Geological Characteristics of a Global Anoxic Event: Ichnological and Sedimentological Analysis of the Mid-Cretaceous Oceanic Anoxia Events I and II in the Vocontian Basin Southeast France and Western North America

1. **This section should present the problem, hypotheses, and the overall objectives of the project. Please be sure to discuss your figure here, if applicable. (1,000 character limit, including spaces)**

   Cretaceous Oceanic Anoxia Events (OAE's) are an internationally recognized phenomenon resulting in globally correlatable organic rich horizons. European OAE outcrop localities have been studied in attempts of paleoenvironmental reconstruction. Yet, in-depth trace fossil analyses have yet to be completed.

   This project involves sedimentological and trace fossil analysis of OAE expressions within France (Fig. 1) and North America (Fig. 2). The goals of this project are to 1) develop a strong sedimentological and trace fossil framework for OAE intervals (Fig. 2); 2) integrate trace fossil data with existing data to create the most extensive continuous datasets for the French extent of these OAE's; 3) integrate new and existing data sets to calibrate oxygenation conditions as they fluctuate throughout OAE events (e.g. Fig. 3); and 4) to assess how OAE units vary laterally over meters (within the same outcrop), kilometers (between outcrops), and globally (between France and North America).

2. **This section should discuss the scientific and societal significance; what is the importance of this project? Describe the "broader impacts" of your research, which are defined by the National Science Foundation (NSF) as "the potential of the proposed activity to benefit society and contribute to the achievement of specific, desired societal outcomes." (https://www.nsf.gov/od/oia/special/broaderimpacts). Please be sure to discuss your figure here, if applicable. Discuss any ways in which this research project supports BAJEDI (belonging, accessibility, justice, equity, diversity, and inclusivity) values. (2,500 character limit, including spaces):**

   Ultimately the results of this study will help to improve global interpretations of small-scale fluctuations in both physical and chemical bottom water depositional conditions of oceanic anoxic events; as well as how these conditions vary globally. This study will provide refined insights into how rapid the onset of an oceanic anoxia event is, the true extent of de-oxygenation, and how such events fluctuate and dissipate over time. Given the parallels in rising atmospheric CO_2 levels between the modern day and those of the Cretaceous period during OAE depositional intervals, 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.

   An example of the potential outcomes of this study are illustrated in Figure 3 (Biddle et al., 2021). Figure 3 represents the results of a similar study conducted on Devonian aged organic rich mudstones, originally thought to represent deposition in entirely anoxic settings. Results of this study, achieved mainly through petrographic sedimentological and trace fossil analyses, showed that these mudstones were deposited in bottom water dissolved oxygen levels that likely fluctuated between 0.0 – 0.1 ml/l.

   The proposed study is focused on the intricacies of geological units and does not include any analysis of living organisms or their impact. Thus, diversity considerations are not considered within the research design. However, the University of Alberta and the Ichnology Research Group (the research group with which this project is conducted under) are both committed to providing

opportunities to underrepresented parts of the university and academic community. This study will support this pledge to increase representation by 1) developing undergraduate honors thesis projects for students interested in gaining research experience; 2) hiring of core lab assistants for the Canadian data sets, and field assistants for the French and American outcrop data sets; and 3) providing an open and safe environment for research-related work to be conducted in. Ultimately, our goal is to foster unbiased creativity and diversity within our research group.

Our intention is to publish results of this study in globally accessible venues (e.g. open source journals), with the aim of encouraging further research and understanding on these environmentally significant Cretaceous oceanic anoxic deposits.

