POTENTIAL PRESERVATION OF LIFE WITHIN FLUID INCLUSIONS IN MARTIAN IMPACT CRATERS. *A. D. Wilkins[1] and J. Parnell[1], [1]Department of Geology and Petroleum Geology, University of Aberdeen, Aberdeen AB24 3UE, U.K. e-mail: a.d.wilkins@abdn.ac.uk*

Introduction: Fluid inclusion studies have the potential to record various important features of impact sites including the heating effects due to impact, hydrothermal fluid circulation history, the subsequent behavior of exposed rocks at the planetary surface and, of most interest to astrobiology, the preservation of organic matter [1, 2, 3].

"Water is of interest not only from the perspective of planetary evolution but also for biology. Liquid water is universally recognized as an essential for life" [4]. Therefore an understanding of Mars's history of water should allow us to determine the probability of life on Mars, for without liquid water it is unlikely that life arose or persisted on Mars [5, 6]. The absence of liquid water also precludes the entrapment of aqueous fluid inclusions.

The emergence of life on Earth and Mars: It is believed that Hadean Earth and Mars shared a similar planetary evolution, in particular their physical and chemical surface characteristics [7]. If life emerges at a certain stage within planetary evolution given the correct environmental necessities, then when life emerged on Earth the conditions on Mars were also likely to be favorable for the emergence of life [8].

Life appears to have emerged on Earth at a time when highly energetic meteoritic impacts would have been deleterious for near-surface emergent ecosystems, yet the Earth's fossil record reveals that surface microbial ecosystems were present by 3.8 Ga [9]. Therefore it is proposed that life originated in Earths subsurface, where the impact events at the surface would have had little consequence on the microbes' survivability at greater depth, outwith the zone of impact shock metamorphism, and later evolved to occupy surface habitats [10].

Archaean impact cratering and the survival and subsequent evolution of early life on Mars: After the initial Hadean planetary bombardment, later Archaean impact shock, gradual erosion of the atmosphere and loss of hydrosphere suggest that if life had spread to the surface of Mars, as on Earth by 3.5Ga [11], then the associated decrease in pressures and temperatures [12] may have wiped out the surface or oceanic-based microbial communities leaving behind a biased deep crustal ecosystem.

If life arose on Mars and survived the period of heavy meteoritic bombardment, it did so within a deep, potentially hydrothermal, environment. As deep hydrothermal fluids are found at high temperatures, and high pressures, and with a high content of dissolved salts, it is possible that the surviving microbes were composed of thermophiles, barophiles and halophiles.

Martian impact cratering and its potential to create new aqueous microbial habitats: Impact cratering on Mars over a period of geological time could have lead to a variety of ecologically enticing environments for an actively flourishing and expanding subsurface biosphere.

Impact craters on Mars are likely to have created various aqueous environments such as evaporative lacustrine basins and hydrothermal systems conducive to life [13]. In such environments, halophiles and thermophiles could have potentially expanded into previously vacated or new near surface niches from their deep crustal abode, by means of impact associated hydrothermally influenced circulating fluids.

It is within these aqueous environments that the study of fluid inclusions is applicable to astrobiology.

Fluid inclusions within aqueous environments: Fluid inclusions are micron scale volumes of ambient fluid entrapped within minerals as they precipitate**.** Within the Martian impact related aqueous environments there is the potential that related fluid inclusions could yield valuable information about the ambient conditions during mineral precipitation including temperature and fluid chemistry.

Hydrothermal Systems: Studies of Earths impact craters show that hydrothermal circulation associated within impact sites involved fluids ranging in temperature from 100^{o}C to 300^{o}C and higher [14].

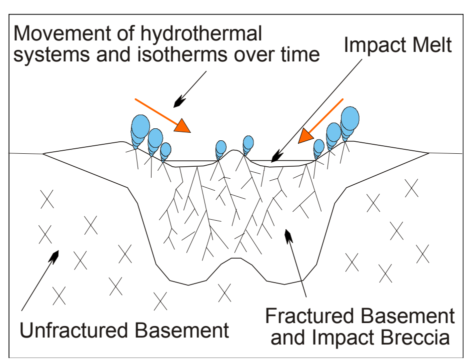

Figure 1. Potential microbial colonised fracture system will be delineated by 100^{o}C isotherm as the hydrothermal system cools and moves from crater rim to edge of impact melt sheet.

As life has been recorded at temperatures up to 113°C [15], thermophiles could potentially colonise fracture systems as the hydrothermal system cools, wherever the isotherm is below 100°C (Figure 1). A decrease in temperature is also coincident with mineral precipitation, preserving a fluid record of the ambient environment. Aqueous fluid inclusions from terrestrial hydrothermal systems have also entrapped bacteria [16] and organic compounds [17].

