FOLLOW THE METHANE: THE SEARCH FOR DEEP BIOSPHERES ON MARS AND EARTH. J.Parnell[1] and A. J. Boyce[2], [1]Dept. of Geology, University of Aberdeen, Aberdeen AB24 3UE, U.K., (J.Parnell@abdn.ac.uk), [2] Scottish Universities Environmental Research Centre, Glasgow, G75 0QF, U.K.

Introduction: The evidence of methane in the martian atmosphere [1] indicates that Mars, like Earth [2] and moons elsewhere in the solar system [3] may be venting gases. This dynamic behaviour is of strong astrobiological significance. Even leaving aside the possibility that gases could have a (partly) biological origin, they are important as potential sources of energy for simple life. On Earth, much simple (prokaryotic) life is in the subsurface [4], and it is highly likely that if Mars supports life it will also be in a deep biosphere where temperatures are high enough to allow liquid water and the dangers of oxidation/ irradiation at the surface are mitigated. If Mars has a deep biosphere, it will be focussed at places where there is an energy source [5] and some minimum level of permeability to allow growth, movement and recharge of nutrients. Sites of gas seepage represent both energy and permeability and are therefore potential windows to any deep biosphere. Methane seepages could, for example, originate at depths of several kilometres, and could help to fuel microbial sulphate reduction, as has been proposed on Mars [1].

Signatures of a Deep Biosphere: Signatures of deep biosphere are limited, especially when sampling can only be done at the surface, i.e. removed from the deep biosphere itself. Examples of deep biosphere on Earth include colonization of oil reservoirs and deep aquifers, colonization of buried basaltic glasses, and microbial populations related to serpentinites and gas hydrates. Identifying and confirming these components of the deep biosphere is difficult on Earth because of the ubiquity of microbial life, and the consequent possibility of contamination. Remote signatures could include the isotopic signatures of gases, and entrainment of microbes into fluids venting to the surface, but the latter would be difficult to prove on Earth because of contamination.

Ancient Deep Biosphere: The detection of signatures from a deep biosphere in deep time on Earth poses different problems, which have not been systematically explored. Other signatures are possible, including mineral precipitates with a distinctive isotopic composition or fabric, or even with entrained microbial remains. The problems lie in proving that the microbial activity was in the deep subsurface, and that it has not been overprinted by younger activity after introduction of the rocks to the surface. Nevertheless, careful study allows the identification of examples of subsurface activity in the geological record, including microbial precipitation of carbonates and sulphides. Given the importance of gas as a source of energy, these microbial signatures are particularly likely to occur along pathways for gas seepage.

Exploration on Mars: What are the consequences of terrestrial deep biosphere studies for our exploration of a deep biosphere on Mars? As regards any current deep biosphere, contamination from the martian surface is not an issue. The measurement of the isotopic composition of venting gases has potential, but requires development of a data base from which interpretations can be made. There is a possibility of entrained microbes being incorporated into mineral precipitates where fluids emerge at the surface, but as this is difficult to prove in terrestrial cases because of contamination, we have no good model to follow.

If we are to find life on Mars, it is more likely to be in the fossil record, and accordingly the emphasis in ESA's ExoMars mission is on the search for ancient biomarkers. The emphasis has been placed on the potential of sedimentary rocks deposited early in Mars' history, when conditions were warmer and wetter, but products of a deep biosphere are also a possibility, and could date from later in Mars' history. The products of a deep biosphere depend on the energy source. The terrestrial record shows that microbial sulphur metabolizers are widespread, including in the deep biosphere, and extend back to the earliest records of life. Microbial sulphate reduction is commonly implicated at sites of methane migration or seepage [6]. Sulphur species occur in both igneous and sedimentary rocks on Mars, so sulphur cycling occurs and could be the basis of metabolism. Most terrestrial sulphate reducers can also use other electron acceptors such as Fe (III) or Mn (IV), widening the variety of potential habitats. A range of redox gradients is also expected on Mars [5], which could allow similar diversity. On Earth, sulphur isotope systematics allow the detection of microbial activity, which at low temperatures induces fractionation of the main sulphur isotopes [7]. Microbially-induced isotope fractionation has evolved through Earth history [7]. Nevertheless, investigation of the isotopic composition of martian sulphur-bearing minerals is a feasible means of searching for a deep martian biosphere.

