Informing geobiology through GIS site suitability analysis: locating springs in mantle units of ophiolites

Alexandrea Bowman[1]*, Dawn Cardace[1], and Pete August[2] University of Rhode Island, Department of Geosciences[1], Natural Resource Science[2]
Kingston, RI 02881-2019, abowman@my.uri.edu, cardace@uri.edu, pete@edc.uri.edu; *Corresponding author

Brief Abstract Springs sourced in the mantle units of ophiolites serve as windows to the deep biosphere, and thus hold promise in elucidating survival strategies of extremophiles, and may also inform discourse on the origin of life on Earth. Spring locations associated with serpentinites have traditionally been located using a variety of field techniques. The chemical properties of these springs reflect a reducing subsurface environment reacting at low temperatures producing high pH, Ca^{2+}-rich formation fluids with high dissolved hydrogen and methane. This study applies GIS site suitability analysis to locate high pH springs in Coast Range Ophiolite serpentinites in Northern California.

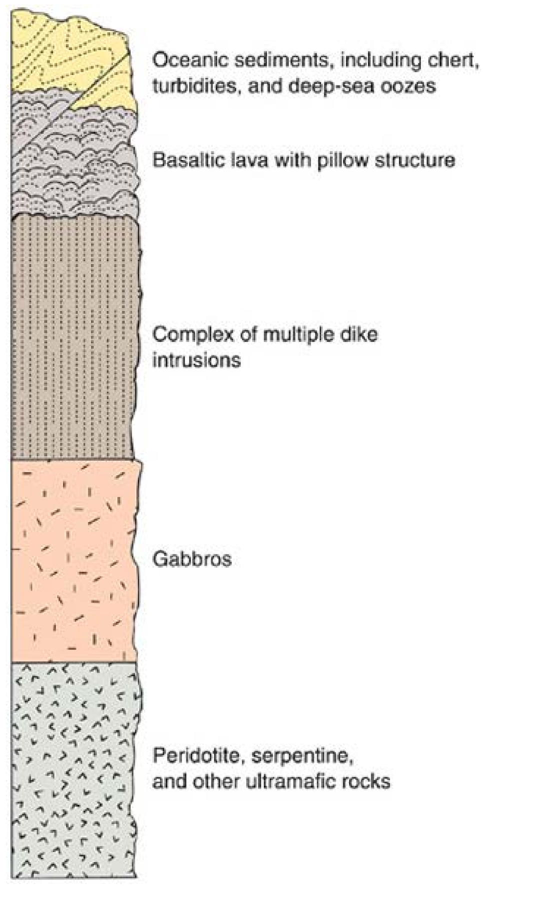

Figure 1: Cartoon of ophiolite showing lithostratigraphic units (Levin, 2006). For this project, the ultramafic unit is prioritized.

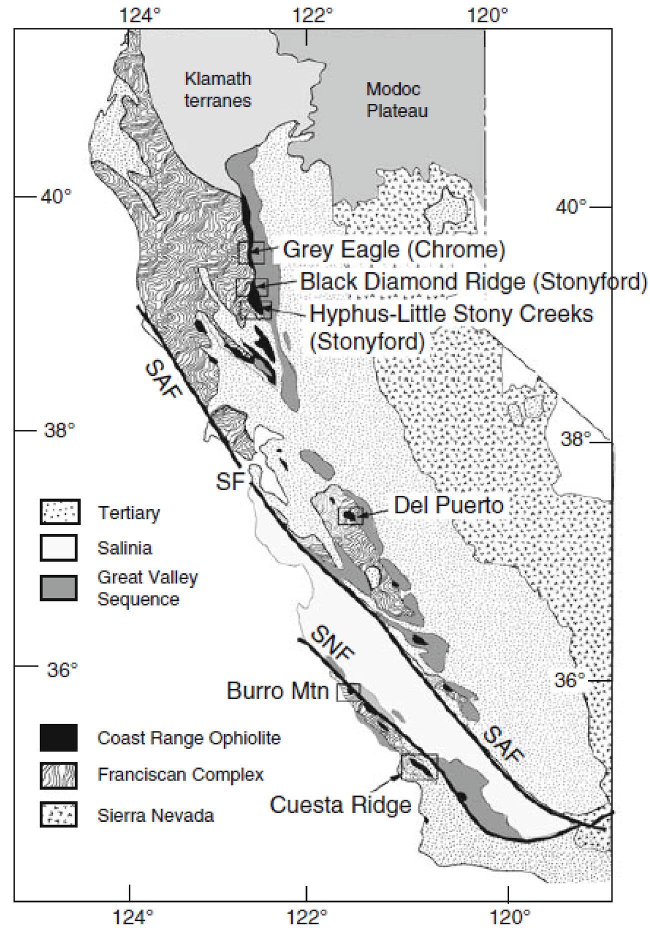

Figure 2: Map of California geology (Choi et al., 2008). Coast Range Ophiolite in black and is part of the study area for this project.

