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Early Jurassic Source Potential and Ocean Redox Conditions Inferred from Trace Metal and Organic Geochemistry of the Gordondale Member and Poker Chip Shale, Northeastern BC

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Summary

The Lower Jurassic Gordondale member and Poker Chip Shale (PCS) of the Fernie Formation, northeastern British Columbia (NEBC), are noted for their source potential (e.g. Creaney and Allen, 1990) but have limited geochemical data available to delineate depositional trends. Samples from a 46 m core from the Altares field (Progress HZ Altares c-B6-A/94-B-8) covering these strata were analyzed for redox-sensitive trace metals (RSTM) and other inorganic (major element) and organic (TOC) geochemical data. We present paleoenvironmental trends for these source rocks, including bottom-water redox state, basin hydrography, and primary productivity. This study helps define intervals for hydrocarbon development that have elevated organic matter deposition and preservation due to high primary productivity and bottom water anoxia.

Background

Gordondale member and Poker Chip Shale

The Gordondale member in NEBC is a 'deep' marine, calcareous, organic-rich mudstone with excellent source potential (Asghar-Deen et al., 2004). The PCS is subdivided into subunits 'A' and 'B'. PCS 'A' is lithologically similar to the Gordondale but typically less organic-rich (Riediger, 2002). In some locations, PCS 'A' is not present and an unconformity exists between the upper Gordondale and the siliceous PCS 'B' or other late-Early to Middle Jurassic units.

Geochemical paleoenvironmental proxies

Bottom water redox state is divided into oxic (> 2.0 ml O₂ per L), suboxic (0.2 – 2.0 ml O₂ per L), and anoxic (0 ml O₂ per L), with anoxia further subdivided into ferruginous (no H₂S in bottom waters) and euxinic (H₂S present in bottom waters) conditions (Tribovillard et al., 2006). Redox-sensitive trace metals (Mo, U, Re) are used to infer bottom water redox state during deposition of ancient sediments. All three metals are soluble in O₂-rich waters and hence occur in low concentrations in oxic sediments (Tribovillard et al., 2006). By contrast, sediments deposited from euxinic waters have high enrichments of all three metals. Elevated U and Re enrichments but mild or low Mo enrichments suggest deposition from suboxic or ferruginous bottom waters (Crusius et al., 1996; Morford and Emerson, 1999; Morford et al., 2005; Turgeon and Brumsack, 2006; Scott and Lyons, 2012; Partin et al., 2013; Sheen et al., 2018). Covariation diagrams for Re–Mo and Mo–U can be used to delineate redox conditions. In addition, the Mo–U covariation diagram can be used to infer the basin paleohydrography, such as open-marine or restricted conditions (Turgeon and Brumsack, 2006; Algeo and Tribovillard, 2009). For example, samples with elevated Mo, Re, and U enrichments and Mo/U ratios similar to the modern seawater weight ratio suggest deposition from euxinic bottom waters in a sedimentary basin with only minor physical restriction of water exchange with the open ocean.



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Source potential

Hydrocarbon potential is tied to organic productivity and preservation inferred from TOC content and redox state. High TOC content (> 2 wt%) implies large quantities of deposited organic matter that was preserved by rapid organic burial/sedimentation or water column and sediment anoxia inhibiting aerobic decomposition (Müller and Suess, 1979; Jessen et al., 2017). By combining TOC content with bottom-water redox state (inferred from RSTMs), intervals of greatest source potential can be highlighted and correlated through the basin.

Methods

The core was sampled for elemental and organic geochemistry. Samples were digested using an iterative dissolution–evaporation process with trace metal grade HNO₃, HCl and HF within a clean room at the Metal Isotope Geochemistry Laboratory, University of Waterloo (UW). Elemental concentrations were measured on an Agilent 8800 triple quadrupole inductively coupled plasma mass spectrometer with a precision of ±5% or better. Carbon content (total [TC], inorganic [TIC], and organic [TOC]) was measured at the Agriculture and Food Laboratory, University of Guelph. Total C and TIC were measured from bulk and ashed samples, respectively. The TOC content was calculated as the difference between TC and TIC.

