3-2020

SUBSEA 2019 Expedition to the Gorda Ridge

Darlene S. S. Lim

Nicole A. Raineault

John A. Breier
The University of Texas Rio Grande Valley, john.breier@utrgv.edu

Eric W. Chan
The University of Texas Rio Grande Valley

Josh Chernov

See next page for additional authors

Recommended Citation

Lim, D. S. S., Raineault, N. A., Breier, J. A., Chan, E., Chernov, J., Cohen, T., Deans, M., Garcia, A., German, C. R., Hauer, M., Hu, S., Huber, J. A., Kane, R., Nawotniak, S. K., Lees, D., Lowe, J., Lubetkin, M., Marsh, L., Milesi, V., … Sylva, S. (2020). SUBSEA 2019 Expedition to the Gorda Ridge. Oceanography, 33(1), 36–37.

Authors

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The SUBSEA (Systematic Underwater Biogeochemical Science and Exploration Analog) program blends ocean exploration with "ocean worlds" research, along with NASA analog and work studies research, to address science, science operations, and technology knowledge gaps related to the exploration of our solar system. The science group researches venting fluids at isolated seamounts and spreading ridges in the Pacific Ocean as analog environments to putative volcanically hosted hydrothermal systems on other "ocean worlds" (defined as places in the outer solar system that could possess subsurface oceans). The science operations research group studies E/V *Nautilus* architecture, distributed teams, communication, and low-latency telerobotics. The technology research group provided Exploration Ground Data Systems (xGDS) software to the shore team to support the integration and visualization of diverse data products during the cruise.

From May 22 to June 9, 2019, the SUBSEA team explored the SeaCliff hydrothermal field, an off-axis submarine vent system located in the northernmost segment of Gorda Ridge, a section of the globe-circling mid-ocean ridge that lies ~200 km off the coast of Oregon and California (Figure 1). Von Damm et al. (2006) reported that SeaCliff emitted clear fluids from barite and anhydrite chimneys at temperatures no greater than 300°C. The 2019 deployment at Gorda Ridge was the second for SUBSEA; the first was to Lō`ihi Seamount off the Big Island of Hawai'i in August 2018 (Lim et al., 2019).

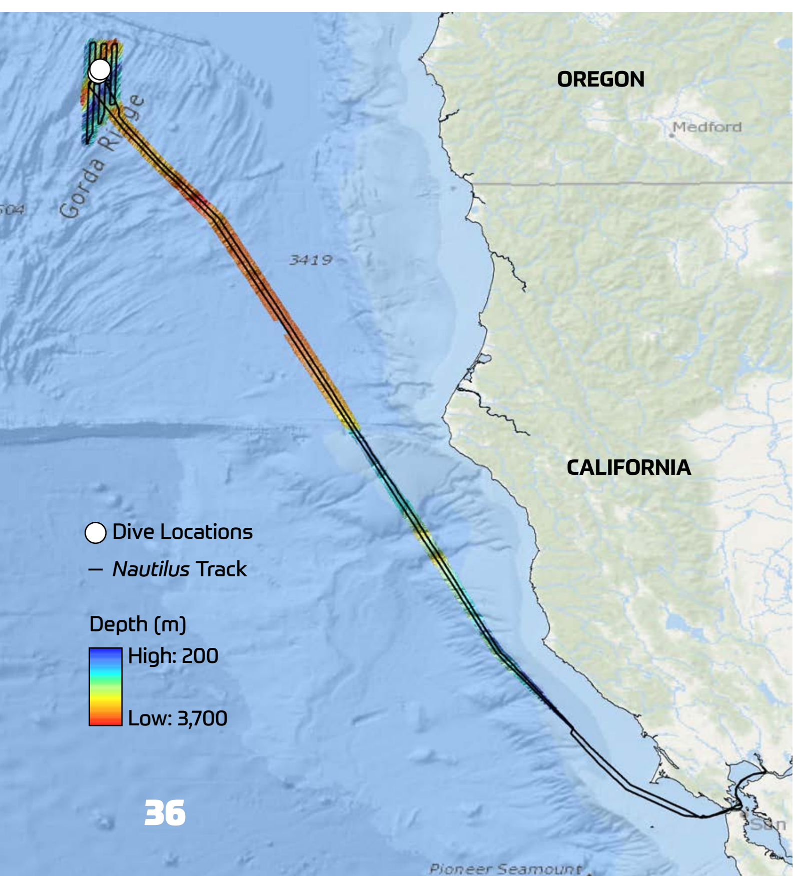

FIGURE 1. A cruise summary map showing the shiptrack (black line), multibeam depth data, and ROV dive locations.

