Exploring Hydrogen-Rich Venting Beneath an Ice-Covered Ocean – On Earth

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Introduction: In July 2023 the Nereid Under Ice (NUI) hybrid (autonomous/remotely operated) vehicle was used to explore submarine hydrothermal venting at two locations in the ice-covered Arctic Ocean, the Aurora hydrothermal field on the Gakkel Ridge and the Lucky B area in Lena Trough. These operations were conducted aboard FS Polarstern Cruise 137 ALOIS (Arctic Lithosphere Ocean Interaction Studies) where NUI, a CTD rosette and the OFOBS (camera and high resolution mapping instrument) were used to conduct hydrothermal investigations in concert with an extensive geophysics program.

Hydrothermal Dives at Aurora: The ice-covered Aurora hydrothermal vent field is located at the westernmost end of the ultraslow spreading Gakkel Ridge at a depth of 3900 m. Three NUI dives were conducted at the Aurora field, each of 9-10h duration including 2-4h of operations at the seafloor and at maximum horizontal separations away from the ship, under ice, of 1.4-2.1km. During the first dive we revisited the three previously known high temperature vents from Aurora and then set down and sampled at a low-temperature vent site, "Dragonfly" for mineralogy/ microbiology. During our second dive we relocated to find three new high temperature vents including a conjugate pair of low and high temperature vents, "Lander" and "OrbiLander" where we sampled for vent fluids. Our third dive started with high resolution bathymetric mapping of the entire system followed by completion of our fluid sampling program and, finally, bathymetry- and sensor-guided discovery of a series of three more low-temperature hydrothermal flow sites and four more high-temperature vents. Post-cruise processing of opportunistic imaging at this site is allowed 3D representations of the terrain to be constructed.

Lucky B Vent-Site, Lena Trough: After relocation to Lena Trough our final dive combined three separate phases of autonomous ocean sensing, autonomous seafloor mapping and a human-guided geological and biological reconnaissance traverse across the seafloor. This was our longest dive (10.33h in the water, 5.25h science operations at depth) and saw the ship travel 7.3km over that time, while NUI roamed up to 2.7km horizontally away from the ship.

Aurora Vent Geochemistry: Hydrothermal vent fluids were collected using gas-tight samplers deployed from NUI to investigate geochemical processes that may contribute to the origin and maintenance of life on ice-covered ocean worlds. Venting of hot-spring fluids at Aurora occurs from numerous tall black smoker chimneys that are surrounded by extensive areas of lower temperature discharge. Our sampling program intentionally targeted an area of lower temperature venting (126°C) located a few meters from a previously unknown high temperature (360°C) black smoker vent. The sites were subsequently named "Lander" and "OrbiLander", respectively, to reflect the nature of their discoveries. Our prioritization of low temperature venting arose because formation of low temperature fluids by subseafloor mixing and cooling may promote chemical reactions that contribute to the aqueous inventory of prebiotic compounds and redox reactive chemical species that represent a source of metabolic energy for vent associated ecosystems. The high temperature endmember vent fluid at Aurora is extraordinarily H_2-rich with dissolved concentrations approaching 50 mmol/L, suggesting substantial interaction with ultramafic rocks in subseafloor reaction zones. The abundant H_2 is accompanied by dissolved CH_4 concentrations in excess of 1 mmol/L. In lower pressure environments such as the ice-covered seafloor of Enceladus, the high levels of dissolved H_2 at "Orbi-Lander" could exceed the aqueous solubility of H_2 resulting in bubble formation with implications for vertical transport through the water column. The lower temperature "Lander" fluid is characterized by a substantially lower H_2/CH_4 that suggests abiotic consumption of H_2 above and beyond what can be assigned to simple dilution during mixing with seawater. Implications for the delivery of chemical energy and sources of reduced carbon compounds to seafloor environments and the overlying water column on Earth, Enceladus and other ocean worlds will be discussed.