Carbon isotopic compositions can also be an indication of deep biosphere, for example from calcite in altered volcanic glass [8], but to date evidence for carbonates on Mars is so limited that sulphur species are a more realistic target. Several domains of the terrestrial deep biosphere yield evidence of microbial activity through the precipitation of sulphides where sulphur isotope composition indicates fractionation greater than explainable by non-biological processes. These include altered basaltic glasses below the ocean floor [9] and serpentinites [10], sandstone aquifers containing redox-controlled metalliferous deposits [11], and hydrothermal systems within impact craters [12] (Fig. 1). In several terrestrial examples, there is a clear link between microbial activity and the exploitation of, or generation of, methane. In serpentinites, the olivine alteration process can produce non-biological methane, while microbes feeding off co-generated hydrogen can be a biological source of methane [13, 14]. Serpentinites are of particular interest, given the discovery of olivine-rich rocks and serpentinite on Mars [15], and they have been highlighted as a potential niche for methanogenesis on Mars [13,16]. They may also be implicated in the evolution of the earliest life on Earth [13,17].

The successful application of the sulphur isotope life-signature in a robust mineral phase (sulphides) that is known to occur on Mars suggests an approach that can be used to search for evidence of a deep biosphere on Mars. Targeting sites of gas seepage or evidence of hydrothermal activity, in turn highlighted by thermal anomalies, will optimize the search.

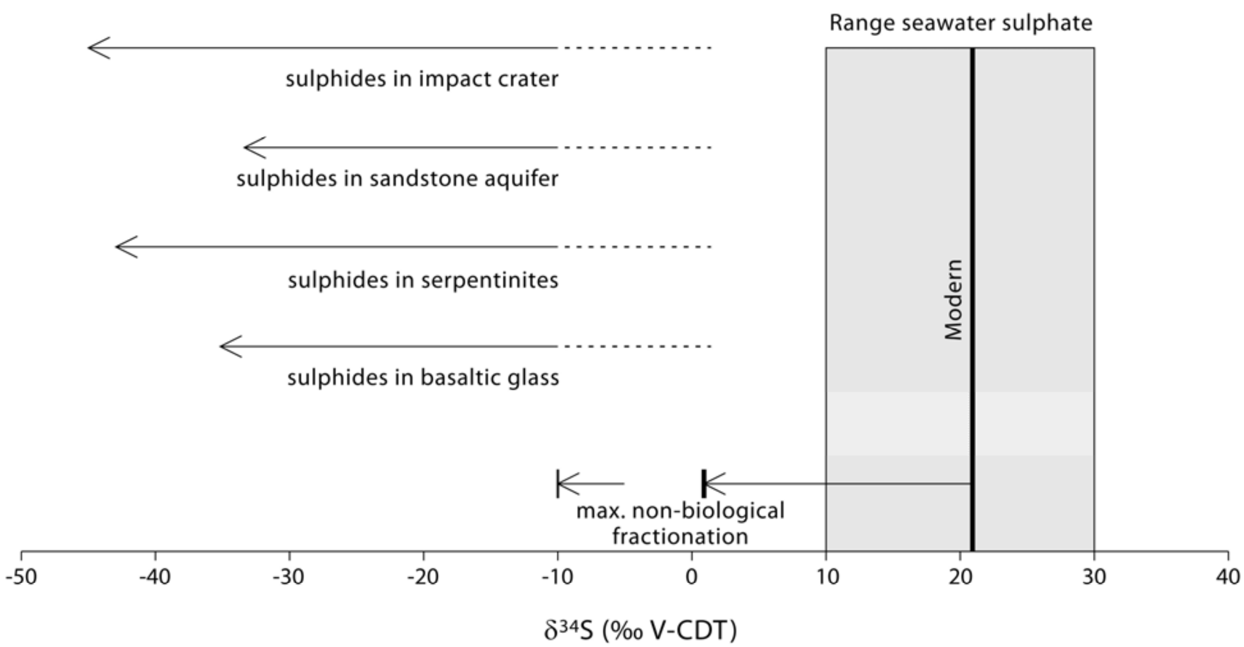

Fig. 1. Ranges of sulphur isotopic composition from sulphides in deep biosphere domains, indicating substantial fractionation from parent sulphate due to microbial sulphate reduction. Maximum non-biological fractionation (about 20 ‰) shown for modern and minimum values of seawater sulphate composition. Data from [9,10,11,12].

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