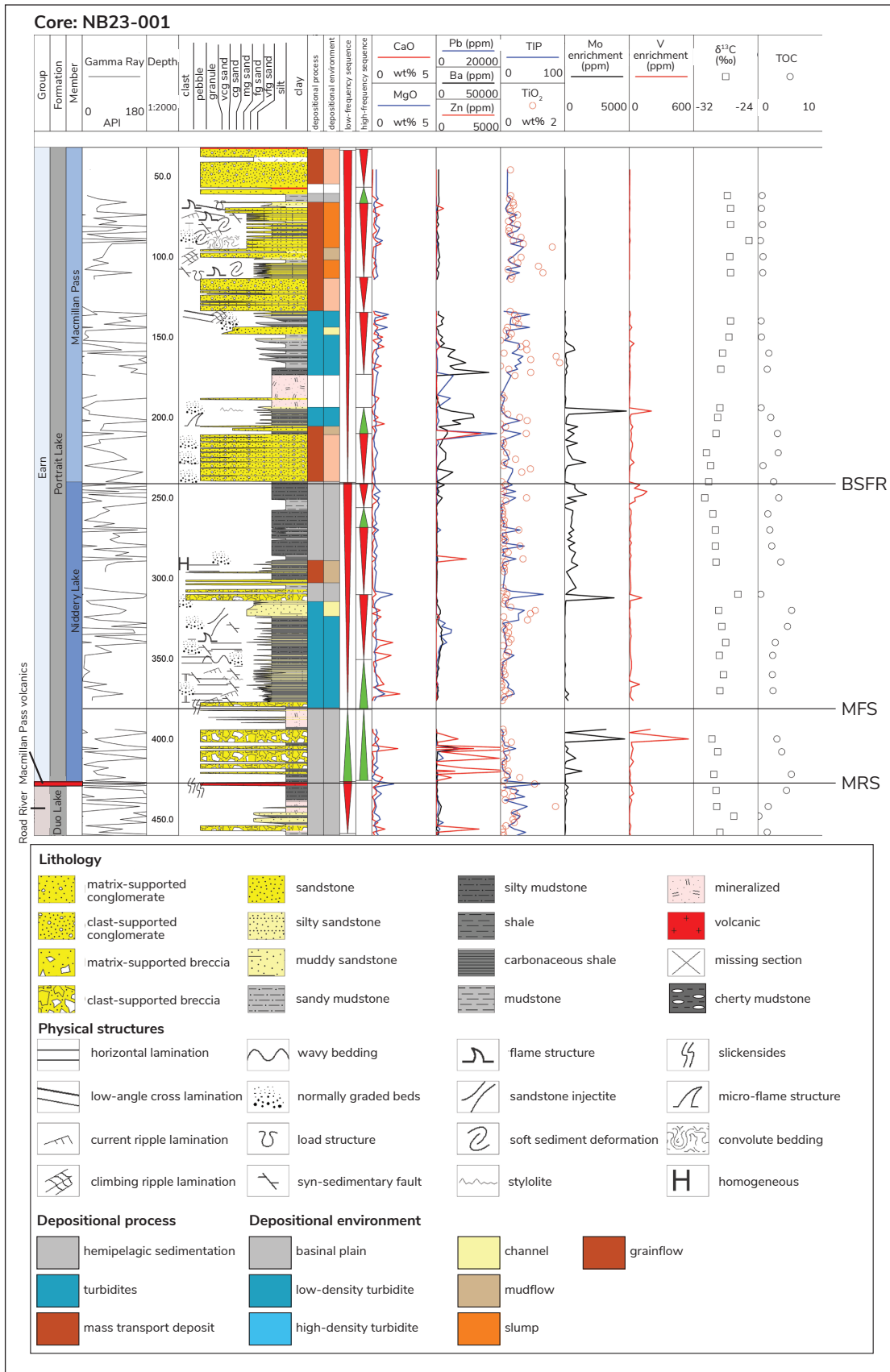


Figure 7. Core log for NB23-001 and select geochemical proxies. For low and high-frequency sequences, red colour represents regression and green represents transgression.

possible that the results may establish variations in the isotope fluctuations, which can be better tied to relative sea level trends.

Total organic carbon (TOC) fluctuates in relation to the mineralization and enrichment of Mo and V. The correlation between TOC and the enrichment factors appears to be a crude match. The incorporation of the additional carbon isotopes and TOC values with this core will increase the certainty of how TOC and the enrichment factors can be used to infer euxinic events.

