PLANETARY SUBSURFACE SCIENCE AND EXPLORATION: AN INTEGRATED CONSORTIUM TO UNDERSTAND SUBSURFACE SOURCES OF ENERGY AND THE UNIQUE ENERGETICS OF SUBSURFACE LIFE:

H.V.Graham[1], B. Sherwood Lollar[2], J. F. Mustard[3], K.L. Rogers[4] and V. Stamenković[5], [1]CRESST/NASA Goddard Space Flight Center, 8800 Greenbelt Rd, Greenbelt, MD 20771 heather.v.graham@nasa.gov, [2]Dept. of Earth Sciences, University of Toronto ON Canada M5S 3B1, [3]Dept. of Earth Environmental and Planetary Sciences, Brown University, Providence RI, [4]Earth and Environmental Sciences, Rensselaer Polytechnic Institute 110 8th Street Troy, NY 12180, [5]NASA Jet Propulsion Lab/CalTech, Pasadena CA

Introduction: Our understanding of planets has been unnecessarily constrained by our position as organisms anchored to the thin surface veneer of the planet Earth. Globally fundamental questions persist concerning the complexities of chemical, physical, and biological interactions in the Earth's subsurface – all of which impact the crust. Our surficial bias has persisted as we explore other worlds, our attention unfortunately focused on high energy, recent and readily accessible systems. Our conception of Mars has been overturned as studies have uncovered the role of water in Martian history [1 and references therein], discovered liquid water at the base of polar caps [2], and introduced the potential for aerobic brines in the subsurface [3]. New models of a more porous planet emerge that may support subsurface habitable zones.

Responding to this knowledge we have, along with a dozen other colleagues, formed a research consortium integrating datasets that explore the co-evolution of planetary processes and habitability (and potentially life) by studying the interactions between the subsurface and the surface on Earth, the only planet we know well. This research addresses recommendations recently identified in the National Academies astrobiology strategy report [4] indicating that future research should include "exploration of subsurface habitability in light of recent advances demonstrating the breadth and diversity of life in Earth's subsurface, [and] the history and nature of subsurface fluids, on Mars. Relevant research questions include:

What are the energetics of subsurface life? A critical component of the consortium's vision is the multi-parameter approach to understanding habitability and the limits of life. In addition to innovations in molecular biology, genomics, and proteomics, the past few decades have seen an explosion in our understanding of fundamental metabolisms for life. Our program will take a long overdue expansion of perspective to understand continental systems - both sedimentary basins as well as the ancient Precambrian cratons. Our research specifically targets rock-hosted life and chemosynthetic life – subsurface systems that are typically less energy rich and characterized by slow rates of growth [5]. Specifically we will examine the potential strategies by which life adapts to low energy environments and how major variation in available energy supply in space and time are overcome by spore formation or other survival strategies [6]. Emerging information suggests ecological rules developed from observations of the surface biosphere may express differently in the subsurface (e.g. inverted trophic triangles) [7]. Given new information about the energetics for subsurface life we also focus on

What novel sources of energy in the subsurface sustain energy gradients for life**:** The diversity of water-rock reactions and environments that supply abundant hydrogen as an electron donor for autotrophic organisms continues to challenge our thinking about the subsurface biosphere. The past decade has revealed the presence of hydrogen-rich environments as a global phenomenon in continental systems [8,9] but electron donors are only half of the equation in the search to understand the source, variety and production rate of electron acceptors. Novel sources such as indirect radiolysis of ancient sulphide containing minerals have changed our estimation of sulphate availability in the subsurface [10] but major questions remain concerning the role of other electron acceptors, including methane and other potentially rate-limiting sources of organic carbon. Addressing these questions, our group focuses on a site-by-site synthesis to build the first global models of deep subsurface carbon, hydrogen, oxygen, and sulfur cycles. Understanding the rate of production and flux of these key elements will provide more inclusive models of planetary habitability [1, 9, 11].

References: [1] Michalski J.R. et al. (2017) Nature Comm, 8, 15978. [2] Orosei R. et al. (2018) Science, 361, 6401. [3] Stamenković. et al. (2018) Nature Geosci, https://doi.org/ 10.1038/s41561-018-0243-0. [4] The National Academies Press, Washington, D.C. https://doi.org/10.17226/25252. [5] Trembath-Reichert. et al. (2017) PNAS 114, 44. [6] Hoehler & Jorgenseon. (2013) Nat Rev Microbio. 11, 83. [7] Lau. et al. (2016) PNAS 113, 49. [8] Vance, S. et al. (2016) Geo Res Lett 43, 4871. [9] Sherwood Lollar, B. et al. (2014) Nature 516,379. [10] Li. et al. (2016) Nature Comm 7, 13252 [11] Tarnas. et al. (2016) Earth Planet Sci Lett 502, 133.