The Gorda Ridge operational environment was significantly different from the first SUBSEA cruise. This year, researchers tested whether telepresence could be used as an analog for developing human space exploration. After the 2018 cruise, members of the operations research group examined the feasibility of implementing flight-like parameters for the Gorda Ridge deployment. They assessed the SUBSEA teams' workflow and decision-making elements in order to develop plans to alter the two-way communication between ship and shore. A planned work schedule and communication protocols were circulated for feedback and adjustments months prior to the cruise. A week-long operational readiness test prior to the cruise allowed the team to enact their workflow within study conditions.

Team members were distributed across two worksites: (1) the University of Rhode Island's Inner Space Center, which included members of the science and technology groups, and (2) on board *Nautilus,* which included members of science (natural and social/operations) groups; experts in navigation, robotics, and mapping; and the ship's crew. Communication across distributed teams was subject to protocols for ship-to-shore and shore-to-ship communications and data sharing. The Mode 1 protocol emphasized the use of written exchanges for communicating between ship and shore workgroups via specific documents sent daily. This was a radical departure from the use of typical *Nautilus* telepresence architecture that uses real-time oral and chat-style text communications. The Mode 2 protocol lifted all restrictions. This experiment was a success. The target number of days for each mode was reached and both natural and social science objectives were achieved.

The technology group enhanced the telepresence architecture by integrating its web-based xGDS open-source software into the shore-side science activities. xGDS supported planning, situational awareness, and data visualization for the ISC team and was tailored specifically to support *Nautilus* data sets. xGDS leveraged OET's data

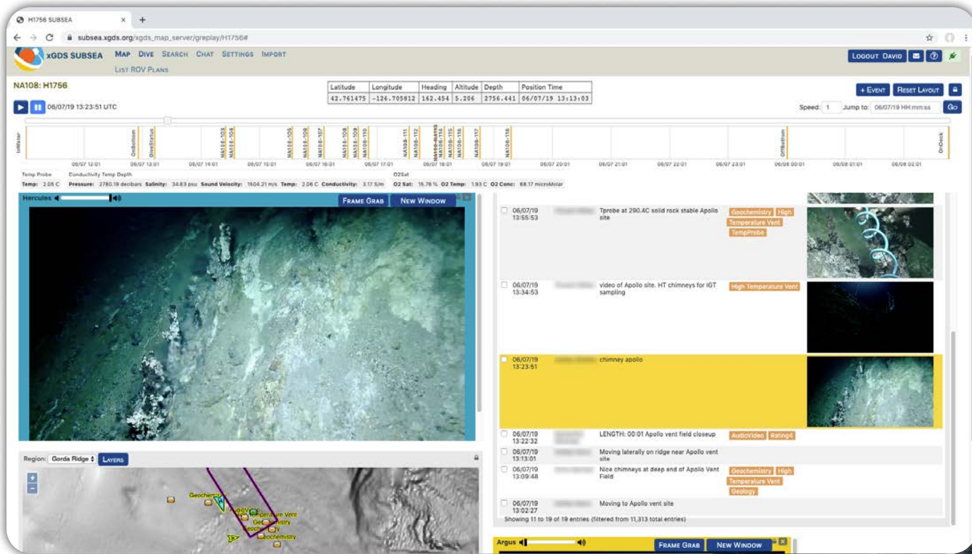

FIGURE 2. The xGDS live, interactive interface with (counterclockwise from top left): streaming video from ROV *Hercules*, navigation/positioning from E/V *Nautilus* and ROVs *Hercules* and *Argus*, collaborative note-taking, and still capture of video frames at the University of Rhode Island's Inner Space Center (yellow row).