Core JS17-002

The core from JS17-002 predominantly intersects a mass transport complex (Fig. 8). Samples were not taken in conglomerate intervals and large sections of the core have data gaps as a result. The slump features document higher values of terrigenous input (e.g., Fig 8 from 90 to 130 m), indicating that the material that forms the slumps had a higher degree of continentally derived material.

Core MP20-001

The MP20-001 core preserves a thick mudstone-dominated package of strata that accumulated by hemipelagic sedimentation or by the distal extent of

turbidite progradation (Fig. 9). Hemipelagic sediments that accumulated during transgression tend to have lower values for CaO (wt%) and MgO (wt%), reflecting their increased distance away from the continental shelf. Additionally, lower values of TiO₂ and Zr (ppm) can be used as a proxy for the distance a deposit is from the shelf. Both elements are more dense and less likely to travel significant distances from the shelf or slope. Regressive packages of hemipelagic sedimentation tend to have higher values for CaO, MgO, TiO₂ and Zr. The increase in these oxides and elements reflect that the deposits are in closer proximity to the shelf and slope leading to an increase in terrestrial input.

The lower package of mudstone from 480 to 632 m is interpreted to have been deposited as a low-density turbidite that accumulated during an overall low-frequency regression (Fig. 9). The section contains a higher TIP value, higher carbonate content and higher TOC values. The Mo and V enrichment values generally show a decreasing trend. This section of regressive mudstone is marked by a decrease in carbonate content and TIP and this is inferred to be a MRS that is documented at 505 m. A slight negative excursion of the δ¹³C isotope occurs over this horizon.

Hemipelagic sedimentation occurs above this marker between 410 to 505 m (Fig. 9). This package of

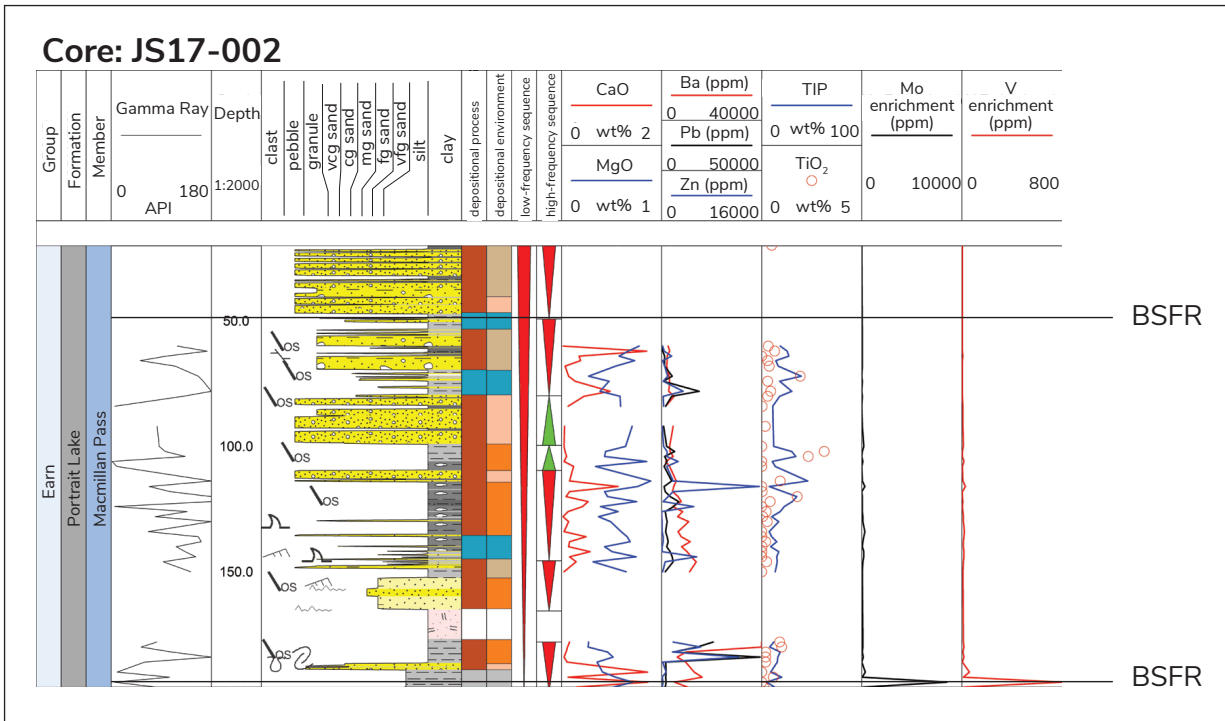


Figure 8. Core log for JS17-002 and select geochemical proxies. Refer to Figure 7 for the legend. For low and high-frequency sequences, red colour represents regression and green represents transgression.

