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Lewis and Clark Fund for Exploration and Field Research in Astrobiology 2017 Project Report

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Project Title: Oxygen, temperature, and the deep-water evolution of animals: investigating fossil occurrences across an Ediacaran shelf-to-slope transect in northwest Canada

Introduction

The first macroscopic, complex eukaryotes appear during the late Ediacaran (~571-541 Ma), characterized by marine assemblages of taxa with frondose, sponge, and cnidarian affinities, and simplistic burrows produced by mobile bilaterians. These assemblages occur as early as 571 Ma in deep-water, aphotic slope facies of the Avalon Terrane in Newfoundland, but are not found in shelfal environments until ~560-555 Ma, occurring stratigraphically above the globally recognized Shuram negative carbon isotope excursion (SIE). The Ediacaran fossil record therefore displays a puzzling ~15 Myr period when large, complex life apparently arose and flourished in deep-water settings, but did not inhabit shallow-water environments. However, mitigating our ability to discern whether this pattern is a genuine reflection of Ediacaran evolutionary dynamics is an imperfect geologic record; in historically well-studied areas it is not possible to investigate fossil appearances across a shelf-to-slope transect to test for co-inhabitance of both deep- and shallow-water environments in space and time. This project proposed to investigate a recently discovered, extremely well-preserved shelf-to-slope transect in fossiliferous Ediacaran sedimentary strata of the Wernecke Mountains, Yukon, Canada, arguably the best place worldwide to conduct such a study. With this natural laboratory, it is now possible to test the timing and veracity of the observation that Ediacaran organisms first appeared in slope settings of the Nadaleen Formation (Fm), below the SIE (recorded within the overlying Gametrail Fm), while remaining absent in time-equivalent shallow-water facies. In contrast, by the latest Ediacaran Blueflower Fm (above the SIE), fossils are found inhabiting both shallow and deep-water environments.

Project Aims

To constrain whether macroscopic Ediacaran life originated in deep-water environments, five field camps, extending from the shallow-water Goz Creek region, to the deep slope Rackla Belt area were mapped and described in detail from July 8 to August 5, 2017 with the following aims:

1. Complete detailed sedimentology and sequence stratigraphic/paleoenvironmental reconstructions of both the unfossiliferous shallow-water Nadaleen Fm, and the fossiliferous, shallow-water Blueflower Fms, with the focus of characterizing preservation potential in both
2. Complete carbonate carbon isotope chemostratigraphy ($\delta^{13}C$) of the Gametrail Fm at each camp, to juxtapose the underlying Nadaleen and overlying Blueflower Fms
3. Collect organic-rich shale samples for Re/Os geochronology in both the Nadaleen and Blueflower Fms as appropriate facies permit
4. Record both body- and trace-fossil occurrences across the basinal transect to reconstruct fossil distributions, and to describe the diversity of fossils present

Aims Successfully Completed

Funding was sought for costs directly associated with fieldwork, specifically, establishing five camps along the Wernecke Mountains shelf-to-slope transect. Five camps were successfully established, allowing geological mapping of each area, in addition to detailed sedimentological and paleoenvironmental analyses of both the Nadaleen and Blueflower Fms at each camp (Aim #1). In addition, we collected >800 carbonate samples from within the Gametrail Fm for $\delta^{13}C$ across the basin, building one of the highest-resolution chemostratigraphic data-sets of the SIE (Aim #2), and allowing the Nadaleen and Blueflower Fms to be placed within a composite stratigraphic

section. Furthermore, we collected multiple black shale horizons for Re/Os geochronology (Aim #3), which are currently undergoing preliminary analysis. Lastly, we collected an abundance of Ediacaran fossils from within the Blueflower Fm at multiple camps (Fig. 2, B), while despite abundant facies amenable to preservation of fossils in the Nadaleen Fm (Fig. 2, D), no fossils were found in the underlying, shallow-water Nadaleen Fm (Aim #4).