Evaporative Basins: Terrestrial surface minerals usually contain aqueous fluid inclusions, and evaporite minerals such as halite (sodium chloride) and epsomite (hydrated magnesium sulphate) can contain abundant inclusions [18]. Studies of terrestrial evaporite fluid inclusions have been found to entrain both dormant bacteria [19] and organic molecules [20].

Martian fluid inclusions: The process of impact cratering over time has produced Mars's distinctive surface morphology. During impact cratering material is excavated and emplaced on the surface, allowing access to materials from ancient geological times, which may contain organic materials. [21]. Therefore, older impact associated environments of astrobiological interest could be sampled where successive craters impact upon each other (Figure 2).

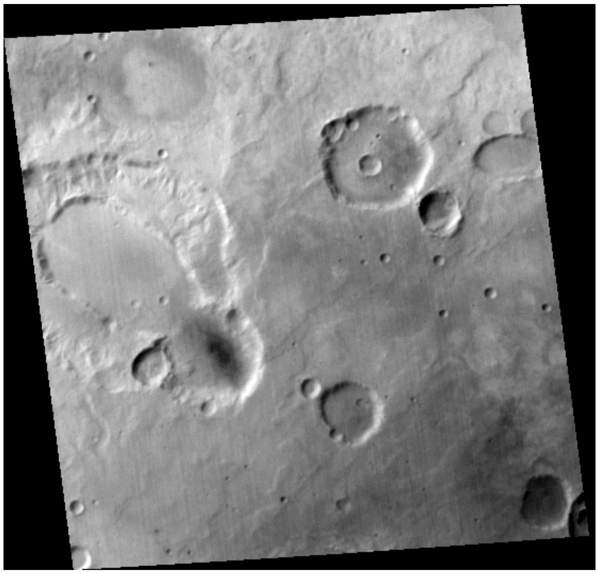

Figure 2. Superimposed craters, as in top right corner, proposed sites for excavating material from beneath the earlier crater floor such as hydrothermal or evaporite deposits. MOC wide-angle image M03-02817.

There are potential difficulties associated with 'excavated' materials containing microbes or biomolecules within the rock pore spaces, specifically the high UV flux and highly oxidizing free radicals that would 'destroy' the organic matter [22]. This would not necessarily present problems for microbes or organic matter contained within fluid inclusions, as it is likely that the host minerals would form a protective casing.

Conclusions: The aqueous environments associated with impact craters are conducive to the formation and preservation of fluid inclusions. Organic materials preserved within the inclusions are likely to be protected from degradation in the same way that hydrocarbon inclusions within oil reservoirs can survive thermal, chemical and biochemical alteration [23]. Therefore, fluid inclusions have significant potential for astrobiological exploration within impact-associated evaporative basins and hydrothermal systems.

References: [1] Sturkell, E. F. F. et al. (1998) *Eur. J. Min.,* 10, 589-606. [2] Anderson, T. and Burke, E. A. J. (1996) *Eur. J. Min.,* 8, 927-936. [3] Pascal, J. et al. (1996) *Earth Plan. Sci.,* 138, 137-143. [4] Carr, M. H. (1996) *Ciba Found. Symp.,* 202, 249-265. [5] Mancinelli, R. L. and Banin, A. (1995) *Adv. Space. Res.*, 15, (3)171- (3)176. [6] Rothschild, L. J. and Mancinelli, R. L. (2001) *Nature*, 409, 1092-1101. [7] McKay, C. P. and Davis, W. (1991) *Icarus*, 90, 214-221. [8] Horneck, G. (2000) *Plan. Space Sci.*, 48, 1053-1063. [9] Schidlowski, M. (1988) *Nature*, 333, 313-318. [10] Trevors, J. T. (2002) *Res. Microbiol.*, 153, 487-491. [11] Westall, F. et al. (2001) *Precambrian Research*, 106, 93-116. [12] Westall, F. et al. (2000) *Plan. Space Sci.*, 48, 181-202. [13] Cabrol, N. et al. (2001) *Icarus*, 154, 98-112. [14] Allen, C. C. et al. (1982) *JGR*, 87, 10083-10101. [15] Bloch, E. et al. (1997) *Extremophiles*, 1, 14-21. [16] Bargar, K. E. et al. (1985) *Geology*, 13, 483-486 [17] Graupner, T. et al. (2001) *Chemical Geology*, 177, 443-470. [18] Roedder, F. (1984) *Amer. Mineral.*, 69, 413-439. [19] Vreeland, R. H. et al. (2000) 407, 897-899. [20] Pironon, J. et al. (1995) *Org. Geochem.*, 23, 739-750. [21] Cockell, C. S. and Barlow, N. G. (2002) *Icarus*, 155, 340-349. [22] Newsom, H. E. et al. (2001) *Astrobiol.,* 1, 71-88. [23] Parnell, J. et al. (2001) *Mar. Petrol. Geol.*, 18, 535-549.

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