Results

Major elements

Based on CaO content (**Figure 1**), the contact between the Gordondale and PCS occurs at ~1575 m depth. The CaO content of the Gordondale member (lower unit) and PCS (upper unit) is 20.7 ± 9.5 wt% and 1.4 ± 0.7 wt%, respectively (1σ). A strong Ca–TIC correlation ($r^2 = 0.96$) and XRD data indicate calcite (CaCO₃) is the main carbonate mineral. Phosphorus content (P₂O₅) declines from the Gordondale (2.0 ± 2.5 wt%; 1σ) to the PCS (0.2 ± 0.1 wt%; 1σ). Detrital content, expressed as Al₂O₃ and TiO₂, increase from the Gordondale (5.1 ± 2.3 wt% and 0.2 ± 0.1 wt%, respectively; 1σ) to the PCS (12.4 ± 2.0 wt% and 0.5 ± 0.1 wt%, respectively; 1σ).

Redox-sensitive trace metals and organic carbon

The RSTMs show a stepwise decrease from the Gordondale to the PCS (**Figure 2**). Mean Mo, U and Re contents are 120.4 ± 95.7 µg/g, 14.4 ± 7.9 µg/g, and 220.5 ± 92.9 ng/g, respectively, in the Gordondale and 14.6 ± 11.0 µg/g, 4.4 ± 2.2 µg/g, and 122.5 ± 85.1 ng/g, respectively, in the PCS (1σ). A Re/Mo covariation diagram (**Figure 3**) reveals a strong suboxic–ferruginous trend ($r^2 = 0.85$) for the PCS, whereas the Gordondale trend ($r^2 = 0.45$) extends into the euxinic field. A Mo/U covariation diagram reveals a strong open marine trend ($r^2 = 0.80$) with redox variation from euxinic–ferruginous (Gordondale) to ferruginous–suboxic (PCS) (**Figure 4**).

Organic carbon content decreases up-section (**Figure 2**). The Gordondale has a mean TOC content of 6.2 ± 2.0 wt% (1σ) and the highest TOC content in the core (10.9 wt%). The PCS has a lower mean TOC content of 4.2 ± 0.8 wt% (1σ) and the lowest TOC values (2.5 wt%).

Conclusions

Preliminary geochemical analysis of the Gordondale and PCS in NEBC reveal broad paleoenvironmental trends through the Early Jurassic. Major elements highlight the contrast between the Gordondale and PCS, where the former is more calcareous/carbonate-rich, phosphatic, and organic-rich. Higher detrital element content is found in the PCS. These

observations suggest an increase in the sediment flux to the basin during PCS deposition, which diluted the CaO, P₂O₅, TIC, TOC and RSTM contents. Lower RSTM contents in the PCS may reflect decreased RSTM burial into sediments in response to a lower prevalence of local bottom water anoxia and euxinia. This interpretation is consistent with the Re/Mo and Mo/U covariation trends. It is also possible an expansion of global ocean anoxia during PCS deposition reduced seawater RSTM reservoirs and caused lower RSTM contents in the PCS.

Source potential through the cored section reflects observations made by others (e.g. Riediger, 2002) where the Gordondale member contains higher TOC than the PCS. More pervasive anoxia and high primary productivity during Gordondale deposition likely aided the preservation of organic matter. Lower TOC content during PCS deposition may reflect more suboxic conditions and/or lower primary productivity. Additionally, it is noted that euxinic intervals have greater susceptibility to contain sulfurized organic matter (e.g. as Type II-S kerogens) and therefore may pose a hazard during drilling due to the release of sour gas (H₂S).

