Antarctic Bursary Award Project Report
Lisa C. Herbert
30 November 2023

Project title: Benthic Iron Fluxes and Cycling in the Amundsen Sea

Project duration: June 2022-December 2023.

Project summary:

This project investigated whether nutrient iron (Fe) sourced from shelf sediments plays a role in fertilizing primary productivity and stimulating carbon drawdown in the iron-limited Amundsen Sea, off West Antarctica. The major goals of this project were to (1) determine the concentrations and forms of Fe present in pore waters of Amundsen Sea near-surface sediments, (2) quantify and characterize fluxes of dissolved Fe across the sediment-water interface, and (3) identify drivers of spatial variability in benthic Fe cycling and fluxes. In particular, this project aimed to determine whether microbially driving reductive Fe release or non-reductive, abiotic Fe release dominated sediment fluxes. To address these goals, I collected sediment cores on the NBP22-02 cruise in January-March 2022 as part of the National Science Foundation-funded ARTEMIS project. Using Antarctic Bursary funds, pore water and solid sediment samples were then analyzed in the lab for trace metal and organic carbon contents, and benthic fluxes of dissolved Fe were calculated. The calculated fluxes were incorporated into a regional model, simultaneously improving the model and testing the possible sources and transport of benthic Fe in the Amundsen Sea.

Activities and results in support of Goal 1 (characterize pore water Fe):

Between October 2022 and March 2023, all collected pore water samples were analyzed for trace metal concentrations at Rutgers University. The resulting high quality pore water data had a low detection limit (<6 nM) and revealed measurable dissolved trace metal concentrations even in sediment regions without significant metal reduction rates, indicating low-level, non-reductive release. Pore water trace metal concentrations and the depth of the metal-reducing zone also varied substantially between sites. To determine colloidal trace metal concentrations, concentrations in 0.02 um filtered sample splits were compared to those in 0.2 um splits of the same sample. Measurable colloidal trace metal concentrations were only identified at two sites, which were also the only two sites where a fluff layer of unconsolidated, fresh algal material was observed on the sediment surface. This indicates that rapid delivery of fresh organic matter generates a larger pool of colloidal, organically complexed trace metals in the pore water.

Activities and results in support of Goal 2 (quantify fluxes of dissolved Fe):

Dissolved trace metal concentrations in bottom water samples were analyzed following pre-concentration at Rutgers University. The bottom water Fe concentrations were used to calculate benthic fluxes assuming simple diffusion along the bottom water – sediment Fe concentration gradient. Benthic Fe fluxes were overall low, ranging from 0.13 $\mu$mol $m^{-2}$ $d^{-1}$ on shallow banks near the coastline to 0.06 $\mu$mol $m^{-2}$ $d^{-1}$ in deeper regions. Dr. Pierre St-Laurent at the Virginia Institute of Marine Science incorporated the calculated flux values as a boundary condition in a regional physical circulation model, which led to accurate reproduction of observed bottom water concentration in about half the sites. However, the model could not reproduce the high bottom water Fe concentrations in the region with the observed algal fluff layer, supporting the idea of an Fe source from the fluff.

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Activities and results in support of Goal 3 (understand spatial variability in benthic Fe cycling):
Profiles of trace metal concentration with depth in the sediment were compared for a suite of redox-sensitive trace metals (Mn, Co, and Ni) to fingerprint reductive Fe release at a given site and sediment depth. In the surface sediments, based on the low concentrations of Fe and lack of correlation with Mn, Co, and Ni, Fe is likely released through nonreductive mechanisms such as organic matter decay or reactive mineral weathering. In contrast, in the deeper sediments dissolved Fe is released through microbially mediated dissimilatory Fe reduction, driven by low availability of other oxidants for organic carbon oxidation. The balance between reductive and non-reductive Fe release may be controlled by total organic carbon (TOC) contents, with higher contents fueling more microbial respiration and higher rates of dissimilatory Fe reduction. Therefore, total organic carbon (TOC) in the solid sediment was analyzed at Rutgers University. The consolidated sediments had relatively low TOC contents, between 0.18-1.5 wt %, while the fluff layers were 2-3 wt % TOC. However, no correlation was observed between pore water Fe and solid sediment TOC, suggesting that TOC is not the main factor controlling Fe release at most sites. One exception was found: elevated concentrations of Fe, Mn, Co, and Ni were observed in the fluff layer, indicating reductive metal release within a reducing microenvironment as the high concentration of fresh algal matter is vigorously remineralized.

Summary of findings
Overall, this project revealed primarily non-reductive benthic Fe fluxes in the Amundsen Sea, a surprising finding in such a productive region. This suggests that most of the carbon fixed by photosynthesis in the highly productive surface waters is respired back to carbon dioxide prior to burial in the sediments, leading to relatively low rates of anaerobic microbial metabolism in the consolidated sediments. However, this research also revealed an exciting new mechanism that could be supplying additional Fe: the rapid remineralization of an unconsolidated algal fluff layer on the sediment surface generating a reducing microenvironment and releasing mineral Fe to the bottom water. This could create a positive feedback loop whereby colloidal Fe released from the fluff could be transported to the surface ocean through glacial upwelling, fertilize more phytoplankton growth, and generate more sinking organic matter. Such a feedback is likely to be seasonal, only occurring in the late spring and summer, and highly sensitive to changes in phytoplankton bloom dynamics and glacial melt rates.

Dissemination of results:
The results of this project will be presented at the AGU Ocean Sciences Meeting in February 2024 (see citation below). A manuscript sharing this research is in preparation for submission to Nature Geoscience in Spring 2024. Upon publication, all data associated with this project will be made available in a public data repository.

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Presentations and publications relevant to the award:

***Herbert, L. C.,** Lepp, A. P., Garcia, S. M., Browning, A., Miller, L. E., Wellner, J., Severmann, S., Hillenbrand, C.-D., Johnson, J. S., Sherrell, R. M. Volcanogenic fluxes of iron from the seafloor in the Amundsen Sea, West Antarctica. Marine Chemistry, Volume 253, 2023, 104250, **https://doi.org/10.1016/j.marchem.2023.104250**

**Herbert, L. C.,** Lepp, A., Simkins, L., Wellner, J., Hillenbrand, C. D., Johnson, J. S., Severmann, S., Sherrell, R. M. A Potential Benthic Source of Nutrient Iron Driving Productivity in the Amundsen Sea in the Context of Current and Past Glacial Retreat. **Presented** at the American Geophysical Union Fall Meeting. December 2022. Chicago, IL.

**Herbert, L. C.,** St-Laurent, P., Steffen, J., Oliver, H., Fitzsimmons, J., Sherrell, R. M. Variable benthic fluxes of iron to a coastal Antarctic ecosystem revealed by a coupled modeling-observational approach (Amundsen Sea, West Antarctica). **Accepted for presentation** in session HE005: Heading South: Contrasting biogeochemical cycling of trace elements and isotopes from tropical to Southern Ocean waters, Ocean Sciences Meeting. February 2024. New Orleans, LA.

**Herbert, L. C.,** St-Laurent, P., Steffen, J., Cohen, C., Fitzsimmons, J., Wellner, J., Robert M. Sherrell, R. M. Benthic fluxes of dissolved trace metals in the Amundsen Sea: a coupled modeling and observational approach. **In preparation** for submission to Nature Geoscience, 2024.

*publication of preliminary data that informed this project