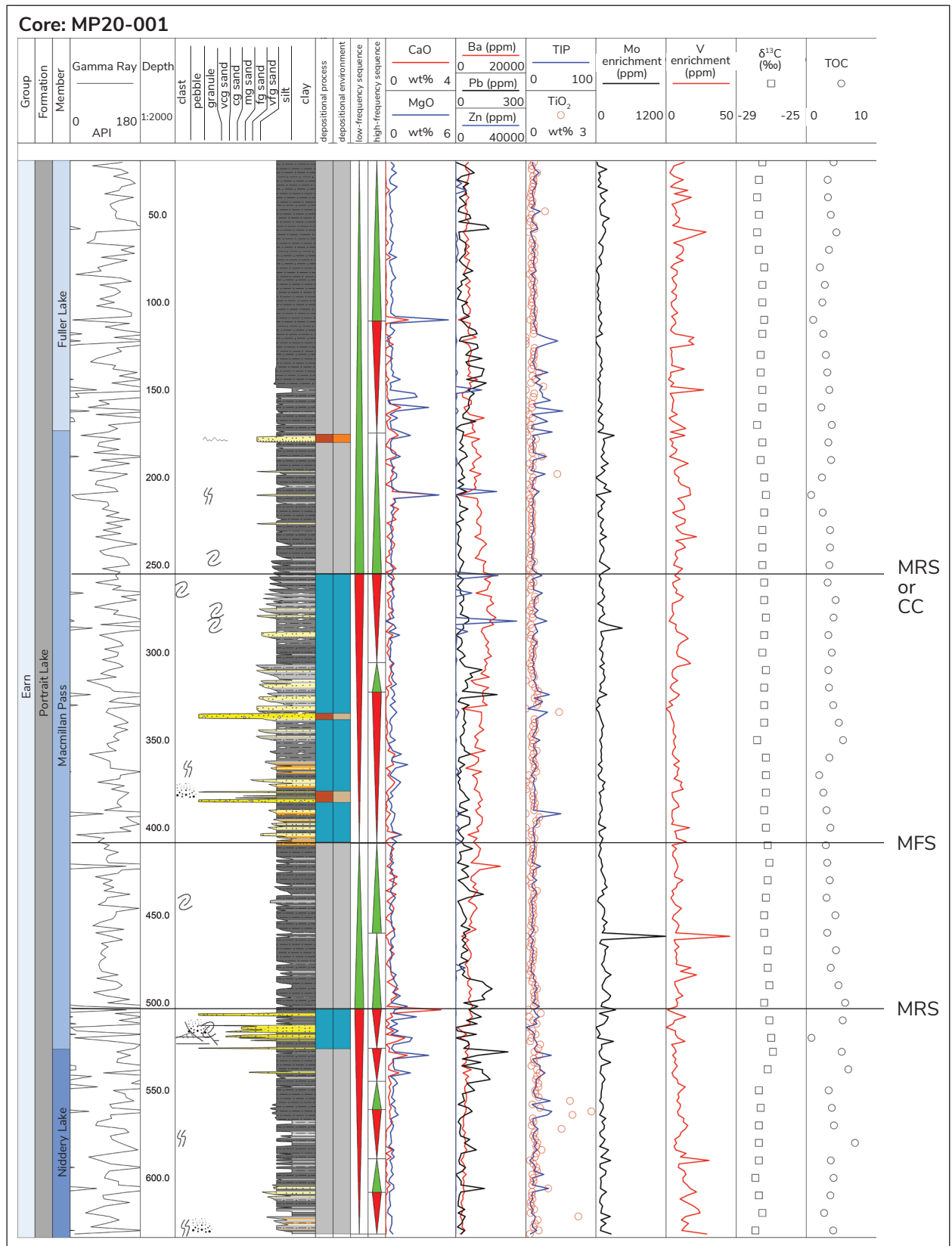


Figure 9. Core log for MP20-001 and select geochemical proxies. Refer to Figure 7 for the legend. For low and high-frequency sequences, red colour represents regression and green represents transgression.

sediment is characterized by low carbonate content, low TIP values and an overall decline in the TOC values. The unit is marked by a MFS, which includes the subtle increase in carbonate content, TIP and TOC values directly over the horizon. Within this package of mudstone, there are two lower-frequency transgressive systems tracts identified. The lower-frequency MFS is preserved at 460 m where there is a prominent spike in the enrichment of Mo and V.