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Figures

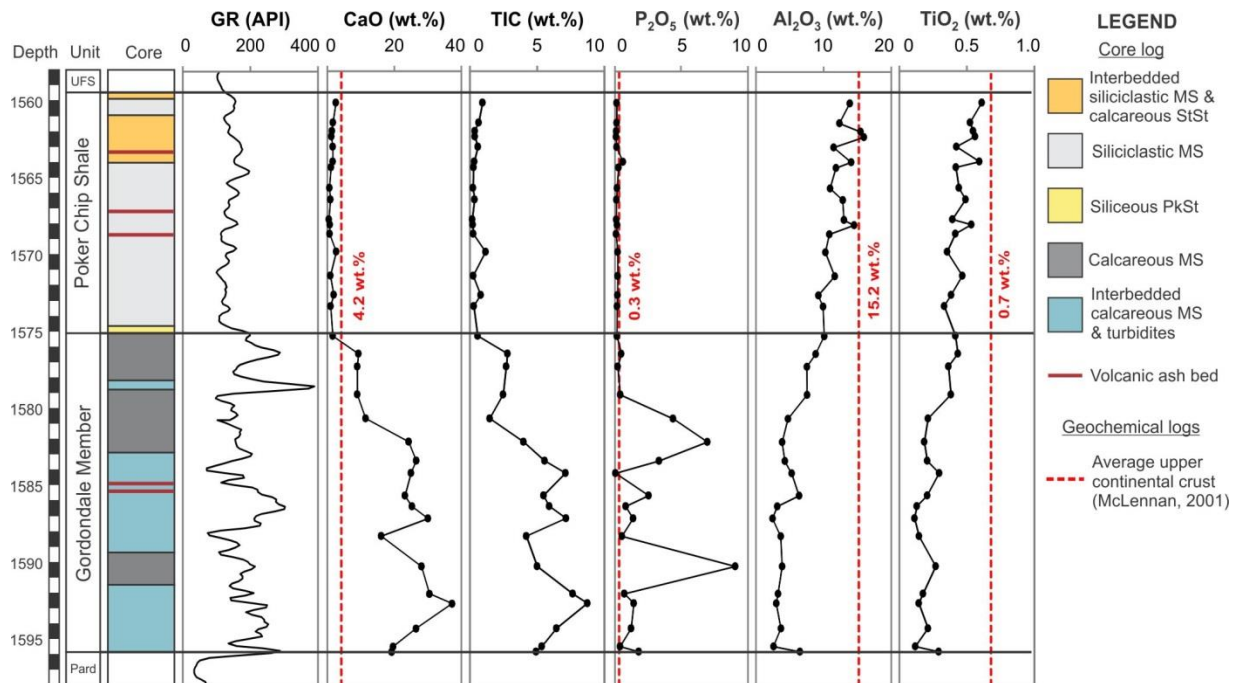


Figure 1. Major element profiles in black shale samples of the Gordondale and PCS. Abbreviations: GR = gamma ray; API = American Petroleum Institute units; TIC = total inorganic carbon; UFS = upper Fernie shales; Pard = Pardonet Formation; MS = mudstone; StSt = siltstone; PkSt = packstone; wt% = weight percent.

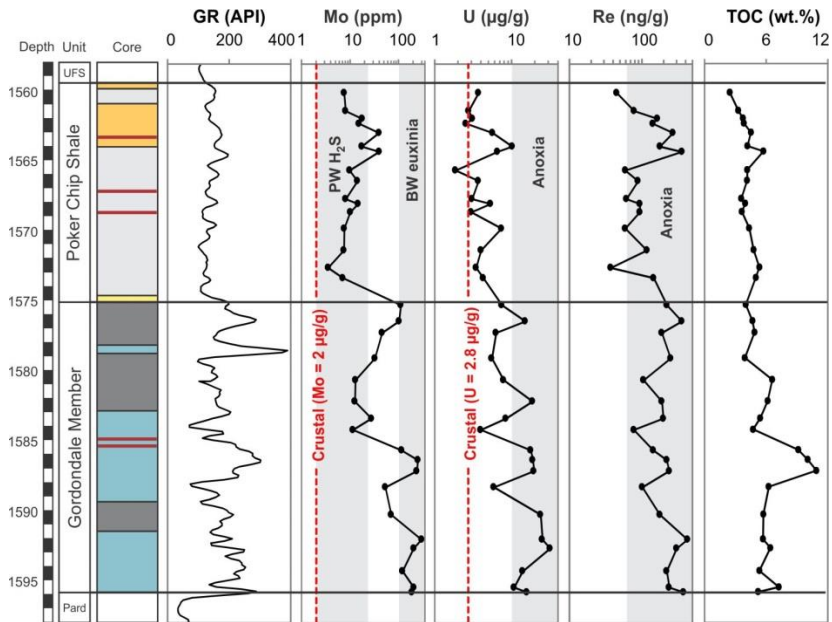


Figure 2. Mo, U, Re, and total organic carbon (TOC) for black shale samples of the Gordondale and PCS. Grey fields represent environments inferred from sediment RSTM concentrations (Mo: Scott and Lyons, 2012; U: Partin et al., 2013; Re: Sheen et al., 2018). See **Figure 1** for core legend and abbreviations. Additional abbreviations: PW = pore water; BW = bottom water.

