# NASA Astrobiology Early Career Collaboration Award Report: Testing the role of oxygen and temperature change in establishing persistently habitable environments for complex metazoan ecosystems

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*In collaboration with Drs. Andy Ridgwell (University of California, Riverside) and Noah Planavsky (Yale University)*

## Research description

The geologic record offers an accessible window into the planetary conditions required for the evolution of complex life. In this research project, I proposed the early Paleozoic (specifically the upper Cambrian through Middle Ordovician, ~497 to 458 million years ago) as a historical laboratory for the investigation of environments conducive to the evolution and persistence of complex ecosystems. The upper Cambrian-Ordovician fossil record is characterized by a transition from an extinction-dominated, relatively low-diversity marine system to one of the most dramatic biodiversity increases in the fossil record (the Great Ordovician Biodiversification Event, or GOBE). Major changes in the Earth system have been suggested as key factors in driving this biological transition, with coeval shifts inferred in global temperature and ocean-atmosphere oxygenation. However, new geochemical proxy records and modeling approaches are required to understand the magnitude of this change, and there remain competing hypotheses that cannot be ruled out without mechanistic evaluation of the links between environmental change and macroecology.

The NASA Early Career Collaboration Award enabled me to begin approaching this research problem with two collaborative research visits. In August 2019, I visited Dr. Andy Ridgwell at the University of California, Riverside to work with the cGENIE Earth system model. The aim of applying a spatially-explicit climate modeling approach to the early Palaeozoic is to test the implications of reconstructed environmental change (as inferred from the geochemical record) for marine animals at the ecosystem scale. I also visited Dr. Noah Planavsky's lab at Yale University in October 2019 to work on developing the geochemical record of early Paleozoic ocean oxygenation. Specifically, I began generating an Ordovician record of trace metal isotopes in black shales, with the aim of using this geochemical record to infer whether the Great Ordovician Biodiversification Event coincided with major changes in the marine redox landscape.

## UC Riverside visit – cGENIE models of Ordovician oxygen and temperature change

My collaborative visit to UC Riverside provided the opportunity to work with Dr. Andy Ridgwell, the developer of the cGENIE Earth system model. cGENIE is an Earth system model of intermediate complexity (EMIC) designed for the geospatial evaluation of deep-time biogeochemical problems (including the incorporation of ancient tectonic configurations), and has recently been utilized by other astrobiology studies bridging the gap between Earth history and the detection of habitable worlds. Visiting UC Riverside provided a valuable learning opportunity for me to develop my understanding of how to parametrize model simulations with cGENIE, and to develop research projects with Dr. Ridgwell. Specifically, we worked on simulating an ensemble of modeled Ordovician oceans at a range of atmospheric oxygen and carbon dioxide concentrations. I am now combining these three-dimensional ocean simulations with an ecophysiological modeling framework known as the metabolic index to investigate the mechanistic implications of changing planetary conditions for ocean habitability with respect to marine animals. Figure 1 illustrates the key environmental variables (dissolved oxygen and seawater temperature, A-B) and a modeled habitability metric (metabolic habitat viability, C) that are evaluated in this framework. Ongoing research will evaluate the impact of changes to the Earth's ocean-atmosphere system (as inferred from the geochemical record) on the habitability of marine environments through the early Paleozoic.

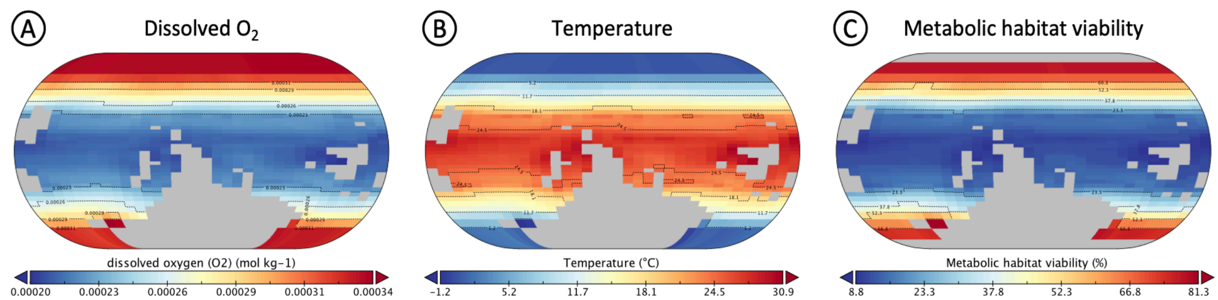


Figure 1: Example oceanographic maps of the Ordovician Earth system. Model uses an Ordovician plate configuration available from the cgenie.muffin GitHub repository. A) Oxygen and B) temperature estimates are directly modeled oceanographic variables. C) Metabolic habitat viability illustrates the percentage of modern ecophysiotypes (from laboratory respirometry experiments) that would be able to inhabit different regions of the modeled ocean.