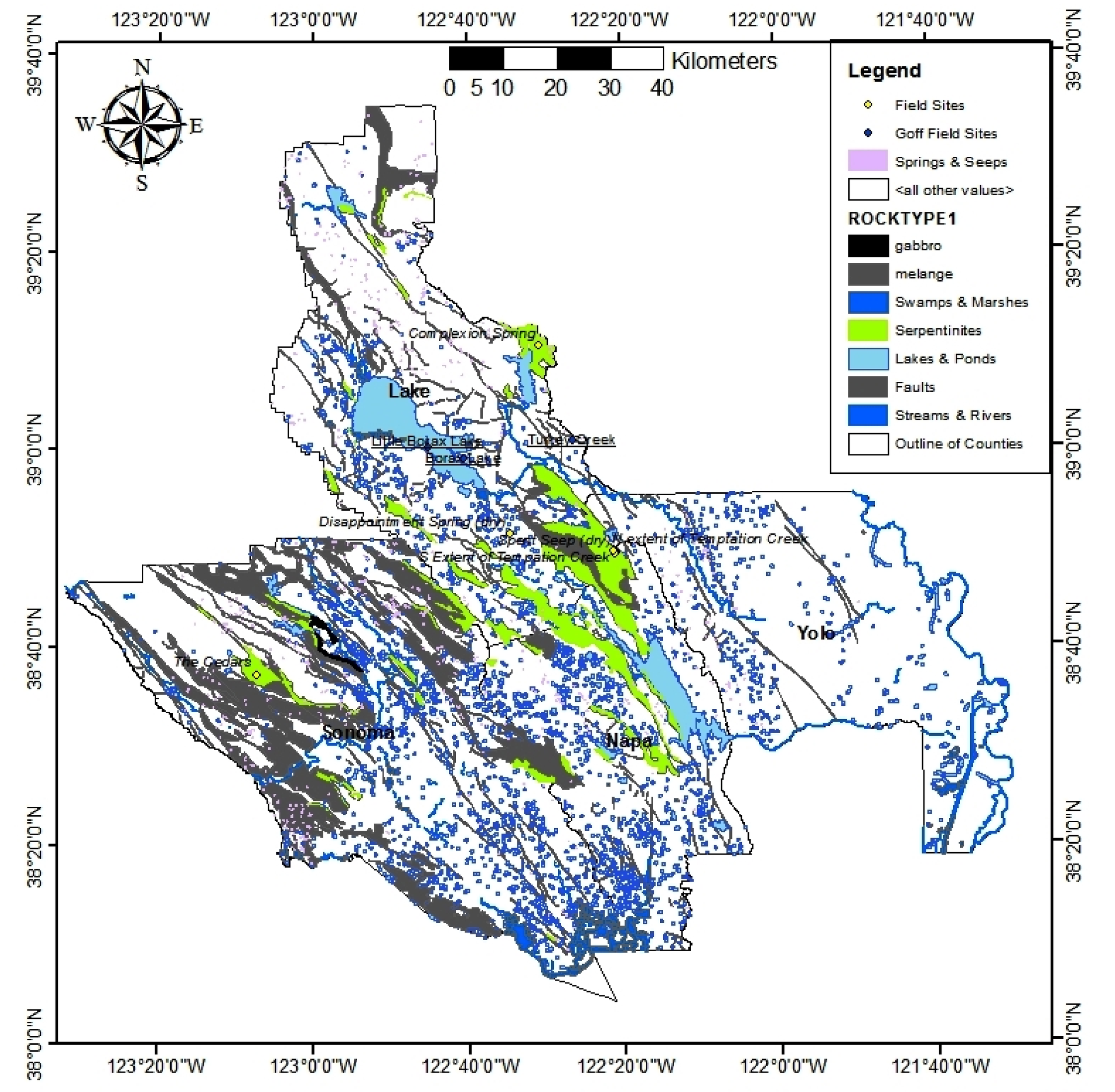

Figure 3: Ultramafic rocks in 4 CA counties: Sonoma, Lake, Yolo, & Napa. Data at http://mrdata.usgs.gov/geology/state and http://nhd.usgs.gov/data. in vector format, clipped to the study area, and converted into raster format.

