The mineralogy of hydrothermal plume particles at the Endeavour mid-ocean ridge

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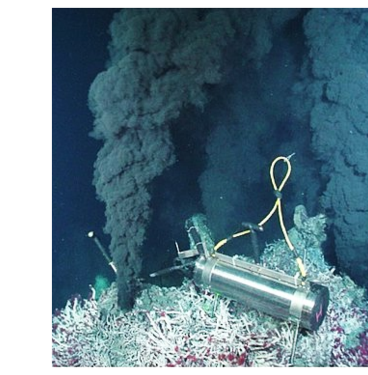


INTRODUCTION

Black smokers venting along mid-ocean ridges are an important source of elements to the ocean [1]. For example, they may be important in controlling the availability of Fe, a limiting micronutrient, to primary producers. The black smoke is generated from particles precipitating from vent fluids. We must understand these particles' deposition and chemical evolution in order to understand how hydrothermal venting contributes to seawater biogeochemistry.

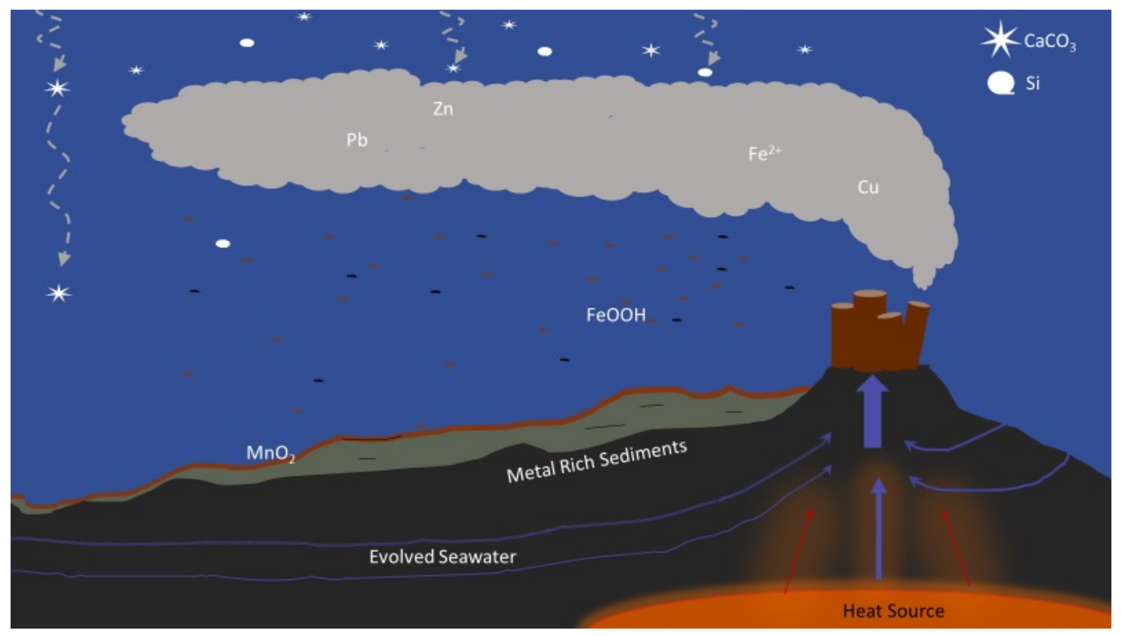


Figure 1. Simplified diagram of hydrothermal vents and their plumes' sedimentation / chemistry.

Hydrothermal vents form at mid-ocean ridges when seawater travels through fractures in the ocean crust. The fluid is heated by the underlying magma body and altered by reacting with the host rock, dissolving components such as Fe(II) and Mn(II). Eventually, fluids reach the surface and the buoyant, metal-rich fluid is expelled into cool, oxidizing seawater, leading to the precipitation of the dissolved constituents [2]. This forms chimney structures and suspended particles that eventually fall onto the seafloor.

