Abiotic CH_4 production in the subsurface of terrestrial planets

JESSE TARNAS[1], JACK MUSTARD[1], BARBARA SHERWOOD LOLLAR[2], VLADA STAMENKOVIĆ[3], OLIVER WARR[2]

[1]Dept. of Earth, Environmental and Planetary Sciences, Brown University, Box 1846, 324 Brook St., Providence RI, 02912. jesse_tarnas@brown.edu
[2]Dept. of Earth Sciences, Univ. of Toronto, Canada M5S 3B1
[3]NASA Jet Propulsion Laboratory, California Institute of Technology

High concentrations of abiotic CH_4 are found in Earth's kilometers-deep subsurface [1]. Many of these fluids have been isolated for ~10^7-10^9 years [e.g. 2]. In Kidd Creek, one of the most abiotic-CH_4-rich subsurface sites, C&H isotpic signatures, CH_4/C2+ ratios [1,2], and radiogenic $^3He/^4He$ values (among other noble gas evidence) [4] indicates that most abiotic CH_4 in this system formed via low temperature reactions with negligible mantle-sourced CH_4 input. Here we use the world's largest database of kilometers-deep subsurface dissolved gases and isotopes to quantify in situ abiotic CH_4 production rates in these subsurface systems, as well as regional variations in production rates between sites in Canada, South Africa, and Finland.

We find that in situ abiotic CH_4 production rates range from ~[0.008-2] X 10^{-4} moles CH_4 m^{-3} $year^{-1}$, with South African sites showing the lowest production rate and Canadian sites showing the highest. This equates to an abiotic CH_4 production rate of ~[0.02-3.6] X 10^{11} moles $year^{-1}$ from the top 10 km of the Precambrian lithosphere (0.53 X 10^9 km^3 in volume). We scale our model for other planetary objects and find that low temperature abiotic CH_4 production is sufficient to explain a variety of phenomena, including generation of transient reducing greenhouse atmospheres to warm ancient Mars above freezing [5], modern detections of CH_4 on Mars, and CH_4 detected in Enceladus' plumes [6]. Low temperature abiotic CH_4 production could also generate CH_4 clathrate layers proposed to insulate Pluto's subsurface ocean [7] as well as subsurface brines inside Ceres [8]. It can also provide an endogenous source for Titan's atmosphere, consistent with noble gas observations [9], and could generate a false-positive 'biosignature' in super-Earth exoplanet atmospheres.

[1] Sherwood Lollar et al. 2006, *Chem. Geo*. 226.[2] Warr et al. 2018 *GCA* 222. [3] Sherwood Lollar et al. 2002, *Nat*. 416. [4] Holland et al. 2013 *Nat.* 497. [5] Turbet et al. 2019 *Icar.* 321. [6] Waite et al. 2006 *Sci.* 311.[7] Kamata et al. 2019 *Nat. Geo.* 12. [8] Castillo-Rogez et al. 2019 *GRL* 46. [9] Glein et al. 2015 *Icar.* 250.