3. **This section should concisely state your research plan and how it will test your hypothesis stated above. Please be sure to discuss your figure here, if applicable. (2,500 character limit, including spaces):**

Methodologies involved in this study include macroscopic sedimentological and trace fossil analysis (e.g. visual analysis and logging) of several outcrop localities in the Vocontian Basin of France (Fig. 1), outcrops within Colorado, and drill core data from western Canada (Fig. 2) to define sedimentological and trace fossil characteristics that are typical of global oceanic anoxic events. These three localities were chosen as they represent globally expansive complete successions of the two major oceanic anoxic events during the Cretaceous (e.g. OAE1a and OAE2). Macroscopic sedimentological and trace fossil analyses will be supplemented with petrographic (microscopic) analyses to understand the subtle fluctuations in depositional conditions throughout fine-grained units that generally lack macroscale details (e.g. these organic rich mudstones; Fig. 3). Macroscopic and microscopic sedimentological and trace fossil data will be integrated with pre-existing comprehensive datasets for the French and North American Cretaceous OAE intervals, including 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; 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 bottom water 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.

4. **Duration of investigation (dates):**

Canadian core data collection: 2022-2023 ongoing
Southeast France field work: October 3rd – 13th 2022
Colorado field work (North American outcrop expressions): May 2023
Petrographic analysis: Summer 2023 (once thin section preparation is complete)

5. **Budget Justification: In this section, explain the need for each item in your budget for which you are requesting funding from GSA. Also, be sure to provide a specific cost breakdown for each item. For example, if you are including the cost of food needed in the field, specify the number of days food would be needed and the daily cost of the food ("10 days at $12/day, for a total of $120").**

Funds are requested to cover the thin section sample preparation necessary to complete this study. Field work in France has been completed, and drill core analysis is ongoing and has no cost associated (free access for students to the core viewing facility where our core is stored). Field work in Colorado will commence in the summer of 2023, and has been sponsored by my supervisor.

- Samples collected during field work need to be made into thin sections. A total of 78 thin section samples were collected from France. We are hoping to get both bedding parallel and bedding perpendicular thin sections from samples collected at the onset, the height, and the dissipation of the OAE intervals (roughly 10 samples). We are estimating a total of 20 thin sections required from OAE2 outcrops in Colorado. The maximum total thin section count is 108 sections (France: 78 perpendicular, 10 parallel; Colorado: 20 total). The total estimated cost of $2160 for preparation is based off the University of Alberta in-house thin section preparation cost of $20/sample.

- One French field site did not have pre-existing geochemical data and required sample analysis. Samples were collected at 50cm intervals above and below the OAE interval, and at 20cm intervals within the OAE resulting in a total of 48 samples. Samples will undergo X-ray florescence (XRF) analysis in house, using our lab owned portable XRF machine. There will be no cost associated with the machine itself, however expenses will be incurred in the form of materials needed to complete the sample preparation. Costs incurred during XRF analysis will include the sample cups for each sample, filter papers, and polypropylene X-ray film. Each sample will need its own cup and will use one sheet of X-ray film. X-ray filter papers can be used for up to 3 samples, resulting in a total of ~20 sheets needed for the 50 samples. All costs for these materials are estimated based on *MFE Inspection Solutions Canada* prices.

Specific break down:

- 108 thin sections at $20 a section, for a total of $2160
- 50 XRF sample cups at $1.50 a cup, for a total of $75
- 50 polypropylene XRF film sheets at $0.30 a sheet, for a total of $15
- ~20 XRF filter papers at $0.55 per filter, for a total of $11.00
- Total: $2261 CAD
- Total in USD using Jan. 26th 2023 conversion rate (0.75): $1693.46 USD

6. Amount and nature of other available funds, facilities, materials, etc. (1,200 character limit, including spaces):

No other funds currently available; portable XRF machine owned by our lab (free access).

7. Abbreviated resume. List education, major positions held, and significant accomplishments. Provide information relevant to your qualifications to undertake proposed research. List up to 5 of your publications and presentations (2,500 character limit, including spaces):

Education

- PhD., University of Alberta, September 2020 – Present
- MSc., University of Alberta, September 2017 – September 2020
- BSc., Honors, University of Calgary, September 2014 – April 2017

Publications:

Published Articles: 1 first authored and 3 co-authored manuscripts. Three most recent listed below.

Non-peer-reviewed contributions: 7 first authored conference abstracts (4 posters, 3 oral presentations), and 1 Master's thesis.

