Successful NSERC PGSD 2021 application materials herein

Contribution to research – pages 2-3

Outline of proposed research pages 4-5

Bibliography for proposed research – page 6

I. Contributions to research and development

a. Articles published or accepted in peer-reviewed journals (3 manuscripts)

Harris, B., LaGrange, M., **Biddle, S.**, Playter, T., Fiess, K., Gingras, M. (accepted July 8, 2021) Chemostratigraphy as a tool for sequence stratigraphy in the Devonian Hare Indian Formation in the Mackenzie Mountains and Central Mackenzie Valley, Northwest Territories, Canada. Canadian Journal of Earth Sciences, 40 pages submitted. **(MSc work)**.

Xang, X., Kuru, E., Gingras, M., **Biddle, S.**, Lin, Z., and Iremonger, S. (2021) Characterization of the Microstructure of the Cement-Rock Interface Using Environmental Scanning Electron Microscopy and Micro-Computed Tomography Scan. SPE Journal, SPE-205512-PA. **(MSc work)**.

Biddle, S., LaGrange Rao, M., Harris, B., Fiess, K., Terlaky, V., and Gingras, M. (2021) A Fine Detail Physicochemical Depositional Model for Devonian Organic-Rich Mudstones: A Petrographic Study of the Hare Indian and Canol Formations, Central Mackenzie Valley, Northwest Territories. Sedimentary Geology, 414, 105838. **(MSc work)**.

b. Articles submitted to peer-reviewed journals (1 manuscript)

LaGrange, M.T., Atienza, N.M., **Biddle, S.K.,** Harris, B.S., Fiess, K.M., Konhauser, K.O., and Gingras, M.K. (submitted Aug. 2021) The nature, origin, and predictors of porosity in the Middle to Late Devonian Horn River Group of the Central Mackenzie Valley, Northwest Territories, Canada. Marine and Petroleum Geology, 78 pages submitted, submission number: JMPG-D-21-01021. **(MSc work)**.

c. Other peer-reviewed contributions (1 technical report)

LaGrange Rao, M., Harris, B., **Biddle, S**., Atienza, N.M., Fiess, K., and Gingras, M. (2020) Preliminary data for an integrated depositional and sequence stratigraphic framework for the Hare Indian and Canol formations (Horn River Group), Central Mackenzie Valley and Mackenzie Mountains, Northwest Territories — Part II. Northwest Territories Geological Survey Open Report 2019–02, 16 pages. **(MSc work)**.

d. Non-peer-reviewed contributions (total 8 (7 first author) of conference abstracts, posters, oral presentations, and 1 thesis; 2 most recent listed here)

Biddle, S.*., Harris, B., LaGrange Rao, M., and Gingras, M.K. (2021, June) Lithofacies, Microfacies, and Chemofacies Comparison in a Devonian Organic-Rich Mudstone. CSPG Core Conference, Online Conference **(international, abstract and oral presentation, MSc work).**

Biddle, S.*., LaGrange Rao, M., Harris, B., and Gingras, M.K. (2021, June) Petrographic Intricacies of Black Shale Reservoirs and their Implication in Physiochemical Depositional Interpretations: A Study of the Hare Indian and Canol Formations, Central Mackenzie Valley, Northwest Territories. SEPM International Sedimentary Geoscience Congress Virtual Student and Early Career Sessions, Online Conference **(international, abstract and oral presentation, MSc work).**

II. Most significant contributions to research and development

Contribution 3 (Biddle et al., 2021): This article presents two novel concepts. Firstly, a classification scheme I have developed to identify and describe microscopic trace fossils in fine-grained sedimentary rocks (the first classification scheme of its type). Secondly, detailed interpretations of the physical and chemical processes leading to the deposition of enigmatic Devonian-aged black shales. The results of this article are significant as they outline the usefulness of microscopic thin section analyses to uncover heterogeneities in fine-grained rocks that are generally assumed to be homogeneous at the macroscopic scale; heterogeneities that are then used to interpret the small-scale paleo-depositional mechanisms that would have otherwise been overlooked. Co-authors provided invaluable discussions and aided in

interpretations and manuscript edits. We chose to publish this article in 'Sedimentary Geology' (Impact Factor 3.4) as the journal's guidelines align with our aims of enhancing sedimentary geologist's understanding of the processes involved in deposition of the currently poorly understood Devonian mudstones. The journal specifically aims to publish papers with significant contributions to the field of sedimentary geology, of interest to the diverse and international readership.