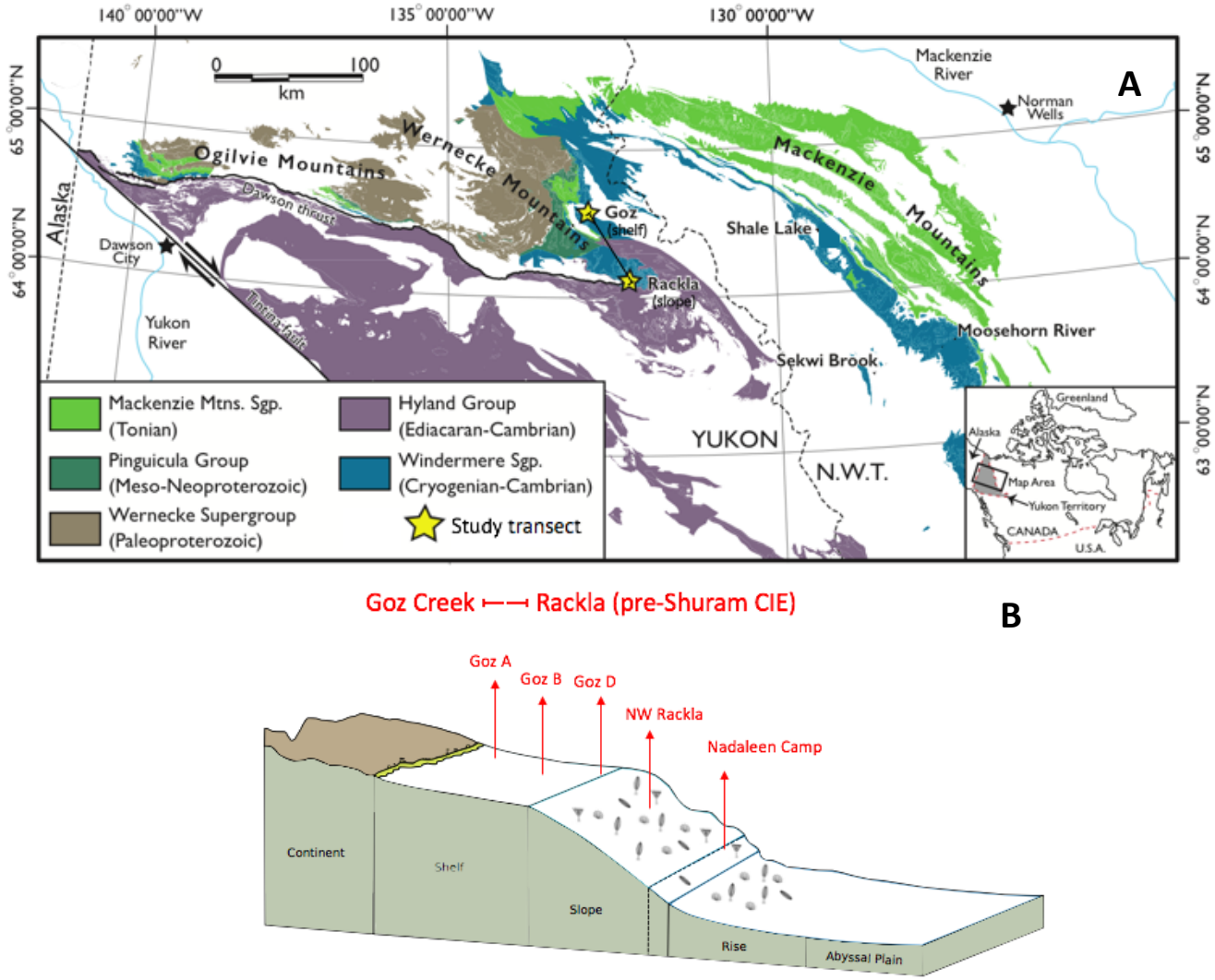
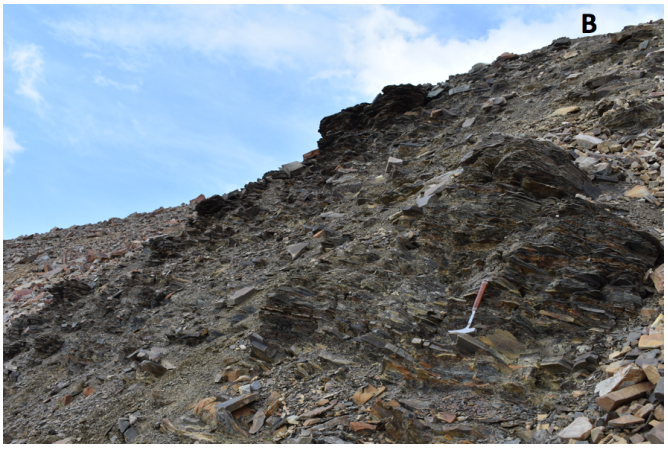


Figure 1: (A) Regional geological map of central Yukon, with Ediacaran sediments of the Windermere Supergroup outlined in blue. The Goz Creek to Rackla area shelf-to-slope transect is overlain by stars and a black line. (B) Schematic box diagram depicting the approximate locations of each fly-camp across this basinal transect.