STUDY AREA

Off the coast of Vancouver Island lies an active hydrothermal area, the Endeavour segments of the Juan de Fuca Ridge. The sediment core examined in this study is from roughly 3km from major vents.

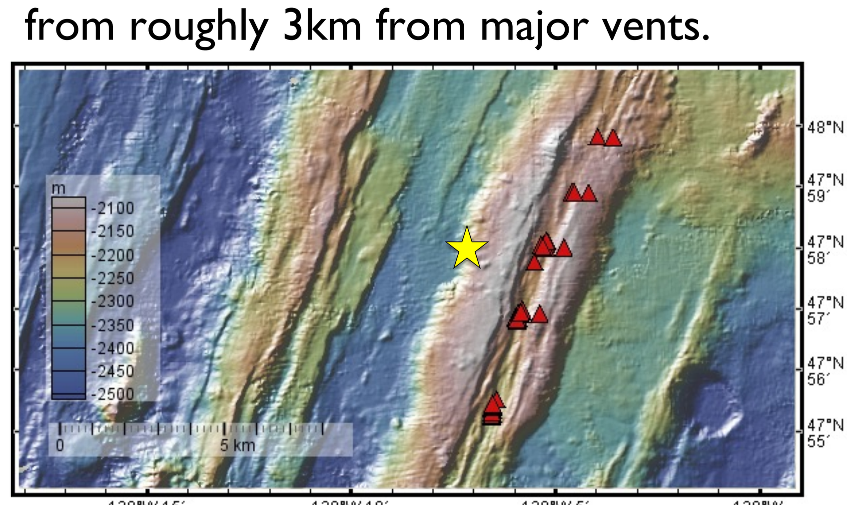


Figure 2. Bathymetry map of Endeavour showing active vents' locations and the sediment core sampling location Figure made with GeoMapApp[3].

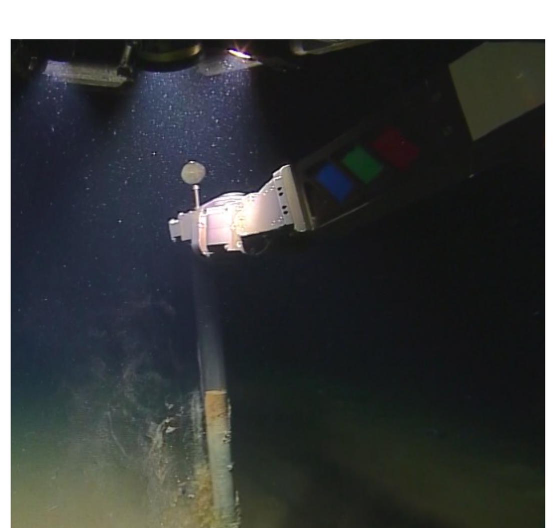


Figure 3. Arm of a remotely operated vehicle (ROV) collecting the sediment core used in this study (Source: ONC SeaTube [4]). For scale the core barrel is ~1 m long.

I used samples from different depths in this core to determine the mineralogical evolution of hydrothermal particles deposited from the Endeavour hydrothermal plume.

METHODS

To determine the amount of different minerals in the sediment, and how these vary with depth, I performed a 6-step dissolution using solvents suited for specific mineral phases, such as carbonates, silicates and oxyhydroxides, like ferrihydrite and magnetite.