A low-density turbidite is preserved from 260 to 410 m (Fig. 9). Within this unit there are two thin grainflow deposits that punctuate the turbidite deposition. This unit was deposited during an overall regression and is characterized by higher TIP values, variable carbonate content and high TOC values. The enrichment of V and Mo is low throughout this package of sediment. There are higher-frequency cycles of transgression and regression preserved in this section, which is reflected by the variable TIP and TOC signatures. This unit is overlain by a MRS or CC which is preserved as a significant change in the Pb, Zn and Ba trends over the contact and is coincident with a decrease in the TIP and TOC.

From the top of the core to 260 m a mudstone-dominated unit that accumulated through hemipelagic sedimentation is preserved. This unit is interpreted to have been deposited during a low-frequency transgressive event that contains higher-frequency regressive and transgressive packages. This succession displays overall lower TOC values, low TIP values and low carbonate content.

The $\delta^{13}\text{C}$ values range from -28 to -26‰ and display a lesser degree of positive or negative excursions of the carbon isotope. As the data points are separated at this time by a 10 m gap, it is possible that the current efforts to infill between points will demonstrate more variability of the isotopes over major stratigraphic horizons.

Core TS18-013

The Macmillan Pass member preserves low-density turbidites, slumps and grainflow features. The low-density turbidite facies occur between 330 to 375 m and 80 to 125 m (Fig. 10). The terrigenous input values for the turbidites are generally high, however the corresponding CaO and MgO values are low. These lower values could be due to diagenesis and alteration of carbonate material.

Slump features in this core tend to be rotational blocks of low-density turbidites that preserve internal deformation. The tops of slumps are invariably marked by abrupt changes in the terrigenous input proxy at 280 m, 225 m and 75 m. Values for terrigenous input abruptly drop at 65 m. This coincides with the transition from the deposition of the low-density turbidites of the Macmillan Pass member to the deposition of hemipelagic sedimentation of the overlying Fuller Lake member.

Discussion

Depositional processes

Facies described from core have been assigned to their corresponding depositional processes (Fig. 6; Table 3). The highest abundance of coarser grained sediment being transported to deep-water settings generally occurs during the falling-stage and lowstand systems tracts when a coarse sediment source would be available near the shelf edge (Fig. 5). Sedimentologically, identifying systems tracts in the coarser-grained units tends to be more straightforward when tying depositional trends to fluctuations in relative sea level. Where sediment deposition becomes finer-grained, these trends are more challenging to identify without the use of thin sections, downhole geophysical datasets, or XRF.

Depositional process 1: hemipelagic sedimentation

Hemipelagic sedimentation occurs within all four systems tracts. The input varies between terrigenous and biogenic, and sediment consists of clay and less commonly, silt-sized grains. In these deposits, sequence stratigraphic surfaces are gradational and cannot be identified using sedimentology alone. Commonly, these deposits contain radiolarians that may have been pyritized following their deposition.

The maximum flooding surface (MFS) and maximum regressive surface (MRS) separate out transgressive from regressive deposits. Within regressive packages, subtle increases in the CaO, MgO and terrigenous input values indicate a more proximal position to the shelf, which would likely occur during HST, LST or FSST. The MRS generally occurs within the fining upward trends in sedimentation and this is marked by the decrease in TIP and carbonate content (Figs. 7–10).

