POTENTIAL FOR DEEP HYDROGENOTROPHIC LIFE ON MARS. S. McMahon[1] and J. Parnell[2], [1]School of Geosciences, University of Aberdeen, Aberdeen AB24 3UE, UK. sean.mcmahon@abdn.ac.uk, [2]School of Geosciences, University of Aberdeen, Aberdeen AB24 3UE, UK.

Introduction: The oxidation of molecular hydrogen (H_2) is a major carbon fixing process for life on Earth, and was probably the first [e.g. 1, 2, 3]. Reports of CH_4 in the atmosphere of Mars have focused attention on the potential for H_2 to act as an electron donor for martian methanogens, while most scenarios for abiotic CH_4 production in the martian subsurface also imply the production of H_2. The estimated martian atmospheric CH_4 flux of ~260 tonnes.yr^{-1} [4], corresponds stoichiometrically to an initial 130 tonnes of H_2 in the Sabatier reaction: $CO_2 + 4H_2 \rightarrow CH_4 + 2H_2O$. This small flux may represent an emission process not usually considered significant on Earth. We are beginning to investigate H_2 fluxes from radiolysis and seismicity-driven mechanoradical chemistry on Mars by adapting terrestrial models to appropriate martian datasets.

Hydrogen in the deep biosphere: It is widely thought that extant life on Mars is most likely to reside in warm subsurface environments protected from the cold, desiccation and hostile radiation environment of the surface [e.g. 5, 6]. This view has been bolstered by the exploration of the Earth's deep biosphere, which extends kilometers into the subsurface, occupying continental aquifers, marine sediments, the oceanic crustal basement and oil and gas reservoirs [7, 8, 9, 10].

H_2 is an important electron donor in the Earth's deep biosphere, supporting a variety of anaerobic chemolithoautotrophic metabolisms including methanogenesis, acetogenesis and sulphate reduction. H_2 from water-rock chemical reactions may support life in deep basalt aquifers analogous to hypothesized martian habitats [11]; H_2 from the radiolysis of water appears to support life in marine sediments and deep continental aquifers [12, 13]; and isotopic evidence suggests that H_2 generated by mechanoradical chemistry may support life on active fault planes [14].

Sources of hydrogen on Mars: Sources of H_2 on Mars potentially include serpentinization, radiolysis, seismicity-driven mechanoradical chemistry, the breakdown of organic matter, and magmatic sources. We discuss the first three sources here.

Serpentinization. Serpentinization reactions between olivine, pyroxene and water produce copious H_2 and, when CO_2 is present, CH_4. Serpentinization has been widely invoked to explain martian atmospheric CH_4 [e.g. 15]. Olivine and pyroxene are ubiquitous in the basaltic martian crust. Serpentine has also been identified spectrally on Mars and in martian meteorites [16, 17]. It has been shown that to generate the observed annual martian atmospheric CH_4 flux would require the serpentinization of up to 8×10^8 kg of olivine per year, followed by the oxidation of H_2 by CO_2 [15].

Serpentinization is energetically favourable at temperatures below about 300 °C and has been observed on experimental timescales at temperatures as low as 30 – 70 °C [18]. Continuing serpentinization on Mars would imply the permeation of liquid water through hitherto un-serpentinized olivine and pyroxene, perhaps in migrating convection cells, from melting ice, or along new faults and joints. These conditions could be associated with magmatic intrusions or impact events [e.g. 19, 20] (Fig. 1).

Radiolysis. α, β, and γ decay of radioactive elements (^{235}U, ^{238}U, ^{232}Th and ^{40}K) in rocks cause H_2 production via the radiolysis of pore water (including ice) and crystallization water in hydrated minerals [12, 21]. It has been suggested that radiolysis might be a significant H_2 source for martian CH_4 production [22] and martian microbial metabolism [12]. On average, however, U, Th and K are about 100 times less abundant in martian meteorites than in the Earth's crust [23], and Th and K (determined by the Mars Odyssey gamma ray spectrometer) are about 10 times less abundant in martian surface materials than on Earth [24]. Thus, low radiation dose rates may restrict the biological significance of this source to unusual geological conditions. We are beginning to constrain H_2 fluxes by adapting the radiolysis model of [12] for the martian geological context.

