HABITABILITY POTENTIAL OF ENCELADUS: AN ANALOG STUDY OF THE LŌʻIHI SEAMOUNT SYSTEM IN HAWAI'I.

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Introduction: In the search for possible microbial life beyond Earth, NASA has focused attention on planetary bodies that have sufficient evidence of past or present liquid water—one such world is Saturn's moon, Enceladus. Measurements from the *Cassini* orbiter revealed that Enceladus contains a hydrothermally-active liquid water ocean underneath its icy shell [e.g., 1-4]. To aid in future missions, we must address fundamental knowledge gaps about volcanically-hosted submarine hydrothermal systems, including to what extent hydrothermal fluids at the seafloor influence seawater-dominated mafic rock alteration processes. This includes understanding which elements are readily available for microbes to use as nutrient and energy sources, and in what concentrations and spatial distributions they exist.

This investigation contributes to understanding the microbial habitability potential of Enceladus by evaluating the major controls on the chemical exchange between submarine rocks, hydrothermal fluids, and seawater at the Lōʻihi seamount in Hawai'i. Lōʻihi is a compelling hydrothermal analog system for Enceladus due to its environmental conditions (temperature, pressure), host rock type (mafic silicate), and geologic setting (isolated hotspot). We hypothesize that mineralogical and chemical changes of the host rock basalt at hydrothermal vent sites are fundamentally different than typical seawater alteration and that these changes improve microbial habitability potential. We utilized petrographic and scanning electron microscopy paired with major and trace element spectrometry to quantify distinct chemical populations of minerals, make qualitive observations of mineral spatial distribution, and compare the relative bulk geochemical abundance of the exterior to interior within samples from across Lōʻihi.

Sample Collection: This work is supported by the NASA PSTAR-funded Systematic Underwater Biogeochemical Exploration and Analysis (SUBSEA) project. Submarine lava samples proximal and distal to hydrothermal vent orifices were collected by a remotely operated underwater vehicle (ROV) via robotic manipulator arm during the SUBSEA scientific cruise to the Lōʻihi Seamount in August and September, 2018. The SUBSEA scientific cruise (NA100) was conducted from the Exploration Vessel (E/V) *Nautilus*, which is equipped with the ROV *Hercules* and ROV *Argus*. The SUBSEA team successfully conducted a systematic program of rock, vent fluid, and microbial sampling at five distinct hydrothermal vent sites (M2, M31, M34/M38, M57a, and M58b) previously identified during the Fe-Oxidizing Microbial Observatory (FEMO) scientific cruise in 2006 across the summit of Lōʻihi [5, 6]. These five vents fell within four regions at Lōʻihi: Loihau (M2), Tower (M31), Spillway (M34/M38), and Pohaku (M57a and M57b) (Fig. 2 and Fig. 3) [7]. This report covers the geologic results of our cruise.

Sample Processing: We used microscopic (petrographic, SEM) and spectrographic (EDS, XRF) analyses to measure the mineralogical and geochemical change over the outer few centimeters in basalt samples taken from hydrothermal vent areas and locations distant from any evidence of sustained thermal activity. We separated interior and exterior fractions of a given rock sample using a visible transition from relatively glassy to stony groundmass as seen in hand sample. The 1-1.5 cm glassy exterior of the rock was separated from the >2cm deep interior using a wet rock saw, with material from each portion used to create thin sections and powder for analyses.

Results: The submarine basaltic rocks collected from the Lōʻihi vent orifices record a spatially and temporally complex hydrothermal system. These changes occur on a local scale within a vent orifice and on a regional scale across the edifice. On a local level, the Tower vent basalt has both high- (pyrite, talc-pyrophyllite) and low-temperature (jarosite, siderite-magnesite) assemblages, recording a temporally variable system consistent with past observations of fluid temperatures. The Tower area is also spatially complex with preferential enrichments of Si-rich precipitates in the exterior and Fe-rich precipitates in the interior. Furthermore, carbonates found at Pohaku, Loihau, and Spillway all show a similar pattern of compositional zoning (siderite-magnesite rim and siderite core) suggesting regional variability in the source of CO_2 at Lōʻihi. The trace element data show different enrichment and depletion patterns in the exterior, with Tower showing the largest change from exterior to interior in Cl, S, Zn, Ba, and Cr; this supports varying fluid histories that influenced the vent basalts.

The basalt petrographic and geochemical results provide evidence for variable olivine phenocryst degradation at Pohaku, Loihau, Spillway, and Tower, ordered least to most alteration. The variety of alteration states could reflect the duration that the basalt was in direct contact with hydrothermal fluids or the ion content of the hydrothermal fluids or rock type. The major element oxide pattern behavior suggest that the aqueous environment at the vents enabled net loss of Fe and Mg but retention of Si, Ca, Al in the exterior over the interior. The behavior of Fe, Si, and Ca contrasts with typical submarine basalt alteration due to a change from ion undersaturated and oxidizing (seawater conditions) to ion saturated and reducing (hydrothermal conditions). Both the petrographic and major oxide investigation shows a consistent pattern in increased bulk change correlated to the increased degree of olivine phenocryst alteration where there are progressively greater wt.% differences from the exterior to interior within each sample as the degree of alteration progresses.

Taken as a whole, the results of this study indicate that the materials necessary for habitability occur not only in the seawater surrounding hydrothermal seeps at Lōʻihi, but also in the rocky subsurface. We hypothesize that the elemental and molecular concentration gradients associated with the rocky substrate may even aid in inhabitation in some instances as the basalt serves to prolong the existence of the gradient compared to the diluting effects of ambient seawater; such areas may be very spatially discontinuous, however, depending on the fluid history. Thus, future work on Enceladus should, if possible, consider not only the habitability of the water but also the warm, nutrient-enriched rocky seafloor. Further work from our microbiology and geochemistry collaborators should indicate which elements or molecules should be enriched in Enceladus' seawater if the seafloor is, indeed,

Conclusions: These analyses indicate that Lōʻihi has a spatially and temporally complex hydrothermal system with large changes in composition, and therefore potential habitability, over centimeter and larger scales. The geological results will be combined with fluid geochemical and microbiological results from research collaborators at other institutions within SUBSEA to more clearly define the Lōʻihi hydrothermal system. These results will be incorporated into geochemical models to expand the range of Earth-based hydrothermal vents to be related later to Enceladus habitability potential.

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References: [1] Porco C. et al. (2006) *Science, 311,* 1393-1401. [2] Spencer J. et al. (2006) *Science, 311* 1401-1405. [3] Postberg F. et al. (2009) [4] Iess L. et al. (2014) *Science, 344* 78-80. [5] Glazer B. and Rouxel O. (2009) *Geomicrobio J., 26,* 606-622. [6] Rouxel O. et al. (2018) *Geochemica et Cos Acta., 220,* 449-482 [7] Davis A. and Clague D. (2003) *Canadian Min, 41,* 457-472.