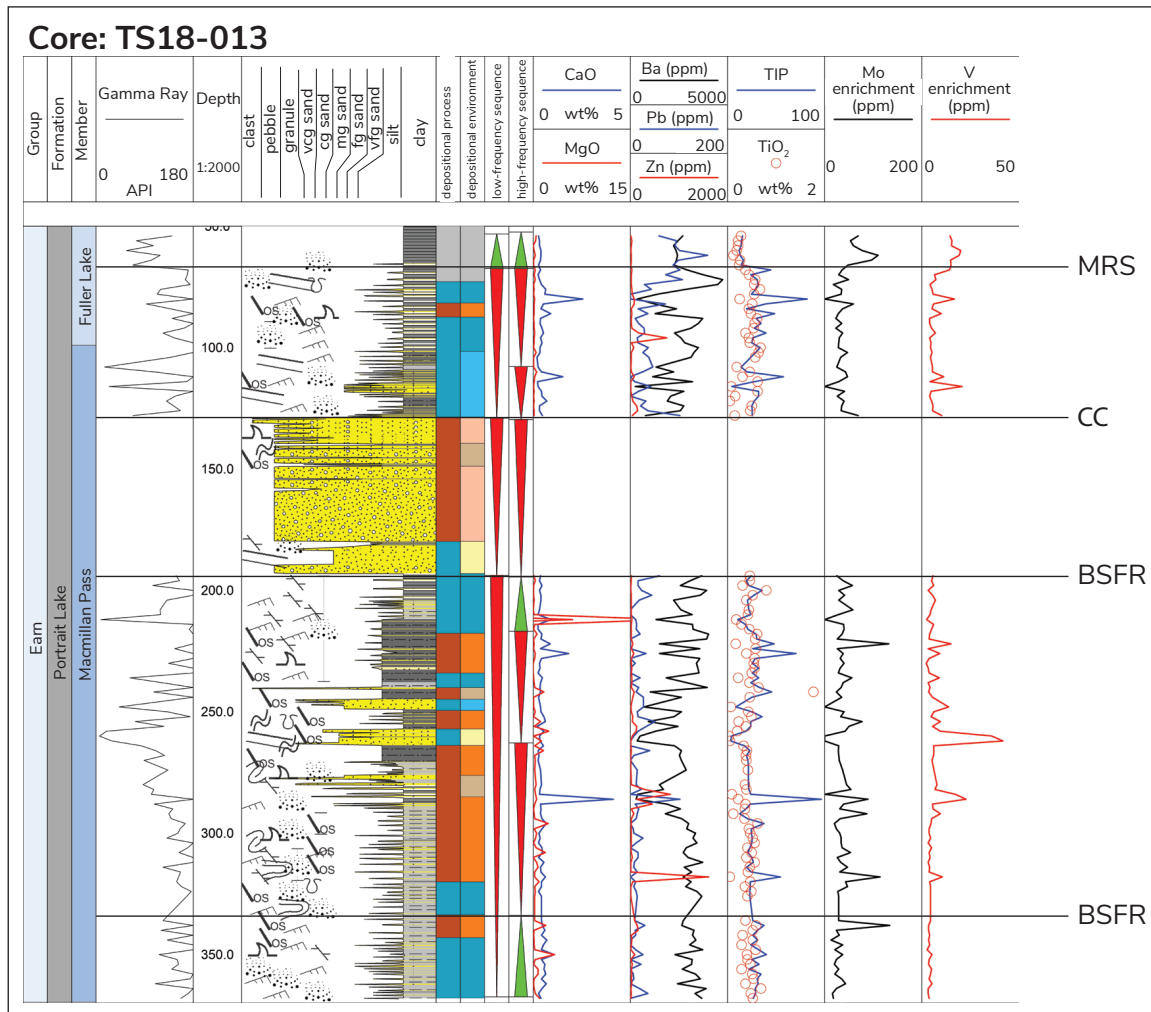


Figure 10. Core log for TS18-013 and select geochemical proxies. Refer to Figure 7 for the legend. For low and high-frequency sequences, red colour represents regression and green represents transgression.

Depositional process 2: turbidites

Turbidites form from gravity-driven turbidity currents in which sediment is supported from fluid turbulence and deposition is occurring through suspension settling (Dott Jr., 1963). Turbidites may form along the continental shelf, slope or deep basin.

The turbidites in this study have been classified as either belonging to high-density turbidites (sand-rich) or low-density turbidites (mud-rich). Although this classification is a broad grouping, it helps delineate the systems tracts that the turbidites may have accumulated in. High-density turbidites likely accumulated in the late FSST or LST due to an increase of coarse material accumulating near the shelf-edge margin and being redeposited in the deep basin. The low-density turbidites likely accumulated during late LST, early TST, or HST. In late LST and early TST, coarse

material is no longer being delivered to the continental shelf, causing turbidites to become finer grained. In HST, much of the coarse material available in the basin is reworked in the continental realm and is less likely to be delivered to the deep basin.

Depositional process 3: mass-transport deposits

It is noted that the deposition of mass transport deposits occurs under the same gravity-driven processes as turbidite complexes; however, it is considered a lesser component to movement of sediment transport. Mass transport deposits in the study area can be categorized as either being deposited as a debris flow (grainflows and mudflows) or slumps.