III. Applicant's statements

a. Research experience

Throughout my academic career I have worked with several individuals on a variety of projects within the field of sedimentary geology. During my masters I worked with individuals from the Northwest Territories Geological Survey (government agency) to create the project scope and curate our data collection. I also participated in a 21-day field season in the Mackenzie Mountains, collecting outcrop data alongside government individuals and other university colleges. I have worked with individuals in the engineering department to categorize a variety of sedimentary rock-types, resulting in a co-authorship for the Xang et al. (2021) publication. I am a trained operator for our departments scanning electron microscopy (SEM) machine, which has afforded me the opportunity to work with many individuals on data collection for a diverse array of projects, such as the submitted LaGrange et al. (Aug. 8th 2021) manuscript. I have spent my first 8 months as a PhD student working on literature review for Cretaceous oceanic anoxia events, and manuscripts for publication and conference proceedings from work done during my masters. I took a four-month leave of absence from my PhD studies (May to August 2021) to work for a prominent natural gas company where I mapped potential reservoir units and developed a paleo-depositional model for the area using various methods (sequence stratigraphy and facies analysis), broadening my skills in these areas.

b. Relevant activities

Teaching: Throughout the duration of my time at the University of Alberta I have worked as a teaching assistant with duties including running two weekly lab sessions where approximately 30 students worked on projects involving various geological skills and evaluating weekly lab assignments.

Leadership: **1)** AAPG Student Chapter President, University of Alberta (2018 – Present). **2)** Two semesters working as the lead teaching assistant for large undergraduate classes; duties included coordinating a group of 10 post graduate teaching assistants for a class of 300 students, leading weekly pre-lab meetings, managing the online portal for the lab portion of the class, and working with the course professor to create and update lab schedules, lab exams, answer keys and rubrics.

Volunteer Work: **1)** Guide for the University of Alberta Paleontology and Mineralogy Museums (2018-2020). **2)** Invited talk for Paramount Resources Ltd., outlining micro-scale sedimentary features in black shales (June 2019). **3)** Student volunteer for the Yellowknife Geoscience Forum (2018, 2019). **4)** Coordinator for the AAPG Student Chapter 2018 field trip to Dinosaur Provincial Park, Drumheller, Alberta.

Industrial Work Experience: **1)** Geology Summer Student for Tourmaline Oil Corp. (May – August 2021). **2)** Geophysical Data Student for ConocoPhillips (May – August 2015).

Presentation Awards: **1)** Baillie Student Award at the CSPG Core Conference for best student presentation (2021). **2)** SEPM Best Student Research Poster at the Geological Society of America Annual Convention and Exhibition, online conference (2020). **3)** SEPM Best Student Research Poster at the American Association of Petroleum Geologists Annual Convention and Exhibition, San Antonio TX (2019).

Outline of proposed research

Since the dawn of complex life in the Cambrian Period (560 million years ago), there have been both evolutionary proliferation events and extinction events. The most well-known of these extinction events are dubbed 'mass extinctions', and are characterized by a global decline, and in some cases near complete cessation of complex living organisms. A catalyst for many extinction events is a de-oxygenating of the global oceans leading to anoxic waters. In the geologic record these anoxia-driven extinction events are characterized by anomalous organic-rich mudstone intervals (or more popularly termed 'black shales'), representing bulk accumulations of decaying organic matter at the ocean floor subsequently preserved in sedimentary rocks as organic carbon. These extinction events and resultant geologic units are referred to as oceanic anoxia events (OAE's) (Schlanger and Jenkyns, 1976).

Cretaceous oceanic anoxia events (occurring between 145 and 65 million years ago) are an internationally recognized phenomenon resulting in globally correlated organic-rich horizons. Perhaps the most well-known of these events are OAE1a and OAE2, ostensibly globally present black shale layers denoting the Cretaceous Albian-Aptian and Cenomanian-Turonian boundaries, respectively. The exact timing and catalyst for OAE1a and OAE2 are still debated, with most researchers citing intense volcanism and resulting increased atmospheric CO_2 as the spark (e.g., Leckie et al., 2002). Geochemical proxies and microfossil data indicate that these two anoxic intervals seemingly coincide with extreme climate warming periods, punctuated by global cooling events and synchronous transient re-oxygenation of oceanic waters (Jenkyns, 2018). European outcrop localities containing the OAE1a and OAE2 have been studied extensively in attempts of such global environmental and climate reconstruction for the Cretaceous period. However, these particular OAE's have yet to be described in detail in the Canadian portion of the Cretaceous Western Interior Seaway. Furthermore, despite the considerable study history of global OAE events, in-depth trace fossil analyses (the study of fossilized tracks, trails, and burrows in sedimentary rocks, created by sediment-dwelling organisms at the time of deposition) have yet to be completed.