broadcast infrastructure (from *Nautilus* to shore) to record and display real-time positioning of the ROVs and *Nautilus*, oceanographic data (e.g., CTD, O_2), and observations logs within the xGDS interface (Figure 2). These data were synchronized with a copy of the satellite video. The onshore team used xGDS to search and replay dives with a unified context comprising a site map, video, telemetry, and event data. xGDS was also used to simulate the distance and duration of upcoming dives, including specific activities (e.g., sampling), to generate a human-readable dive plan and to export the plan in formats for delivery to various navigation and mapping software.

Science activities for volcanology, geochemistry, microbiology, and chemical engineering groups were conducted within Mode 1 and Mode 2. During the pre-cruise period, the group developed a tool that would maximize scientific return. Geochemists modeled thousands of prospective water-rock interactions at the origin of hydrothermal fluids venting at the SeaCliff site to identify shipboard chemical measurements that would allow them to learn in real time about the hydrothermal system. The comparison between daily sample measurements and modeled fluid compositions provided answers and posed new questions about the functioning of the system, which were used to define subsequent dive and sampling objectives.

Researchers explored the broader morphologic context of the rift valley, measuring how sediment infill impacts apparent surface roughness over time and used apparent textural anomalies to identify and discover the Apollo hydrothermal field. Basalt substrate was collected from the targeted areas to better constrain the chemical evolution of surface rocks that are in contact with both hydrothermal fluids and ambient seawater. Fluid, rock, and eukaryotic mat samples were collected in order to understand how the geochemistry and energetics of the vent fluids affect the abundance, distribution, and metabolic function of microbial communities. These samples are currently being studied using a variety of techniques, including stable isotope probing, culturing, grazing experiments, cell counts, and DNA-based analyses. Colonization devices that contained rock and mineral grains as prospective colonization substrates for vent microbes were deployed and recovered during the 2019 expedition (Figure 3). These devices were deployed for up to one week to examine the identity and function of the microbial community associated with mineral surfaces as compared to the free-living planktonic community present in venting fluids. The addition of colonization experiments at vent sites on Gorda Ridge allowed the team to gain a more complete picture of microbial processes occurring in the subsurface at hydrothermal vents.

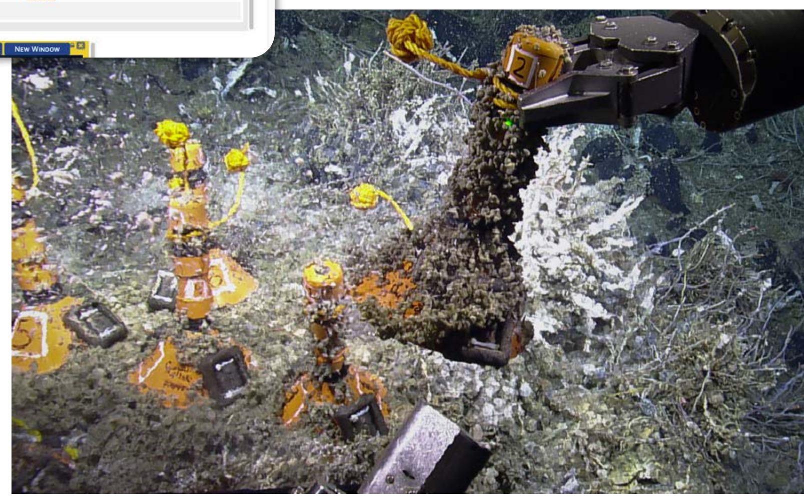

FIGURE 3. An ROV manipulator retrieves a colonization experiment from a vent system on Gorda Ridge.

Gorda Ridge was the final cruise for the SUBSEA research program. We anticipate that our partnership between the ocean and space science research communities will broadly impact and contribute to the state of knowledge in (1) the habitability and energetics of an expanded range of analog vent systems for ocean worlds, (2) methods for conducting science-driven exploration in representative deep space environments such as Mars, and (3) the capability to support mission science teams as they conduct telerobotic missions.