Mudflows and grainflows are classified based on the material that was available along the shelf-slope break

when deposition and movement occurred. Grainflow deposits are characterized by poorly sorted, clast and matrix-supported conglomerate. In the study area, the clasts may be composed of re-entrained turbidite material, chert and quartz. Grainflow deposits are generally deposited in the FSST and LST, given that the matrix material is more sandstone-rich. Progressive lowering of sea level will result in sandstone and siltstone-rich intervals being deposited closer to the shelf-slope break.

Mudflows are documented in the area as matrix-supported conglomerate that are predominantly hosted in a mudstone matrix. Mudflows are most commonly deposited in the early stages of the FSST or in later stages of the TST.

Slumps consist of a coherent mass of sediment that undergoes rotational movements, which results in internal deformation of beds. The slumps in the Macmillan Pass region contain soft-sediment deformation, syn-sedimentary faulting, and convoluted bedding. These deposits are generally the remobilization of turbidite lobes into graben features, resulting in overturned or inclined bedding of thick packages of sediment (usually around 25 to 100 m in thickness). The movement of this slump material would have likely occurred as a result of, or during tectonic activity.

Depositional history

Niddery Lake member

The initial deposition that occurred in the Macmillan Pass region likely accumulated during a low-frequency sequence of regression (HST). The deposits are predominantly characterized by hemipelagic sedimentation and distal turbidite lobe deposition (Fig. 11a). The XRF geochemistry from the NB23-001 and MP-20-001 cores indicate that the Niddery Lake member preserves high-frequency sequences of transgression and regression (Figs. 7 and 8).

The Niddery Lake member is mudstone-dominated at the Boundary deposit (Fig. 7). Moving along depositional strike in the basin toward the Tom deposit (Fig. 10), the turbidite facies become more sandstone-rich. It is likely that either the lower depositional units at the Tom deposit are laterally equivalent to the mudstone-rich facies near the Boundary deposit; or the initiation of turbidite deposition near the Tom deposit was erosive in nature and removed the underlying mudstone units. The turbidites may have accumulated

during a lowstand; however, minimal evidence for a fall in relative sea level at that time is preserved within the region. This could indicate that the FSST facies associations may be preserved in a more proximal position, and the lowstand fan has prograded a significant distance away from that region.

Macmillan Pass member

A significant tectonic event occurred that facilitated the rapid creation of accommodation space adjacent to fault margins, which resulted in the deposition of the falling-stage systems tract (Fig. 11b). This is documented by the thick conglomerate packages that are preserved (Figs. 7 and 9), as well as slump features of previously deposited turbidite material (Fig. 10). Following the syn-depositional tectonic reactivation, horst and graben features would have become pronounced topographic highs and lows in the region, redirecting sedimentation patterns (Fig. 11b).

Relative sea level would have fallen prior to, or during this time. The available source of material along the shelf-slope margin was coarse-grained, as indicated by the sandstone matrix that forms the conglomerate units in the Macmillan Pass area (Fig. 10). This indicates that the shorelines in proximal areas of the basin were downstepping in a seaward direction and depositing coarse-grained material in very distal regions of the continental shelf. This material would have then been transported to the deep basin following the extensional event.

In regions where the accommodation space is less pronounced and farther from fault margins, finer material tends to accumulate. This leads to the rapid juxtaposition and lateral transition of the coarser material that accumulates near fault margins into the finer grained deposits (Figs. 10 and 11b). In zones where horst features are prominent, coarse material will only begin to accumulate when the accommodation that is created in the grabens becomes filled. This leads to coarser material spilling out onto the horsts as coarse-grained lags and thin conglomerate packages (e.g., Fig. 9 at 340 m).

The Macmillan Pass member was deposited during a low-frequency fall in relative sea level. Limited evidence exists at this point in the study that indicates the preservation of a lowstand systems tract. This could be due to the rate of tectonism outpacing the fluctuations in relative sea level, thus suppressing the expression of the development of a lowstand fan. Alternatively, it may be that more data must be integrated to be able