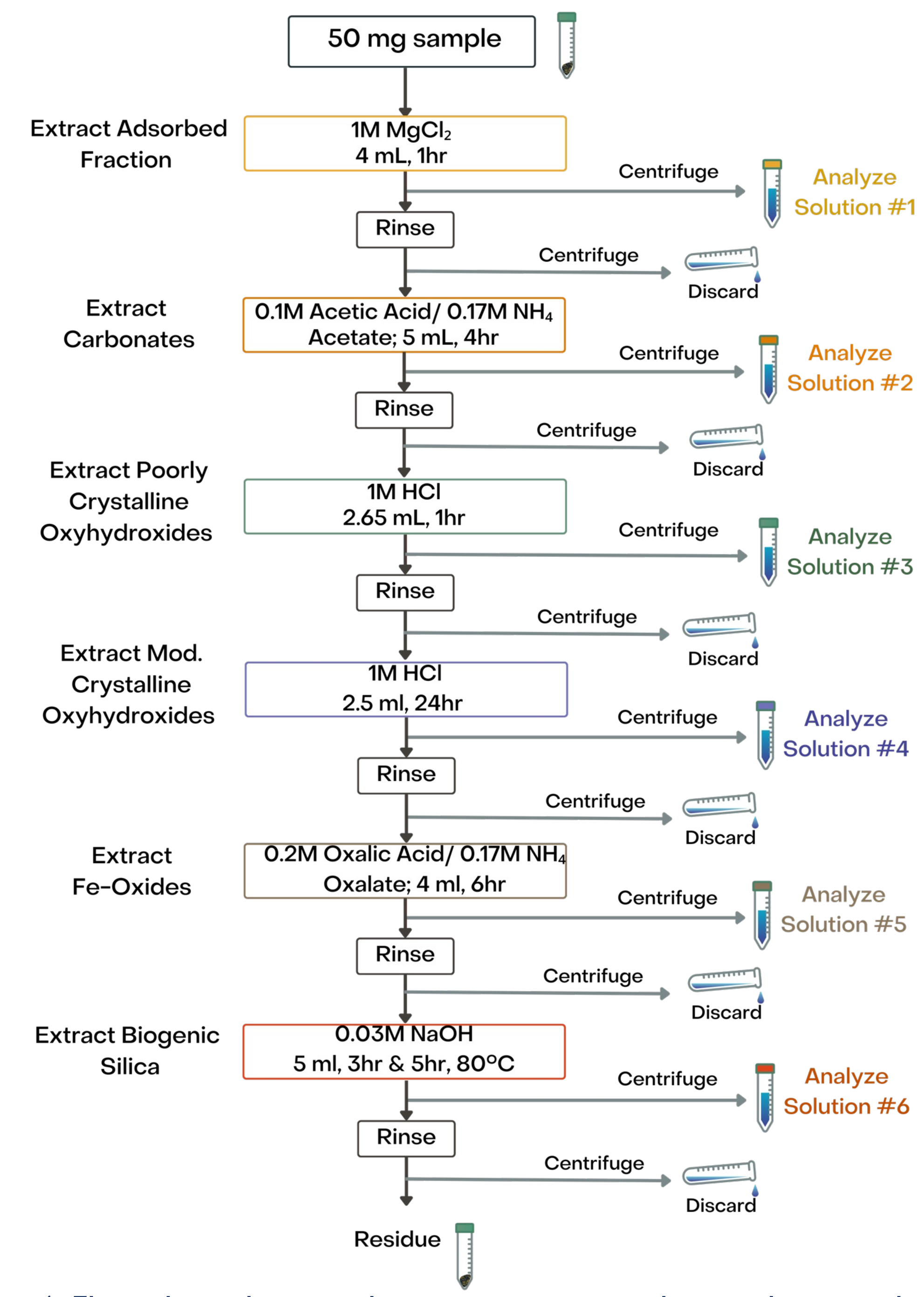


Figure 4. Flow chart showing the extraction procedure and target phases for each step. Rinse used de-ionized H_2O. Centrifuge is at 3500 rpm for 10 minutes.

The analysis uses ICP-MS, a mass spectrometer in SEOS that separates ions by their mass-to-charge ratio allowing high-precision determination of the major and trace elements removed with each extraction.