Introduction and Geologic Setting Ophiolites (Fig. 1) are blocks of tectonically uplifted oceanic lithosphere; constituent rock units include marine lithostratigraphic sequences spanning marine sediments to mantle peridotite. Springs sourced in the mantle units of ophiolites serve as windows to the deep biosphere, analogous to the Lost City Hydrothermal Field vents (Kelley et al., 2005; Martin et al., 2008). Ocean vent systems fed by serpentinization may be places where life originated (Sleep et al. 2011). Aqueous fluids reacting with peridotite generate secondary mineral assemblages dominated by serpentine and distinctive formation waters with extremely high pH, elevated Ca^{2+}, and high dissolved gas loads, observed both in the seabed (Kelley et al., 2005) and in continental settings; (Barnes et al., 1972). The Coast Range Ophiolite (Fig. 2), located in N. CA, has ample surface outcrops of altered peridotite (McLaughlin et al., 1998) and multiple regional examples of high pH, Ca^{2+}-OH^- water-bearing springs (Barnes et al., 1972). We used a suitability analysis focused exclusively on four CA counties to predict spring localities for further study (Fig. 3).

Results GIS model results are shown in Fig. 4 a total area of 375,251.8 m^2 have been predicted by the model. In areas which appear to have more of the required geological and environmental factors.

Methods We used available geospatial data (*e.g.*, geologic maps, elevation data, fault locations, known spring locations, etc.) and ArcGIS software to predict new spring localities. Important variables in the suitability model were: (a) bedrock geology (*i.e.*, serpentinite/peridotite), (b) fault locations, (c) regional data for the location of groundwater and (d) slope. After field work we integrated serpentinite contact boundaries and serpentine endemic plants to the site suitability analysis.