LaGrange, M.T., Atienza, N.M., **Biddle, S.K.,** Harris, B.S., Fiess, K.M., Konhauser, K.O., and Gingras, M.K. (2022). *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, 105738.

Harris, B., La Grange, M., **Biddle, S.K.**, Playter, T., Fiess, K., Gingras, M. (2022) *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, 59, 29-45.

Biddle, S.K., LaGrange Rao, M., Harris, B., Fiess, K.M., Terlaky, V., and Gingras, M.K. (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.

Major Positions Held:

- Instructor – "Introduction to Earth Sciences", NorQuest College, Edmonton, Winter 2023
- Course designer – "Introduction to Earth Sciences", NorQuest College, Edmonton, Fall 2022
- Lead Teaching Assistant, University of Alberta, Edmonton - Fall 2019, Winter 2020-2022
- Geology Summer Student, Tourmaline Oil Corp., Calgary, Summer 2021

Significant Accomplishments:

- Christopher Scarfe Memorial Graduate Scholarship in Geology (2022)
- NSERC Postgraduate Scholarship (2022-2024)
- President's Doctoral Prize of Distinction (2022)
- Alberta Graduate Excellence Scholarship (2021)
- Baillie Student Award, CSPG Core Conference best student presentation (2021)
- SEPM Best Student Research Poster at the GSA Annual Convention and Exhibition, online conference (2020)
- University of Alberta Doctoral Recruitment Scholarship (2020)
- Canadian Association of Petroleum Producers Graduate Scholarship in Geology (2019)
- SEPM Best Student Research Poster at AAPG ACE, San Antonio, Texas (2019)
- BP Canada Energy Scholarship in Geology (2016)
- Suncor Energy Emerging Leaders Scholarship (2015)

8. Personal Statement: Please describe your professional and educational goals and explain how this research funding would help you reach your goals. If you have encountered obstacles along the way to your goals, please discuss them. Discuss any ways in which your goals support BAJEDI (belonging, accessibility, justice, equity, diversity, and inclusivity) values. (1,000 character limit, including spaces):

My educational goals include finishing my doctorate and completing a post-doc in a related field (e.g. physical and chemical paleodepositional conditions of fine-grained siliciclastic units). My professional goal is to be a professor, teaching and researching in the field of sedimentology and ichnology. I enjoy teaching and sharing my passion for geology with incoming students. Ideally, I would like to see myself supervising graduate students and lecturing undergraduate and graduate level sedimentary geology courses, while also participating in active research. The successful funding of this grant will help me along my path to professorship by providing me valuable experience designing, budgeting, and executing my own research project. Ultimately the successful funding of this grant application will provide a stepping stone towards a professor position.

Research Budget

Category	Item		Description	Estimated Cost
Data Collection and Sample Analyses	**1**	Field Work (5 days in Colorado)	Flights for 3 people (~$800/person)	$2400
			Rental van (5 days)	$800
			Accommodations (~$200/night x 4 nights)	$800
			Food (per diem x 3 people @ $70/day)	$1050
			Shipping of samples to Edmonton	$100
			Subtotal	**$5,150**
	2	Thin Sections	~40 Samples x $20/thin section	$800
	Subtotal			**$800**
Total				**$5950**

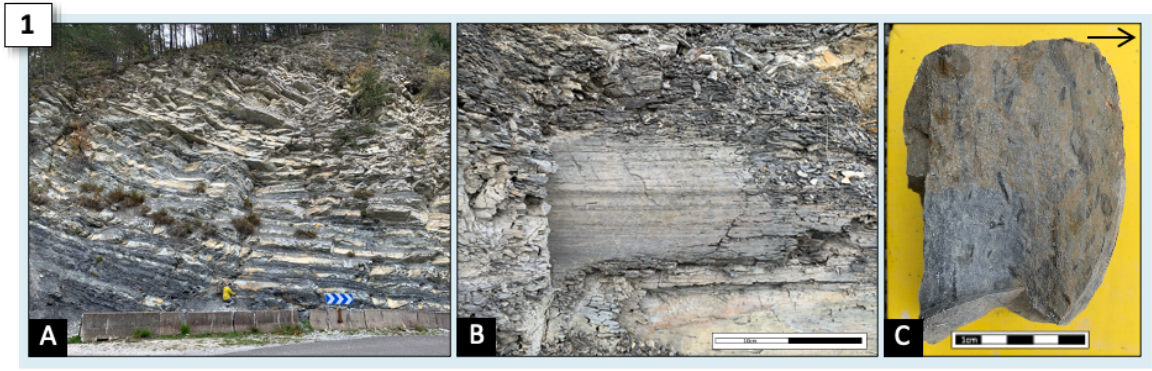
Budget Justification (Itemized)

