DEEP GROUNDWATERS ON EARTH AS ANALOGS FOR MODERN MARTIAN HABITATS. J.D. Tarnas[1], J.F. Mustard[1], B. Sherwood Lollar[2], O. Warr[2], A.M. Palumbo[1], A.-C. Plesa[3], [1]Brown University Department of Earth, Environmental and Planetary Sciences, [2]University of Toronto Department of Earth Sciences, [3]German Aerospace Center Institute of Planetary Research.

Introduction: Deep, briny, fracture-network-filling groundwaters accessed by the drilling of boreholes during mining operations provide an analog for modern subsurface martian habitats, where liquid water is a key condition for habitability. Mines in Canada and South Africa have accessed groundwaters in boreholes as deep as 2.9 km and 3.3 km, respectively [1,2]. Drill holes in the Fennoscandian shield reach depths of 6.6 km [3]. Groundwater in Kidd Creek has a minimum mean residence time of ~1.5 Gyr [4], while groundwaters in other Canadian and South African mines have ages of 10^6-10^8 yrs [1,5, 6]. Waters at all of these sites have significant quantities of dissolved CH_4 (produced both abiotically and biotically [3,7]), with varying amounts of accompanying H_2, C_2H_6, and C_3H_8 [2,3,7] that are typically produced abiotically. The briny ancient groundwaters in Kidd Creek, which have clearly been relatively isolated for a substantial period of time, contain low abundances—but measureable amounts—of microbial biomass [8]. Kidd Creek and Mponeng mines, in Canada and South Africa respectively, have some of the highest relative quantities of abiotically-produced CH_4 of any sites identified thus far, though these CH_4 abundances vary locally [7].

Methods: We estimate the respective rates of microbial and abiotic CH_4 production at each of 17 different borehole sites. To do this, we demonstrate that H_2 production at all deep borehole sites is primarily controlled by radiolysis—previously shown to have likely operated on ancient Mars [9] and operate on modern Mars [10]—with secondary H_2 contributions from serpentinization at some sites. We then use the current CH_4 versus H_2 concentrations, CH_4 versus C_2H_6 and C_3H_8 concentrations, and $\delta^{13}C$ measurements in CH_4 to quantitatively separate the contribution of CH_4 production from biotic and abiotic sources. This allows us to demonstrate that the detection of high dissolved CH_4 concentrations is not by itself a biosignature. Thus, biosignature detection of extant life in a modern martian habitat requires measurements that go beyond dissolved or exsolved gas concentrations. Instead, extant life detection on Mars requires deep drilling missions that are capable of directly accessing brine pockets in the crust [11].

We model the temperature, pressure, and compositional conditions within the martian crust that would be conducive to formation and sustainment of a briny, dissolved-gas-rich, and isolated liquid pocket. We take the Kidd Creek fluid composition as a starting composition and explore how variations in salt content affect the melting temperature of the brine, and thus where it can exist as liquid within the modern martian cryosphere. Furthermore, we explore the thermal effects of efficient insulators and convection-inhibitors such as clathrate hydrates [12], which are expected to have existed in the ancient martian crust [13] and may be the source of CH_4 detections on modern Mars [14].

Results & Discussion: We find that the ancient, highly saline, deep groundwaters of Kidd Creek represent an excellent Earth analog for a habitable environment on modern Mars. Variations in brine composition significantly affect the freezing point of liquids, with perchlorates lowering the freezing point most significantly [15]. Having an efficient insulator surrounding these brine pockets, such as CH_4 clathrate hydrates [12], significantly increases the likelihood that these liquid pockets would remain liquid until present day. Kidd Creek-type fluids in the modern martian crust would contain high concentrations of dissolved CH_4. This CH_4 would form via reduction of CO_2 by H_2, formed via radiolysis and mineral hydration reactions [9,10,16], through Fischer-Tropsch-Type (FTT) reactions. CH_4 formed through these abiotic (and possibly through additional biotic) processes would diffusive into surrounding ice, forming CH_4 clathrate hydrates, which then act as insulators and convection-inhibitors to maintain the brine pockets in their liquid state.

Conclusions: Ancient, deep groundwaters accessed in the Kidd Creek mine provide an Earth-analog for the most likely habitable environment to exist on modern Mars. The self-sustaining architecture of these modern habitable environments likely consists of liquid brine, which fills pre-existing rock fractures and pore space, and is surrounded by CH_4 clathrate hydrates that act as an insulating and convection-inhibiting agent over long geologic timescales [12]. The potential for preservation of water in fracture networks on Mars over significant geologic time is supported by terrestrial analogs where life in isolation has been documented [2,8]. As a result, characterizing the (bio)geochemistry of these environments via deep drilling missions will maximize our potential for identifying any extant life on Mars.

References: [1] Warr, O. et al. (2018) *GCA* 222: 340-362. [2] Onstott, T.C. et al. (2006) *Geomicrobio. J.* 23: 6. [3] Kietäväinen, R. et al. (2017) *GCA* 202: 124-145. [4] Holland, G. et al. (2013) *Nat.* 497: 357-360. [5] Lippmann, J. et al. (2003) *GCA* 67: 4597-4619. [6] Heard, A.W. et al. (2018) *Chem. Geo.* 493: 379-395. [7] Sherwood Lollar, B. et al. (2006) *Chem. Geo.* 226: 328-339. [8] Lollar, G.S. et al. (2019) *Geomicrobio.* . [9] Tarnas, J.D. et al. (2018) *EPSL* 502: 133-145. [10] Onstott, T.C. et al. (2006) *Astrobio.* 6: 377-395. [11] Stamenković, V. et al. (2019) *Nat. Astro.* 3: 116-120. [12] Castillo-Rogez, J.C. et al. (2019) *GRL* 46: 1963-1972. [13] Kite, E.S. et al. (2017) *Nat. Geo.* 10: 737-740. [14] Webster, C.R. et al. (2018) *Sci.* 360: 1093-1096. [15] Toner, J.D. et al. (2014) *Icar.* 233: 36-47. [16] Sherwood Lollar et al. (2014) *Nat.* 516: 379-382.