An understanding of the trace fossil data of any sedimentary unit is paramount. This is owed to the fact that the size, distribution, and types of trace fossils present provide insights into the physical (e.g., wave energy) and chemical (e.g., oxygenation) conditions of depositional settings that are not discernable from primary sedimentary structures or geochemical data alone (Bromley and Ekdale, 1984; Bromley, 1996; MacEachern et al., 2007; Gingras et al., 2011). Furthermore, bioturbation represents *in-situ* instantaneous reflections of sea water chemistry at the sea floor during the time of an organism's burrowing; whereas diffusion of elements through porewaters can affect the distributions of elements, and the resultant geochemical data, over time (Scott and Lyons, 2012). Moreover, trace fossil analysis is especially important in organic-rich black shale intervals where descriptions of primary sedimentary features resulting purely from physical depositional processes are often limited to 'laminated' and provide little environmental insight beyond apparently relatively stable and quiescent depositional conditions.

The proposed research involves in-depth sedimentological and trace fossil analysis of OAE1a and OAE2 expressions in outcrops within the French Vocontian Basin, as well as time-equivalent units in the Canadian portion of the Cretaceous Western Interior Seaway. The goals of this project are to: 1) develop a strong sedimentological and trace fossil framework for Cretaceous OAE intervals; 2) integrate trace fossil data with pre-existing macrofauna and microfauna body fossil data, and geochemical data to create the most extensive continuous dataset for the European extent of OAE1a and OAE2; 3) use multidisciplinary data integration of the newly collected and pre-existing data sets to calibrate oxygenation conditions as they fluctuate throughout the OAE events, refining interpretations of the onset and subsequent waning of anoxia; and 4) to assess how OAE units vary laterally over meters (within the same outcrop), kilometers (between outcrops), and globally (between France and western Canada). Ultimately

the results of this study will help to improve global interpretations of small-scale fluctuations in both physical and chemical depositional conditions of OAE's. This will provide refined insights into how rapid the onset of an anoxia event is, the true extent of de-oxygenation, and how such events fluctuate and dissipate over time. Furthermore, given the parallels in rising atmospheric CO_2 levels between the modern day and those of the Cretaceous period (e.g., Wang et al., 2014), perhaps there is relevance to considering the results of this study as a potential proxy for what may happen with climate and ocean anoxia in our near future.

Methodologies involved in this study include sedimentological and trace fossil analysis of several outcrop localities in the Vocontian Basin of France as well as core data from western Canada to define individual sedimentological and trace fossil characteristics that are typical of OAE events. Unbiased hiring of both field assistants and lab assistants will be executed for data collection. This outcrop and core data will be supplemented with petrographic analyses (microscopic thin section analysis) to understand the subtle fluctuations in depositional conditions throughout fine-grained units that lack macroscale details. Macroscopic and microscopic sedimentological and trace fossil data will be integrated with pre-existing comprehensive datasets for Albian-Aptian and Cenomanian-Turonian outcrops within the French Vocontian Basin. This includes high-resolution geochemical data (stable isotopes, x-ray fluorescence, total organic carbon measurements) and micropaleontological data (calcareous nannofossils, foraminifera, ammonite), providing an exceptional control on the ability to confidently link horizons, and thus their unique sedimentological and trace fossil characteristics between individual outcrops and continents. These existing datasets also provide access to established paleo-redox proxies (estimations of amounts of dissolved oxygen in the water column at the time of deposition), such as pelagic and benthic foraminifera to estimate surface and bottom water oxygenation, and trace metal vanadium and molybdenum enrichment to estimate anoxia and euxinia, respectively. Trace fossil analysis complements and completes these proxies where there is uncertainty. Such multiproxy data integration will lead to the development of the most comprehensive temporal assessment of oxygenation throughout the OAE1a and OAE2 events, providing a better framework for their identification and interpretation. This framework will be used to help identify and link the OAE1a and OAE2 in western Canadian deposits.

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