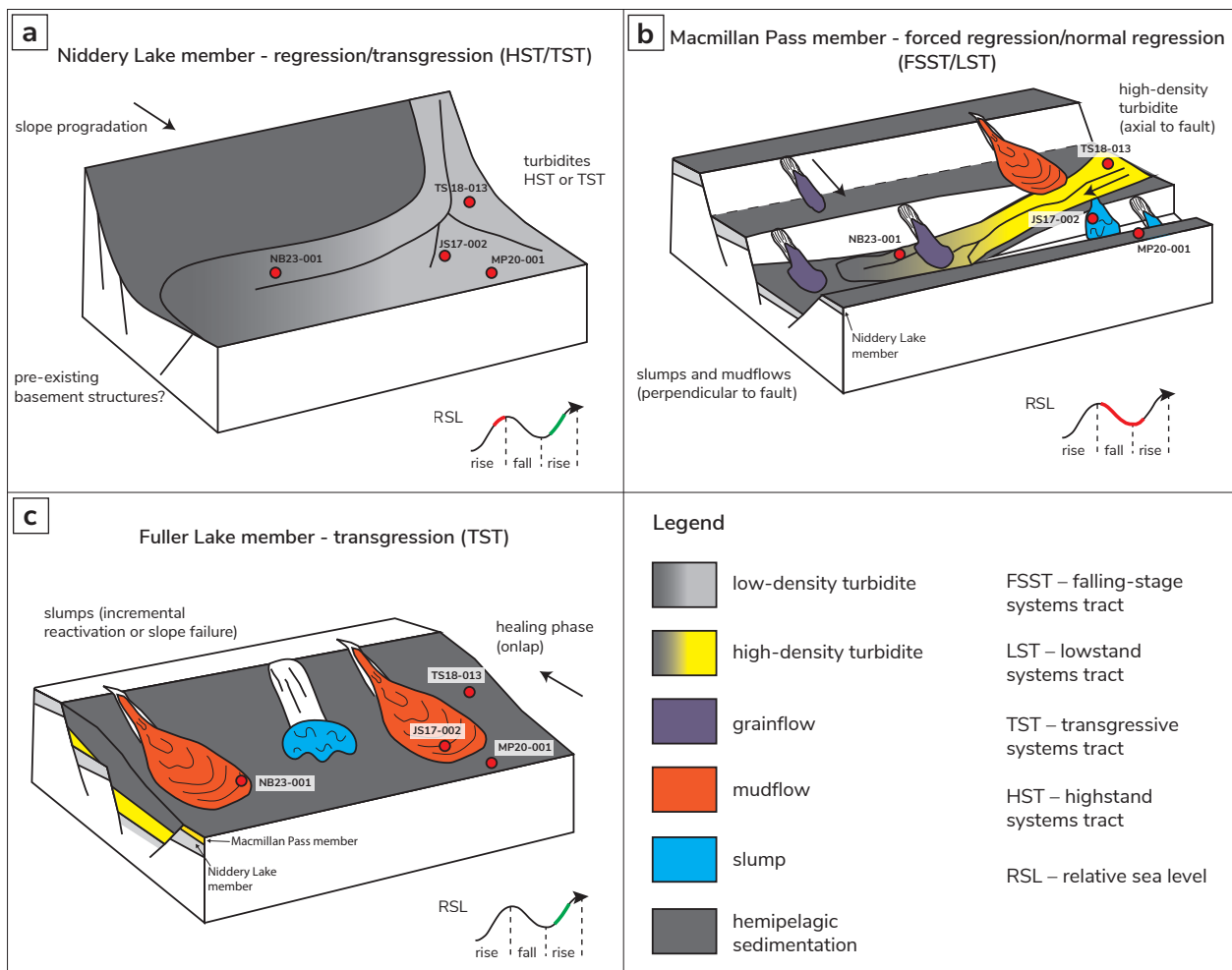


Figure 11. Block diagram illustrating the orientation of sedimentation sources during the deposition of the Portrait Lake Formation. **(a)** Niddery Lake member that records deposition during transgression and highstand normal regression. **(b)** Macmillan Pass member that records deposition during forced regression. This is documented by the increase in coarse sand into the basin. Deposition of turbidites during this time is axial to the fault planes. The mass transport complexes are perpendicular to the fault plane orientation. **(c)** Fuller Lake member that records deposition during an overall transgressive phase in the basin history. This is documented by thick mudstone intervals that infill topographic lows in the region.

to map the distribution of sediments that would have accumulated at that time.

Higher-frequency sequences of deposition are preserved within the overall falling-stage systems tract deposit of the Macmillan Pass member. Grainflows are commonly interstratified with low-density turbidite packages (Fig. 9), indicating local variation in the fluctuations of relative sea level. This is attributed to ongoing tectonism throughout the deposition of this member. Slumps and mudflows that are observed in this member may have been deposited during higher-frequency cycles of transgression or during progressive drops in relative sea level during the FSST.

