

MODERN-DAY SUBSURFACE HABITABILITY AND HOW TO EXPLORE IT. V. Stamenković¹, L. M. Ward², M. Mischna¹ & W. W. Fischer³. ¹Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA 91109 USA. ²Harvard University, Cambridge, MA 02139 USA. ³Division of Geological and Planetary Sciences, California Institute of Technology, Pasadena, CA 91125 USA.

Introduction: Due to the scarcity of O₂ in the modern Martian atmosphere, Mars has been assumed incapable of producing environments with sufficiently large concentrations of O₂ to support aerobic respiration. Here we present a thermodynamic framework for the solubility of O₂ in brines under Martian shallow subsurface conditions and discuss implications for deeper subsurface environments. We find that modern Mars can support shallow subsurface liquid environments with dissolved O₂ values ranging from 2.5·10⁻⁶ mol m⁻³ to 2 mol m⁻³ across the planet, with particularly high concentrations in polar regions because of lower temperatures at higher latitudes promoting O₂ entry into brines. General circulation model simulations show that O₂ concentrations in shallow subsurface environments vary both spatially and with time—the latter associated with secular changes in obliquity. Even at the limits of the uncertainties, our findings suggest that there can be shallow, and possibly also deep, subsurface environments on Mars with sufficient O₂ available for extant aerobic microbes to breathe [1].

Here, we show the framework for modern-day subsurface habitability driven by oxygen and also present the technologies and mission scenarios that would enable the exploration of the modern-day subsurface habitability of Mars in the next decade.

Methods: We develop a new comprehensive thermodynamic framework applicable to Martian conditions that calculates the solubility of O₂ in liquid brines. We then couple this solubility framework to a Mars general circulation model (GCM) [2, 3] to compute the solubility of O₂ as a function of annually averaged values of pressure and temperature varying with location on Mars today in shallow subsurface environments (for an obliquity of ~25°). Following this, we examine how the distribution of shallow subsurface aerobic environments evolved over the past 20 Ma and how it may change in the next 10 Myr. To achieve this, we extend the modern-day Mars climate model [2, 3] using different values of obliquity to obtain annually averaged climate maps for each obliquity, and use calculations of Mars' obliquity changes over the past ~20 Ma and the next ~10 Myr [4] to identify those epochs in time with different axial tilts. Last, we discuss implications for deeper subsurface environments where oxygen may be sourced differently.

Results: We find that, on modern Mars—accounting for all uncertainties—the solubility of O₂ in various fluids can exceed the level required for aerobic respiration of ~10⁻⁶ mol m⁻³ for microbes [5, 6] by ~1-6 orders of magnitude. Thus, in principle, Mars could offer today a wide range of shallow subsurface environments with enough dissolved O₂ for aerobic respiration like that seen in diverse groups of terrestrial microorganisms. Moreover, for supercooled Ca- and Mg-perchlorate brines on Mars today, ~6.5% of the total Martian surface area could support far higher dissolved O₂ concentrations—enabling aerobic oases at levels of O₂>2·10⁻³ mol m⁻³ sufficient to sustain respiration demands of more complex multicellular organisms like sponges [7]. Such shallow subsurface aerobic oases are common today at latitudes poleward of ~67.5°N and ~72.5°S. Other shallow subsurface aerobic environments with intermediate O₂ values of ~10⁻⁴-10⁻³ mol m⁻³ can occur today closer to the equator in areas of lower topography like Hellas, Arabia Terra, Amazonis Planitia, and Tempe Terra, with larger mean surface pressures. The trends for shallow subsurface environments we show here are robust, as they can be tracked back to model-independent findings: (1) higher solubility for lower temperature and higher pressure, (2) temperature as the main control factor for solubility, (3) the poles being colder than the equator for modern Mars, and (4) the poles warming at higher obliquities.

This study focused on shallow subsurface environments. Recent results have indicated the potential existence of deep Ca- and Mg-perchlorate-rich subsurface brines at a temperature of ~205 K and a depth of 1.5 km [8]. Our results also imply that the O₂ solubility in such a deep reservoir would be high, raising the possibility that they could be rich in O₂ if the supply either from intermittent communication with the atmosphere or from the radiolysis of water is sufficiently large.

Last, we discuss how our framework can help explore the shallow and deep Martian subsurface in the next decade—with a focus on modern-day subsurface habitability. We will discuss the available technologies and mission scenarios that could enable such exploration of the modern Martian subsurface habitability [9].

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