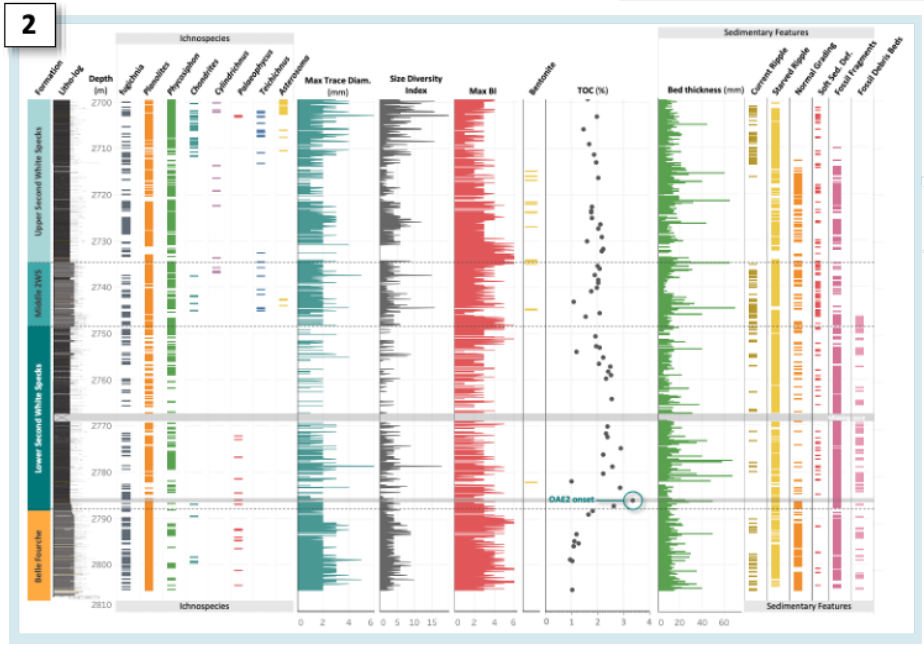
- Field work is necessary to analyze the sedimentology and ichnology of Vocontian Basin outcrops. The three people involved in field work include myself, my thesis supervisor, and one field assistant. Rock samples would be collected at regular intervals throughout the sections (e.g., samples collected every 50 cm) making it necessary to have a field assistant to help collect and carry samples. We have planned for 3 days of field work and 2 days of travel for a combines 5 days.
- Samples collected from field work would be made into bedding perpendicular thin sections to analyses the microscopic sedimentological and ichnological features of the black shales. These thin sections would be used to create the microfacies scheme discussed in the proposal. The 5 proposed outcrop localities vary in thickness from 10 – 50m, with an average thickness of about 50 m. If thin section samples were taken every 50 cm, we expect between 150-200 thin sections. Estimated cost is based off the university in-house thin section preparation cost of $20/sample.