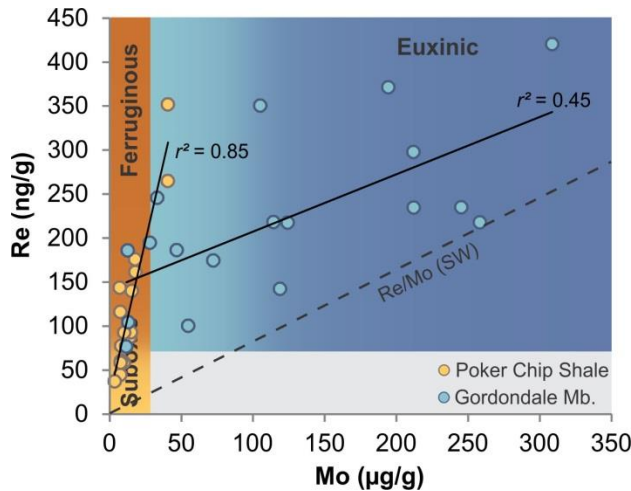


Figure 3. Re/Mo covariation (modified from Turgeon and Brumsack, 2006; additional information from Crusius et al., 1996 and Scott and Lyons, 2012) for the Gordondale and PCS. The dashed line represents the average modern seawater (SW) Re/Mo weight ratio (0.73). The orange field represents the suboxic–ferruginous trend, while the blue field represents euxinia (lighter blue = transitional). Gordondale samples fit a fair ferruginous–euxinic trend ($r^2 = 0.45$), and PCS samples are trend strongly along a suboxic–ferruginous trend ($r^2 = 0.85$).

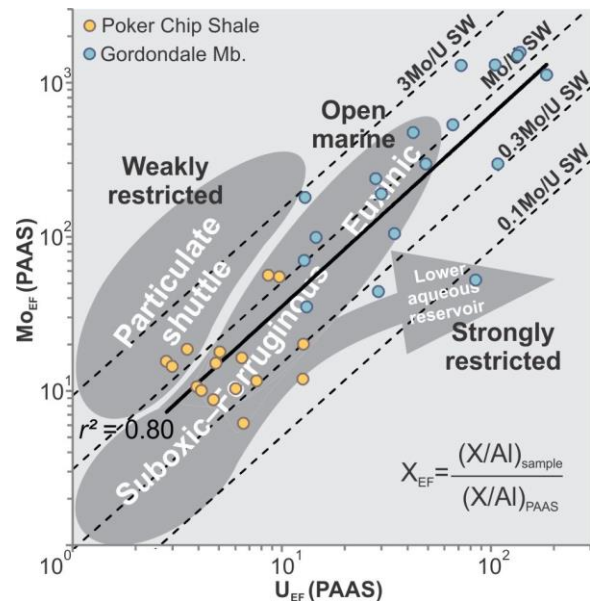


Figure 4. Mo–U covariation (modified from Algeo and Tribouillard, 2009) showing an open marine trend ($r^2 = 0.80$) and redox variation from euxinic–ferruginous (Gordondale) to ferruginous–suboxic (PCS). Dashed lines are modern seawater (SW) Mo/U weight ratio (3.1) and fractions thereof. Abbreviations: Mb. = member; EF = enrichment factor (corrects for variable detrital and carbonate content); PAAS = Post-Archean average Australian Shale (Taylor and McLennan, 1985) deposited from oxic bottom waters.