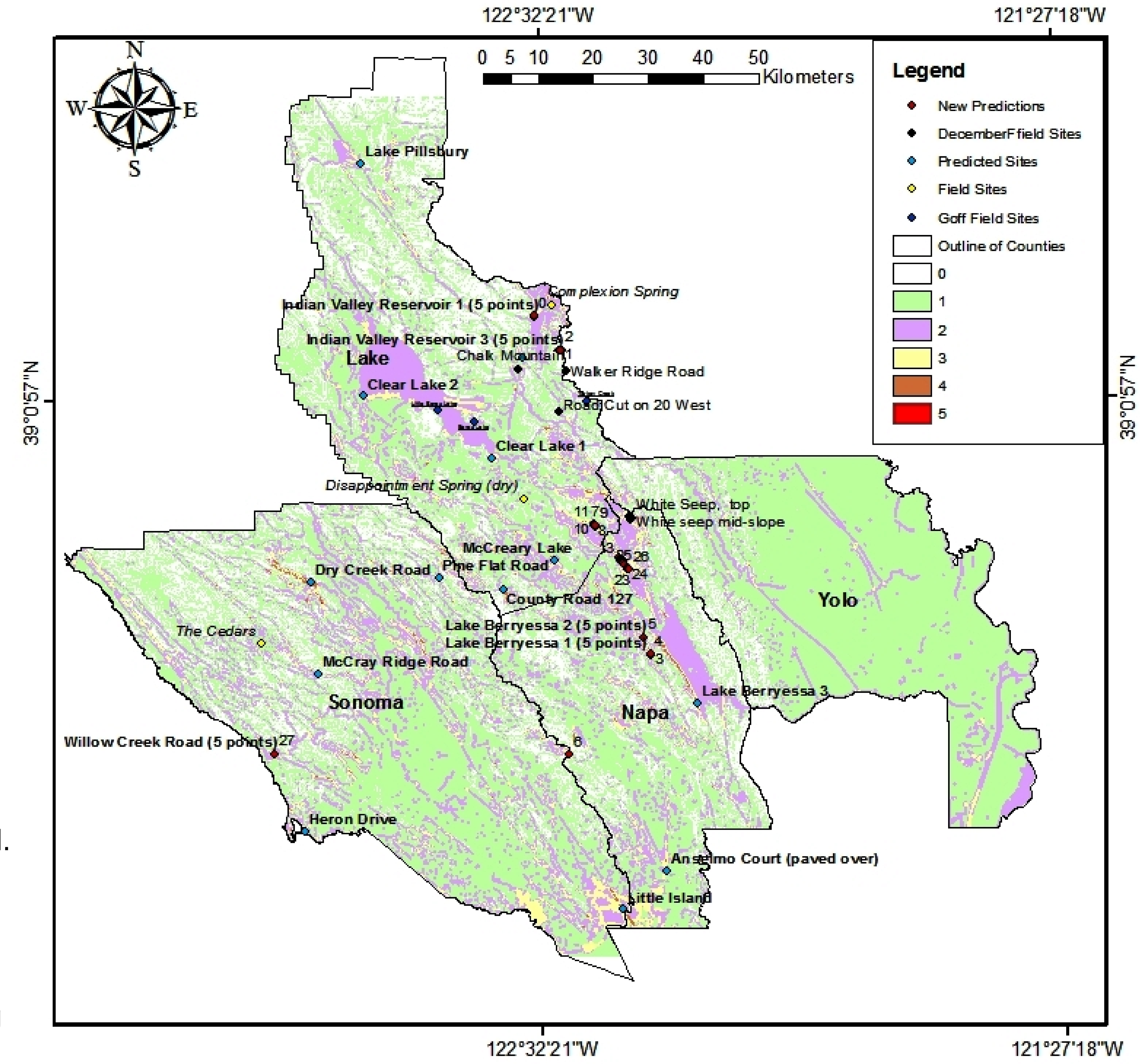

Figure 4: Suitability analysis was performed using the weighted sum ArcTool, which overlays raster data sets, multiplying each by their given weight, and summing them together. Results show that surface water, bedrock geology, and geologic features (*i.e.*, faults) control spring location. Points labeled "Goff Field Sites" are referenced in Goff et al., (2011). .

Implications Site suitability analysis successfully predicts new spring localities for ongoing deep biosphere research, given simultaneous evaluation of (a) bedrock geology (*i.e.*, unit boundaries/contacts for peridotite, serpentinite), (b) fault locations, (c) groundwater, spring, and other surface water distribution data, and (d) landform slope data. These factors appear to be controlling spring expression. Future directions include systematic survey of these aqueous features, because they are windows to active, dislodged remnants of deep habitat from the ocean crust, and provide exciting points of comparison for global scale geobiology of ultramafic rocks, helping to define extremophile adaptations to high pH, carbon-poor waters.

References: Barnes, I., Rapp, J. B., and O'Neil, J. R., 1972. Metamorphic Assemblages and the direction of Flow of Metamorphic Fluids in Four Instances of Serpentinization. Contr. Mineral. and Petrol. 35, 263--276 ; Choi, S. H., Shervais, J. W., Mukasa, S. B., 2008. Supra-subduction and abyssal mantle peridotites of the Coast Range ophiolite, California. Contrib Mineral Petrology. 156:551–576. DOI 10.1007/s00410-008-0300-6; Goff, F.,Bergfeld, D., Janik, C. J., Counce,D.,Stimac, J. A., 2011.Geochemical Data on Waters, Gases, Rocks, and Sediments from The Geysers–Clear Lake Region, California (1991–2000). Los Alamos National Laboratory is operated by the University of California for the United States Department of Energy under contract W-7405-ENG-36. LA-13882-MS; Kelley, D. S., Karson, J. A., Fruh-Green, G. L., Yoerger, D. R., Shank, T. M., Butterfield, D. A., Hayes, J. M., Schrenk, M. O., Olson, E. J., Proskurowski, G., Jakuba, M., Bradley, A., Larson, B., Ludwig, K., Glickson, D., Buckman, K., Bradley, A. S., Brazelton, W. J., Roe, K., Elend, M. J., Delacour, A., Bernasconi, S. M., Lilley, M. D., Baross, J. A., Summons, R. E. and Sylva, S. P., 2005. A Serpentinite-Hosted Ecosystem: The Lost City Hydrothermal Field. Science, Vol. 307, 1428.; Levin, H. L., 2006. The Earth Through Time. 8th Edition, p. 169. John Wiley and Sons, ISBN: 13 1978-0471-69743-5.; Martin, W., Baross, J., Kelley, D., and Russell, M.J., 2008, Hydrothermal vents and the origin of life. Nature Reviews Microbiology, 6, 805- 814; McLaughlin, R. J., Blake, M. C., Griscom, A., Blome, C. D., and Murchey, B., 1988. Tectonics of formation, translation, and dispersal of the Coast Range ophiolite of California. Tectonics, Vol. 7, No. 5, pp. 1033-1056.; Ponsa, M. L., T. Fujiib, G. Q., Rosingc, M. T., Reynarda, B., Moynierd, F., Doucheta, C. and Albarèdea, F. 2011, Early Archean serpentine mud volcanoes at Isua, Greenland, as a niche for early life. PNAS, 108, 17639–17643; Sleep, N. H., Bird, D. K., and Pope, E. C., 2011. Serpentinite and the Dawn of Life. Philosophical Transactions of the Royal Society, 366, 2857-2869.

Acknowledgments: We gratefully acknowledge funding for this project from the Sloan Foundation Deep Carbon Observatory: Deep Life I: Microbial Carbon Transformations in Rock-Hosted Deep Subsurface Habitats, Project number 0003148, The University of Rhode Island College of the Environment and Life Sciences and Geosciences department. Special thanks to AISES, especially the Lake Erie Chapter for their help and guidance. URI, especially my advisor Dr. Cardace, Joe Klinger and thesis committee members, Drs Pete August, Steve Carey, Brian Savage and my friend and colleague Justice Mensa for his advice on this project. I would also like to thank Dr. Cheryl Wilga, LEPC of AISES, and Catalina Martinez for mentorship.