RESULTS

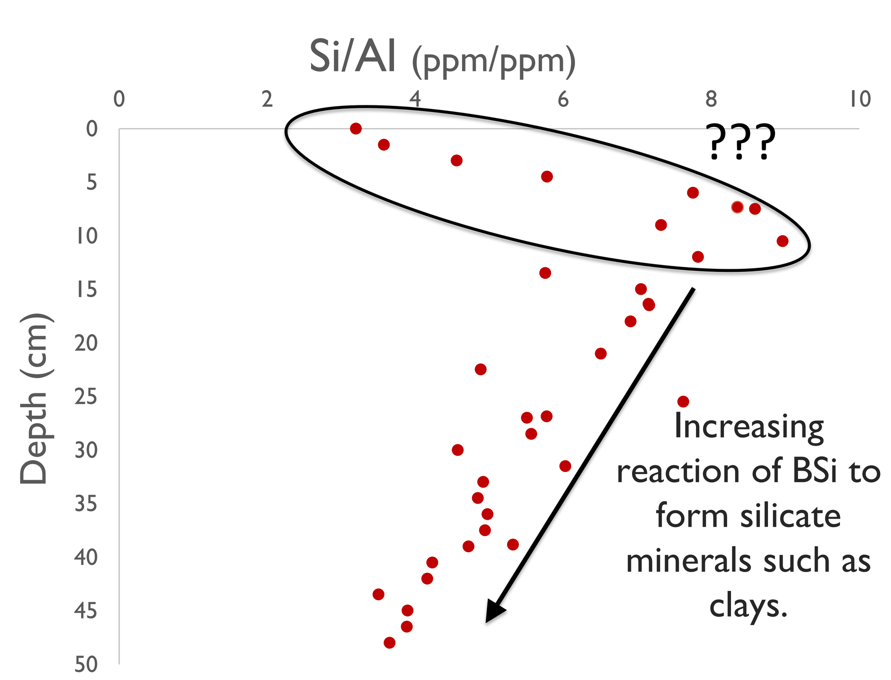


Figure 5. Unexpected trend in the ratio of Si/Al in upper sediments.

The Biogenic silica (BSi) in this setting is provided by diatoms. These diatoms (high Si/Al relative to any contribution from silicate minerals) break down over time, forming aluminosilicate phases. The upper sediments, however, display an unexpected rise in Si/Al ratio toward the redox boundary.