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References

- Algeo, T.J., Tribovillard, N. (2009): Environmental analysis of paleoceanographic systems based on molybdenum – uranium covariation, *Chemical Geology*, 268, 211-225.
- Asgar-Deen, M., Riediger, C., Hall, R. (2004): The Gordondale Member: designation of a new member in the Fernie Formation to replace the informal “Nordegg Member” nomenclature of the subsurface of west-central Alberta. *Bulletin of Canadian Petroleum Geology*, 52(3), 201-214.
- Creaney, S., Allan, J. (1990): Hydro carbon generation and migration in the Western Canada Sedimentary Basin; *in* *Classic Petroleum Provinces*, J. Brooks (ed.), Geological Society of London, Special Publications, 50, 189–202.
- Crusius, J., Calvert, S., Pedersen, T., Sage, D. (1996): Rhenium and molybdenum enrichments in sediments as indicators of oxic, suboxic and sulfidic conditions of deposition; *Earth and Planetary Science Letters*, 145, 65–78.
- Jessen, G.L., Lichtschlag, A., Ramette, A., Pantoja, S., Rossel, P.E., Schubert, C.J., Struck, U., Boetius, A. (2017): Hypoxia causes preservation of labile organic matter and changes seafloor microbial community composition (Black Sea). *Science Advances*, 3(2), 14p.
- Kunert, A., Kendall, B., Moslow, T.F., Nyberg, G., Pedersen, B., Smith, C. (2019): Preliminary characterization of Early Jurassic source rock and ocean-redox conditions based on trace-metal and organic geochemistry of the Gordondale and Poker Chip Shale members, Fernie Formation, northeastern British Columbia; *in* *Geoscience BC Summary of Activities 2018: Energy*, Geoscience BC, Report 2019-2, 10p.
- McLennan, S.M. (2001): Relationships between the trace element composition of sedimentary rocks and upper continental crust; *Geochemistry, Geophysics, Geosystems*, 2, 24p.
- Morford, J.L., Emerson, S.R., Breckel, E.J., Kim, S.H. (2005). Diagenesis of oxyanions (V, U, Re, and Mo) in pore waters and sediments from a continental margin. *Geochimica et Cosmochimica Acta*, 69, 5021-5032.
- Morford, J.L., Emerson, S.R. (1999). The geochemistry of redox sensitive trace metals in sediments. *Geochimica et Cosmochimica Acta*, 63, 1735-1750.
- Müller, P.J., Suess, E. (1979): Productivity, sedimentation rate, and sedimentary organic matter in the oceans – I. Organic carbon preservation. *Deep Sea Research Part A. Oceanographic Research Papers*, 26(12), 1347-1362.
- Partin, C.A., Bekker, A., Planavsky, N.J., Scott, C.T., Gill, B.C., Li, C., Podkovyrov, V., Maslov, A., Konhauser, K.O., Lalonde, S.V., Love, G.D., Poulton, S.W., Lyons, T.W. (2013): Large-scale fluctuations in Precambrian atmospheric and oceanic oxygen levels from the record of U in shales; *Earth and Planetary Science Letters*, 369–370, 284–293.
- Riediger, C.L. (2002): Hydro carbon source rock potential and comments on correlation of the Lower Jurassic Poker Chip Shale, west-central Alberta; *Bulletin of Canadian Petroleum Geology*, 50(2), 263–276.
- Scott, C., Lyons, T.W. (2012): Contrasting molybdenum cycling and isotopic properties in euxinic versus non-euxinic sediments and sedimentary rocks: refining the paleoproxies; *Chemical Geology*, 324–325, 19–27.
- Sheen, A.I., Kendall, B., Reinhard, C.T., Creaser, R.A., Lyons, T.W., Bekker, A., Poulton, S.W., Anbar, A.D. (2018). *Geochimica et Cosmochimica Acta*, 227, 75-95.
- Taylor S.R., McLennan S.M. (1985): *The continental crust: its composition and evolution*. Blackwell Scientific Publication, Carlton, 312p.
- Tribovillard, N., Algeo, T.J., Lyons, T., Riboulleau, A. (2006): Trace metals as paleoredox and paleoproductivity proxies: an update; *Chemical Geology*, 232, 2–32.
- Turgeon, S., Brumsack, H-J. (2006): Anoxic vs dysoxic events reflected in sediment geochemistry during the Cenomanian–Turonian Boundary Event (Cretaceous) in the Umbria–Marche Basin of central Italy. *Chemical Geology*, 234, 321-339.