IMPACT METAMORPHISM OF SUBSURFACE ORGANIC MATTER ON MARS: A POTENTIAL SOURCE FOR METHANE AND SURFACE ALTERATION. D. Z. Oehler[1], C. C. Allen[1] and D. S. McKay[1], [1]NASA-JSC, Houston, TX 77058, doehler@ems.jsc.nasa.gov, carlton.c.allen@nasa.gov, david.s.mckay@nasa.gov.

Introduction: Reports of methane in the Martian atmosphere have spurred speculation about sources for that methane [1-3]. Discussion has centered on cometary/ meteoritic delivery, magmatic/mantle processes, UV-breakdown of organics, serpentinization of basalts, and generation of methane by living organisms. This paper describes an additional possibility: that buried organic remains from past life on Mars may have been generating methane throughout Martian history as a result of heating associated with impact metamorphism.

Discussion: There is now consensus that early Mars was wetter than Mars today and that if life ever emerged there, it is likely to have developed during that early period [4]. As on Earth, if ancient biotas were present on Mars, then their organic remains are likely to be preserved in Martian sediments.

On Earth, sedimentary organic matter (kerogen) is converted to oil and gas by a process of organic maturation, dependent mainly on elevated temperature at burial depths; this is true for kerogen of all ages, including Proterozoic and Archean examples [5-7]. At temperatures >150^{o}C, organic maturation yields mostly methane [8-9].

On Mars, burial alone may not be sufficient to produce hydrocarbons; Mars has been relatively cold for much of its history and the planet appears to have had limited tectonic basin development [10]. Thus, an alternative source of heat may be required to generate methane and other hydrocarbons from buried organic matter. It is proposed that impact heating could be that source.

Concerns that Mars may be devoid of organic matter [1] are based on Viking data. However, since those data applied only to the upper few centimeters of regolith, it is likely that deeper organics would have been missed [10]. Moreover, some scientists dispute the conclusion that Viking data indicated a lack of organic matter [11]. So, the questions remain open of whether, how much, and where organic matter lies buried beneath the Martian surface. It is conceivable, therefore, that impact metamorphism of ancient kerogen has been generating methane throughout Martian history and that reservoirs of this gas, if well sealed, may still exist.

Impetus for proposing a relationship between Martian impacts and methane generation stems from the resemblance (Fig. 1) of high-albedo Martian crater rings [12-13] to terrestrial areas of red bed bleaching caused by hydrocarbon seepage [14-16].

Oehler and Sternberg [17] documented near-surface geochemical anomalies (including red bed bleaching) due to methane microseepage over Ashland Gas Field in Oklahoma. They proposed a model whereby *methanotrophic bacteria* oxidized seeping methane and *sulfate-reducing bacteria* reduced pore water sulfate to H_2S; methane was converted to carbonate and H_2S reacted with iron in hematite to produce pyrite; these reactions caused a "bleaching" of originally red, hematite-rich sandstones to light grey, pyrite- and carbonate-cemented sediments.

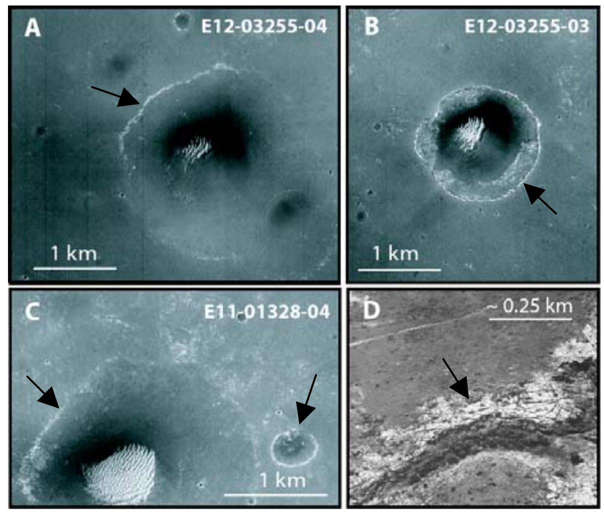

Fig. 1. A-C, MOC images of high-albedo crater rims (arrows) at Meridiani Planum (*NASA/JPL/Malin Space Science Systems*); **D**, Aerial photograph of bleached red bed (arrow) over Garza Oil Field, Texas [18].

Related processes might occur on Mars, although living microbes may not be necessary there to produce H_2S. This is because at temperatures >140^{o}C (common in impact zones [19]), methane and pore water sulfate react - abiologically - to produce carbonate and H_2S [20]; such Martian H_2S would reduce oxidized iron to produce pyrite, and excess methane might accumulate and still be present in traps capped by permafrost, salts or other excellent seals. Small amounts of methane would leak continuously from traps to the surface through fractures in impact zones, leading to release of methane from crater rings and central uplifts. This microseepage could be a source for the methane detected in the Martian atmosphere.

Pyrite might remain in the subsurface of Mars, but, on the surface, it may be oxidized to the yellowish mineral, jarosite, as frequently occurs on Earth [21-22]. Given the oxidized nature of the Martian regolith, jarosite is the likely end result on that surface. This reaction also yields sulphuric acid [23] which could then mobilize iron and dissolve surface carbonates - a process perhaps helping to explain the apparent deficiency of carbonates on Mars.

Since subsurface fluids in impact craters flow towards central and rim uplifts [24-31], the above geochemical changes, along with evaporite precipitation would occur as light-colored rings, concentric with crater rims and/or as bright zones over central uplifts; in orbiter imagery, these mineral accumulations might appear as high-albedo anomalies. While there could be magmatic and even living sources for both methane and H_2S, it is difficult to envision such sources having a spatial correlation with impact craters, as is expected in the proposed model.

Summary: If life ever developed on Mars, then there probably are regions where remnant organic matter is preserved in the subsurface; those areas, if affected by impact metamorphism, would have generated methane which could be trapped in sealed reservoirs today. H_2S could have been generated abiologically, by interaction between sulfate and methane at temperatures >140°C in impact zones. Microseepage of reservoired gases and briny pore fluids, through fractures in impact zones, could account for methane release to the atmosphere and evaporite deposition; in addition, these processes could produce 1) subsurface pyrite and carbonate cements and 2) surface jarosite with sulphuric acid (which in turn could mobilize iron and dissolve carbonates). Any of these mineralogical changes could result in surface discoloration (e.g., red bed bleaching) that might appear as the high-albedo crater rims in MOC imagery.

Concluding Remarks: The intent of this paper is not to suggest that organic metamorphism is the only, or most important, source of methane on Mars. Clearly, there are other potential sources [1-3, 32-36]). Rather, the aim is to bring this process to the attention of the astrogeological community for further consideration.

The proposed model requires sulfate and a source of oxidized iron, and it predicts atmospheric methane, surface jarosite and high-albedo crater rings. All of these features appear to be present at Meridiani Planum [1-3, 12, 37-38], and their combined occurrence there is consistent with this hypothesis.

Additional insight into the composition, and thus origin, of the bright crater rings may be gained by comparison of their spectral signatures with those of various alteration/evaporite zones on Earth [39]. If high-albedo anomalies were linked to hydrocarbon seepage, that information might be useful in planning for future missions, as those anomalies might signal locations of deeper pools of methane (perhaps useful as fuel for human missions) and/or buried evidence of past life.

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