RESULTS CONTINUED

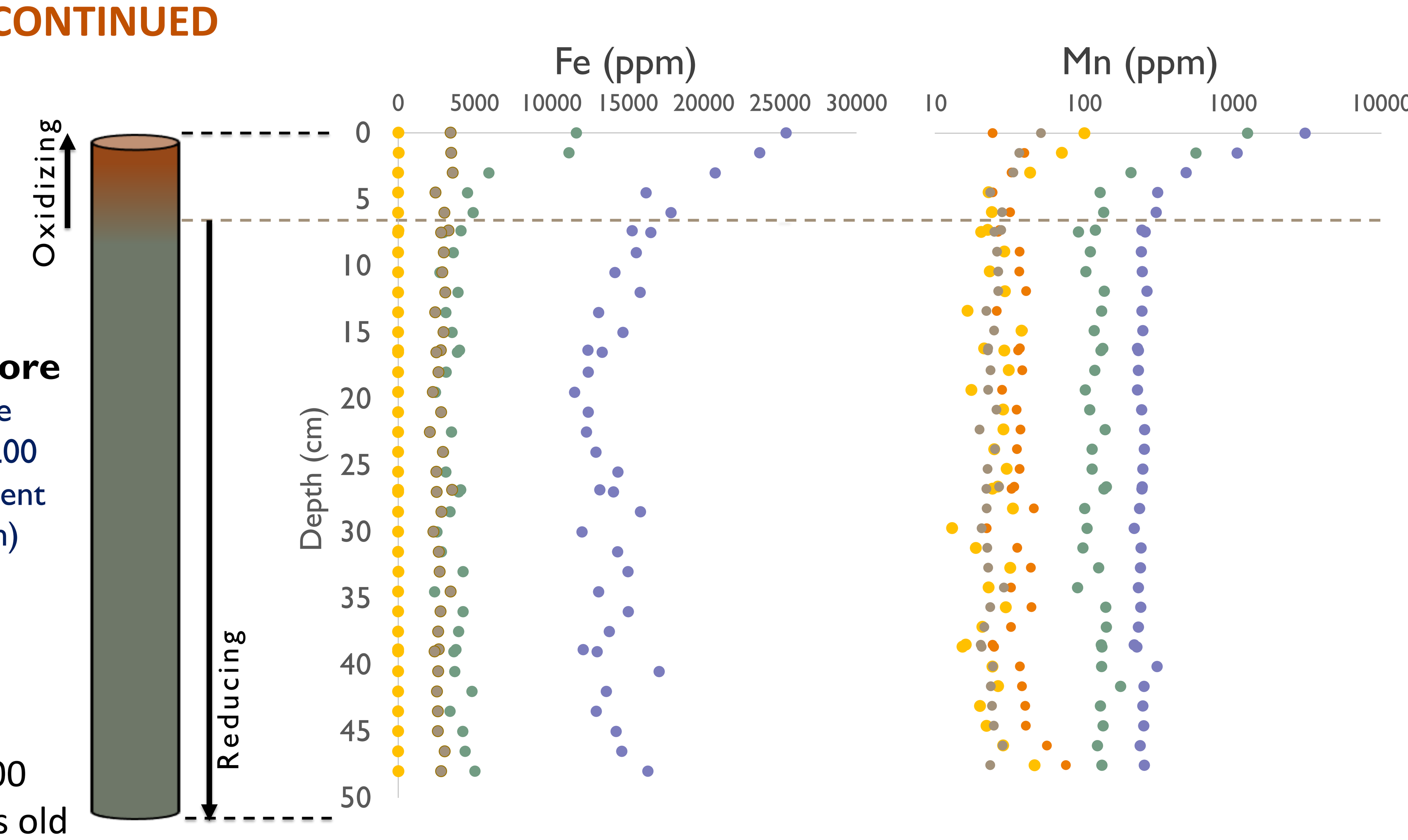


Figure 6. Fe and Mn content for each extraction and change with depth aligning with redox transition in the sediment core.

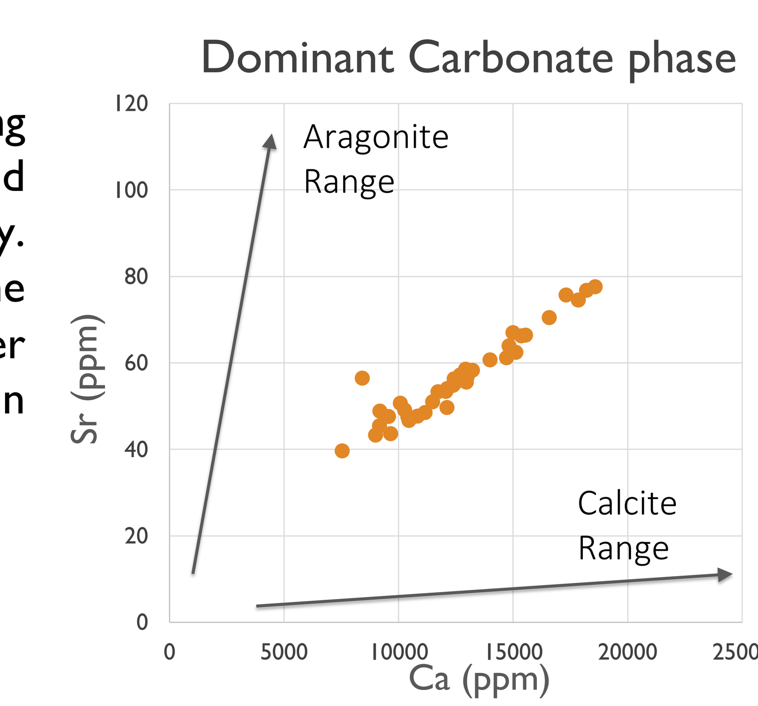
These sediments have a very high hydrothermal component, mostly in oxyhydroxide phases as reflected in the large amount of Fe and Mn extracted in solutions 3 and 4, but little from other steps. The Redox transition at ~6 cm coincides with the change in trend in the data for these elements.