Seismic activity. Faulting and fracturing during Mars-quakes or impact events increases the permeability (and hence potential habitability) of the martian crust and can stimulate the production of H_2 in at least two ways: (1) by exposing new fracture surfaces to circulating water for water-rock reactions and radiolysis [25]; and (2) by the mechanoradical chemistry associated with frictional grinding on fault planes [14]. This latter mechanism, which creates highly reactive radical species that generate H_2 from pore waters, has so far received little attention in the context of Mars.

Experimental simulations of mechanoradical H_2 production in fault planes have been coupled with estimates of global seismic activity to derive a global H_2 flux of 2.3×10^2 mol m^{-2} yr^{-1} on Earth [14, 26], a much higher flux than typically estimated for radiolysis

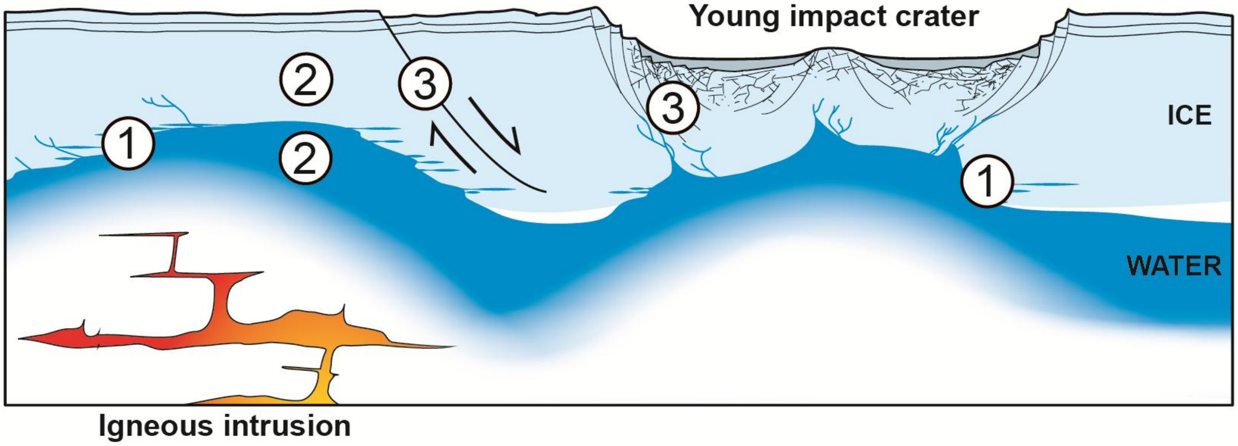

Figure 1: Possible sources of molecular hydrogen on Mars: (1) serpentinization along new fractures or by newly melted water; (2) radiolysis of water in aquifers, ices and fluid inclusions in minerals; (3) mechanoradical chemistry on active fault planes.

or water-rock reactions. There is now potential for this modeling approach to be adapted for Mars. Until data arrives from the SEIS planetary seismometer intended to fly to Mars on the 2016 Insight mission [27], we will lack direct information about the seismic activity of Mars. However, a Mars-quake frequency-magnitude relationship has been estimated based on a modeled seismic moment budget and a fault catalogue, [28]. (The Tharsis region, over which methane concentration reaches its yearly maximum [29], appears to be particularly densely faulted.) We are beginning to estimate mechanoradical H_2 production using this resource.

Conclusions: To understand the potential for subsurface hydrogenotrophic life on Mars requires an investigation of H_2 sources, fluxes, reservoirs and sinks, with a particular focus on the concentrations accumulating in habitable niches. Serpentinization, radiolysis and mechanoradical chemistry are good candidates for sources of H_2 on Mars. Estimates of radiolytic H_2 production must take into account the likelihood of low concentrations of radioactive elements on Mars as well as the porosity and grain size of martian rocks. Estimates of mechanoradical H_2 production can now be constrained by models of seismic activity on Mars.

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