Fuller Lake member

The Fuller Lake member is a mudstone-dominated interval that tends to contain more radiolarian-rich intervals indicating deposition during hemipelagic sedimentation. At the base of this unit, mudstone-dominated turbidites are present and they gradually grade into thick mudstone units with minor siltstone lamina. The Fuller Lake member likely reflects a healing phase of deposition during an overall transgressive period in the basin's history (Fig. 11c). Mudstone units infill the remaining topographic lows and form a thick package of sediment across the region. Slumps that have been termed 'diamictites' in previous studies

are prevalent in this unit, indicating that the slope is periodically destabilized. The presence of the slumps could mean that minor tectonic events are occurring syn-depositionally or that there are higher-frequencies of deposition superimposed on the lower resolution sequence. The geochemistry of the Fuller Lake member in the MP20-001 core indicates that there are short-lived periods of regression as is evidenced by the increase in carbonate content, terrigenous input and TOC values.

Next steps

Macmillan Pass

The along-strike variability in sediment supply, coupled with the localized occurrence of depositional elements, poses a challenge when correlating in deep-water settings. Turbidites in one location of the basin can abruptly be replaced laterally along-strike by hemipelagic mudstone. This is further complicated by syn-depositional fault reactivation that redirects and localizes sedimentation into graben features in the region. Careful sedimentologic analysis of the turbidites along with the clarification of the relative timing of deposition will refine the depositional model for the Earn Group in the Selwyn basin region.

Additional core logging and geochemical data must be collected in order to infill existing data gaps to create a consistent model. Completing the geochemical analyses throughout the mudstone intervals to identify the maximum regressive surface and the maximum flooding surface will be an integral part in the creation of this model. It is proposed that wireline log data be collected at key stratigraphic drillholes to facilitate meaningful mapping of the rock properties; this will also help determine the geophysical characteristics of the mudstone-dominated successions, and of the ore bodies.

Howards Pass

During the summer of 2025, work was initiated at Howards Pass where we began by infilling the stratigraphic gaps between the two major lead-zinc deposits in the region: Howards Pass and Macmillan Pass. Howards Pass is located approximately 100 km southeast of Macmillan Pass. The site is accessible by driving the Nahanni Range Road and the Howards Pass Access Road during the summer months. Travel along the Howards Pass Access Road is controlled by Selwyn Chihong Mining Ltd. and Parks Canada. Howards Pass

records deposition in more distal settings, farther away from the transition of slope to basin.

At Howards Pass, three cores were logged and sampled in July and August 2025. Cores were selected based on vintage (2005–2010 drilling programs), length, and the intersection with the lower and upper boundaries of the Portrait Lake Formation. Hole DON-142 was drilled from the upper members of the Portrait Lake Formation into the mineralized rocks of the underlying Road River Group. Additional core is available outside of what was logged for the current study. The cores from holes XYC-208 and XYC-241 form a composite section from the Steel Formation into the upper informal members of the Portrait Lake Formation. These two holes are less than 800 m away from each other, were of newer vintage, and had overlapping strata preserved in them, which is why they were selected for creating the composite section. Core from drillhole XYC-241 was previously sampled in 2023 by John Xu from the University of British Columbia. To preserve the remaining material in the core, John has provided the samples he collected to Yukon Geological Survey (YGS) to be used in the XRF study.

Additional cores that intersect the Portrait Lake Formation are available for logging and sampling. Cores will infill the current stratigraphic gaps between the Don and XY properties. Outcrops that were logged by Gordey and Anderson (1993) and preserve mudstone-dominated sections will be given preference for sampling in the geochemistry study.

Nááts'j'ch'oh National Park Reserve and Nahanni National Park

A sequence stratigraphic model is more robust when we understand the evolution of the paleoshoreline in relation to changes in deep-water packages of sediment. Platform and slope deposits that are age-equivalent to the deep-water Devonian strata are going to be sampled to compare geochemical markers, organic carbon isotopes, and the position of stratigraphically significant horizons to our current research. The next steps for this project include fly camping at outcrops that occur in Nááts'j'ch'oh National Park Reserve and in Nahanni National Park. In these regions, proximal expressions of the Late Devonian strata are preserved in the Funeral, Grizzly and Sapper formations. This will assist with understanding the history of the basin as the various sedimentary systems evolved throughout the Ordovician to Late Devonian. A reconnaissance trip to these areas was conducted in August of 2025 (Schultz and Reynolds, this volume), and three key outcrops

were identified that will be sampled in the summer of 2026 for analysis. Additionally, mapping of outcrops that occur between Macmillan Pass and Howards Pass must be incorporated to bridge the stratigraphic gap between these two significant lead-zinc districts.

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