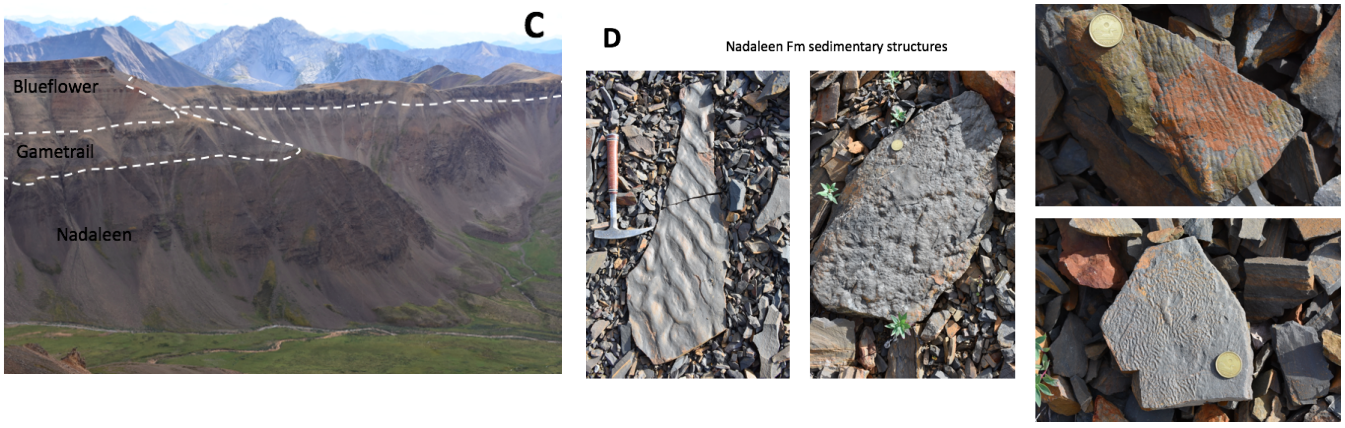


Figure 2: (A) Unfossiliferous parasequences exposed within the shallow water Nadaleen Formation at Goz A, with the start of the Gametrail Formation at the top of the ridge (N 64° 52' / W 133° 0'). Section T1702. (B) Fossiliferous Blueflower Formation at Goz A, containing *Aspidella*, *Beltanelliformis*, and *Planolites* trace fossils (N 64° 53 / W 133° 0'). Section T1703. (C) Exposure of Nadaleen through Blueflower Fms at Goz D (N 64° 30' / W 132° 58'). Sections T1710-T1711. (D) Variety of microbial mat textures and wave rippled slabs present within the unfossiliferous Nadaleen Fm at Goz D. These structures are indicative of both deposition within wave-base, as well as optimal taphonomic conditions for the preservation of Ediacara-style cast and mold fossil impressions.

Remaining Aims and Significance

The major fieldwork elements of Aims #1-4 were all successfully completed in the field. This fall, all carbonate samples have been inventoried, while cutting, drilling, and preliminary $\delta 13C$ measurements have begun as of late October. Black shale samples are currently undergoing preliminary screening for TOC and initial Re content to determine suitability for Re/Os geochronology. Stratigraphic logs and field notes are currently being digitized with preliminary interpretations being made. Two major, additional aims have been made to this study: 1. Recent experimental taphonomic evidence of fossiliferous slabs from South Australia suggest that Ediacaran cast- and mold-style preservation was due to rapid, early-stage precipitation of silica cements facilitated by extremely high silica saturation states in the oceans prior to the evolution of silica biomineralizers. Thick & thin sections of fossiliferous slabs from the Blueflower Fm will therefore be compared to unfossiliferous shallow-water sandstones of the Nadaleen Fm by measuring germanium (Ge) to silica (Si) ratios in both detrital quartz grains and surrounding silica cements. This will determine whether differential silica saturation states in the deep vs shallow ocean during the early Ediacaran can explain the observed bathymetric trend in fossil occurrence. This is possible because elevated Ge/Si values suggest precipitation of cements on early diagenetic timescales directly from the water column. Ge (umol) will be measured on thick sections using a LA-ICP-MS at the University of Santa Barbara, CA. Si (mol) will be measured on thin sections using an electron microprobe at Stanford University, CA. This device can also perform cathodoluminescence and scanning electron microscope energy dispersive spectroscopy which will be used to view cement and quartz grain morphology, and other major metals. 2. It is well understood that Ediacaran oceans were characterized predominantly by anoxic ferruginous water columns (free ferrous iron) with evidence for periodic episodes of oxygenation in shelf settings coinciding with the occurrences of Ediacaran fossils at basin-scale resolutions. Characterizing the redox landscape of the Wernecke transect is therefore extremely important for understanding how both the magnitude and spatiality of ocean oxygenation may have affected fossil occurrences. Specifically, >80 black shale samples from both deep- and shallow-water Nadaleen sections have been collected and will be analyzed for iron speciation to reconstruct the water column redox structure across the basin prior to the SIE. Iron speciation is a mature paleo-redox proxy which compares total iron (FeT) to species present in pyrite (FeP) plus other minerals formed by reducing pathways under an anoxic water column (FeHR). Iron speciation can therefore be used to distinguish between oxic, ferruginous, and euxinic (free sulfide) conditions based on the ratios of these phases. At Stanford, FeT will be measured using a handheld XRF, while FeHR will be measured using standard sequential extraction protocols. Together with a systematic description of newly collected fossils, this integrated taphonomic, sedimentological, and redox framework for the Wernecke shelf-to-slope transect will

provide critical insights into both the veracity and causal mechanisms for the deep-water origination of macroscopic metazoan life.