**Yale visit – trace metal isotope geochemistry of Ordovician black shales**

My collaborative visit to Dr. Noah Planavsky's lab at Yale University enabled me to begin a trace metal isotope geochemistry project investigating the marine redox landscape of the early Paleozoic. Specifically, I analyzed the major and minor trace element concentrations, and uranium isotope compositions of Ordovician black shales. The aim of generating this trace metal isotope dataset is to use these data to understand whether there were major shifts in the marine redox landscape that coincided with the changes we observe in marine ecosystems through the Ordovician. I performed bulk rock digestions of black shales that I had previously collected (with collaborators from Stanford University, Dartmouth University and the Yukon Geological Survey) from the Road River Group, Yukon, Canada, and additional black shale samples from the graptolitic shale collections of the University of California Museum of Paleontology (originating mainly from sedimentary successions in New York and Norway). With collaborators at Yale, I measured the bulk metal concentrations of these black shale samples on the Thermo Finnegan Element XR ICP-MS at the Yale Trace Metal Geochemistry Center. I further used previously described column chromatography and double spike methods to prepare splits of these dissolved rock samples for uranium isotope analysis on the Thermo Finnegan Neptune Plus MC-ICP-MS at the Yale Trace Metal Geochemistry Center (Figure 2).

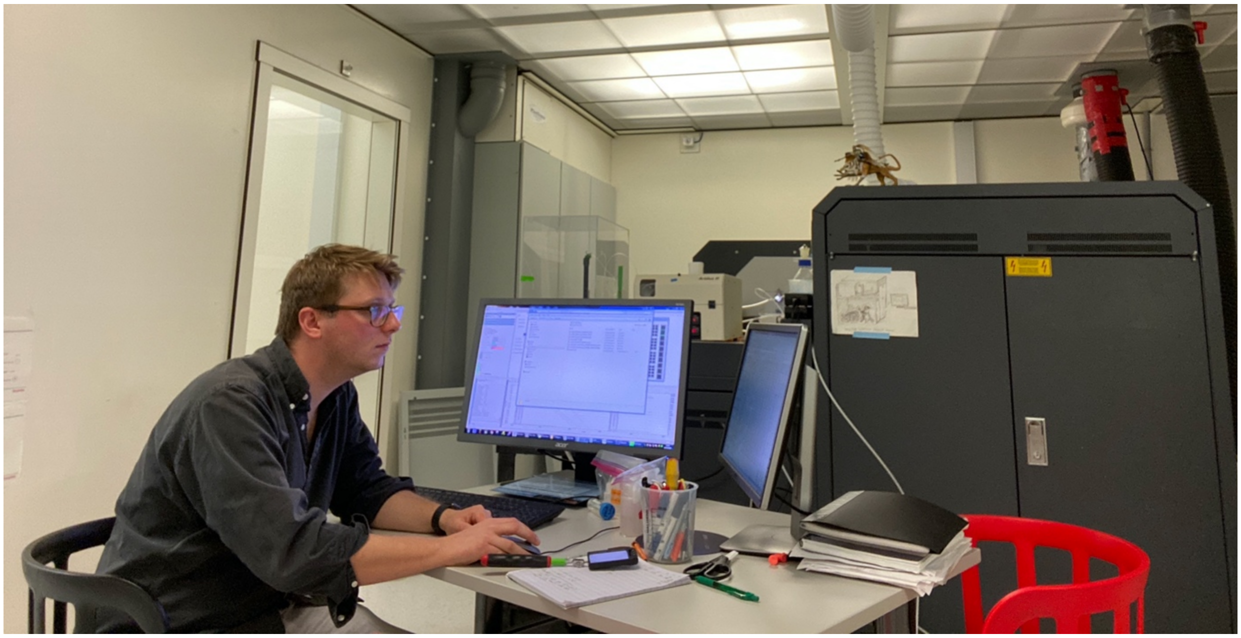

Figure 2: Richard working on the Thermo Finnegan Neptune Plus MC-ICP-MS at the Yale Trace Metal Geochemistry Center.


## Thanks to the NASA Astrobiology Program

I am very thankful to the funding provided by the NASA Astrobiology Early Career Collaboration Award in support of the collaborative research visits described above. This research award facilitated valuable learning experiences and enabled the initiation of new research projects that otherwise would likely not have been possible. Thank you to the NASA Astrobiology Program for providing these opportunities.