Three hypotheses are consistent with the higher concentrations near the surface:

1. Poorly crystalline oxyhydroxides such as ferrihydrite, recrystallized into more refractory phases that aren't targeted by these reagents over 500-1000 years.
2. Poorly crystalline oxyhydroxides dissolved and the elements released were lost by diffusion upward through pore fluids into seawater.
3. Upward movement of dissolved species may re-precipitate once reaching oxidizing conditions near surface.

RESULTS CONTINUED

Carbonates are contributed to these sediments by raining down of biological material such as pteropods and foraminifera, composed of aragonite and calcite, respectively. Both these minerals are undersaturated when they reach the seafloor, but aragonite is lost more rapidly due to higher solubility. Sr/Ca is a tracer of this since it is concentrated in aragonite more than in calcite.



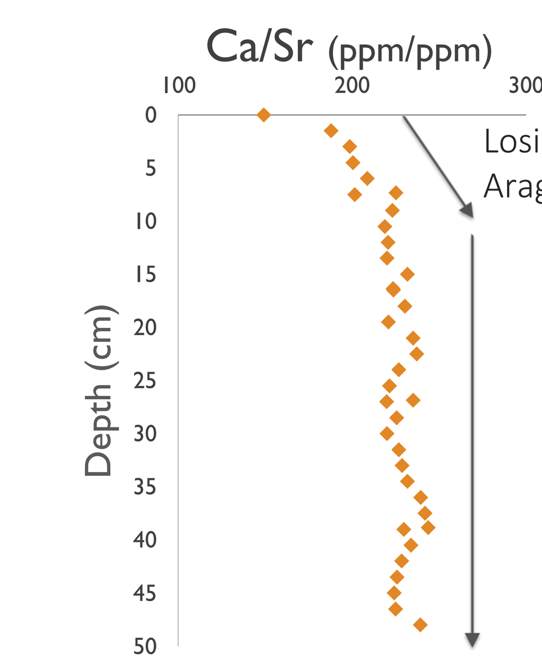


Figure 7a. (Left) Sr content in solution 2 showing both carbonates present in the core. 7b. (Right) Losing aragonite in the core within 10 cm depth.

CONCLUSIONS

The method developed for this study produced excellent data allowing for a detailed analysis of mineralogical and geochemical changes occurring on long timescales in sediments at hydrothermally active sites. Presented are a few examples of the kind of data and associated interpretations.

FURTHER RESEARCH

- Carry out pore fluid analysis to test the hypotheses suggested for Mn and Fe.
- Perform the method and analysis on sediment trap samples to determine the composition of the initial sediment.
- Compare the results to cores we have now collected from various distances from primary vents to add a spatial variation component to the data.

REFERENCES

1. Fitzsimmons, J.N., John, S.G., Marsay, C.M., Hoffman, C.L., Nicholas, S.L., Toner, B.M., German, C.R., and Sherrell, R.M., 2017, Iron persistence in a distal hydrothermal plume supported by dissolved-particulate exchange: Nature Geoscience, v. 10, p. 195–201.

2. German, C. R., & Seyfried, W. E. (2014). 8.7 - Hydrothermal Processes. In *Treatise on Geochemistry* (Second Edition, pp. 191–233).

3. Bathymetry map and vent location data from GeoMapApp, (www.geomapapp.org) last accessed on February 22, 2022.

4. Ocean networks Canada's Hercules ROV taking a sediment core sample -> photo of collection -ONC SeaTube; July 17, 2017, 16:54.

Image of black-smoker source: "The-Sound-Generated-by-Mid-Ocean-Ridge-Black-Smoker-Hydrothermal-Vents-pone.0000133.g002" by Crone T, Wilcock W, Barclay A, Parsons J is licensed under CC BY 3.0.

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