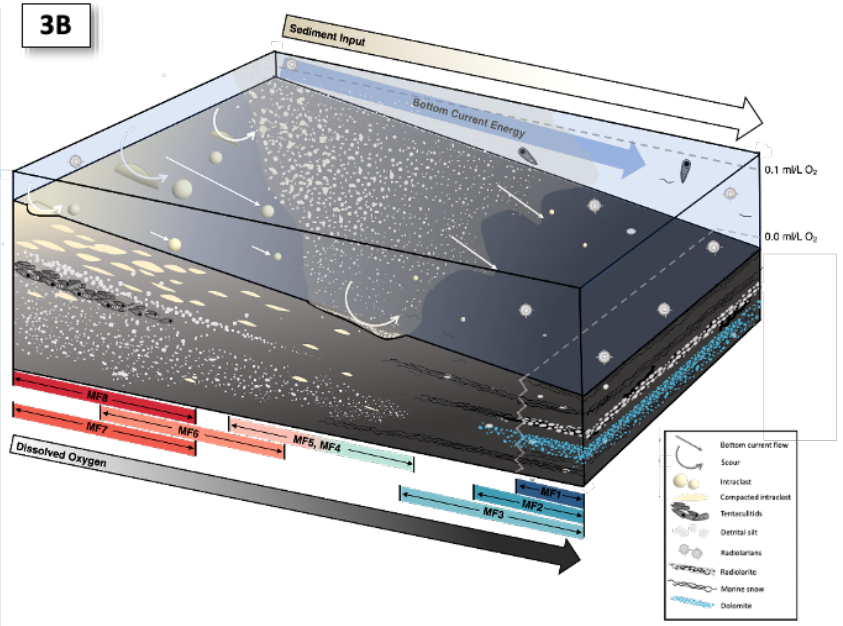
Figure 1: Photographs of features present in the OAE2 interval, Pont d'Issole outcrop, France. A) Representative photograph of the Pont d'Issole outcrop (person for scale). **B)** Photograph of weathered mudstone bed lacking macroscopic features (e.g. dark beds in A). **C)** Photograph of macroscale trace fossils (dark features) in a carbonate bed (e.g. light-beige colored beds in A) between dark mudstone beds. Arrow indicates way up.

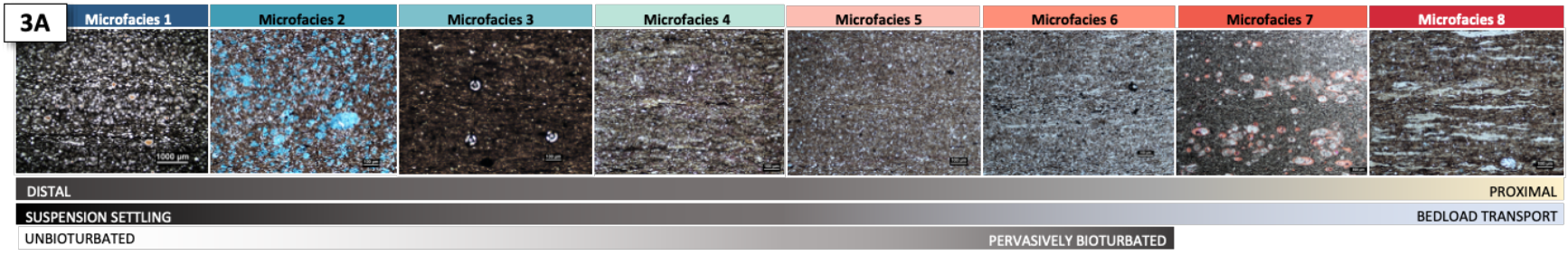
Figure 2: Trace fossil and sedimentary data plots for the Canadian expression of OAE2. Binary ichnological and sedimentological data plots representing distribution of features throughout the western Canadian expression of the OAE2 event (Cenomanian-Turonian Second White Specks Formation).

Figure 3: Example results of petrographic analysis of organic rich mudstones. A) Example microfacies scheme developed using petrographic data from a sedimentologically similar unit to the mudstones of the Cretaceous OAE's (Devoninan Canol Formation). **B)** Block diagram illustrating relative distribution of these microfacies and bottom water conditions (e.g. bottom water energy, sediment load, and dissolved oxygen content). A and B from Biddle et al., 2021.









Sara Biddle, PhD Student
2023 GSA Research Grant Application