IMPACT CRATERS AS HABITATS FOR LIFE ON EARLY MARS. G. R. Osinski[1], L. L. Tornabene[1], N. R. Banerjee[1], C. S. Cockell[2], R. Flemming[1], M. R. M. Izawa[1], J. McCutcheon[1], A. Pontefract[1], J. Parnell[3], H. Sapers[1], and G. Southam[1], [1]Centre for Planetary Science and Exploration, University of Western Ontario, London, ON, N6A 5B7, Canada, [2]School of Physics and Astronomy, University of Edinburgh, Edinburgh, EH9 3JZ, UK, [3]Department of Geology, University of Aberdeen, Aberdeen, AB24 3UE, UK (gosinski@uwo.ca).

Introduction: Impact cratering is a fundamental geological process that is common to all planetary bodies in the solar system. On Earth, it has become increasingly clear over the past decade that meteorite impacts have played an important role throughout Earth's history; shaping the geological landscape, affecting the evolution of life, and resulting in economic ore deposits. During the first few hundred million years of their history it is likely that Earth and Mars shared many similarities, particularly with respect to their impact cratering rates and endowment of the ingredients necessary for life.

Much attention has been paid to the deleterious effects of meteorite impacts. It is now widely accepted that meteorite impacts can negatively affect life on a planet, as evidenced by the destructive effects associated with the formation of the Chicxulub impact structure, Mexico, 65 Myr. ago and its link to the Cretaceous–Paleogene mass extinction event [1]. In terms fo the origin of life on Earth, despite the controversy over when exactly life appeared, it is likely that it did so during one of the harshest, most inhospitable times in Earth history: the Late Heavy Bombardment Period ~4.0–3.8 Ga. During this time, asteroid and comet impacts were ~10–20 times as frequent as they are at the present day. This may seem counterintuitive at first until one considers that perhaps these cataclysmic, initially destructive impact events also had beneficial effects. Indeed, work conducted over the past decade has revealed that impact events produce several beneficial effects with respect to microbial life. The purpose of this contribution is to present a case that impact craters on Early Mars would have represented prime habitats for life, and potentially even for its origin, and that impact craters, therefore, should be prime exploration targets for future missions.

Habitats for life within impact craters: Work conducted over the past decade at several impact structures on Earth has shown that impact craters can generated several habitats for life. A key point to consider is that many of these habitats would not be present if it not for the impact event. Major habitats include:

1) *Impact-generated hydrothermal systems*, which could provide habitats for thermophilic and hyperthermophilic microorganisms [2];

2) *Impact-processed crystalline rocks*, which have increased porosity and translucence compared to unshocked materials, improving colonization by endolithic organisms [3, 4];

3) *Impact glasses*, which, similar to volcanic glasses [5], provide an excellent readily available source of bioessential elements [6];

4) *Impact crater lakes*, which form protected sedimentary basins with various niches and that increase the preservation potential of fossils and organic material [7].

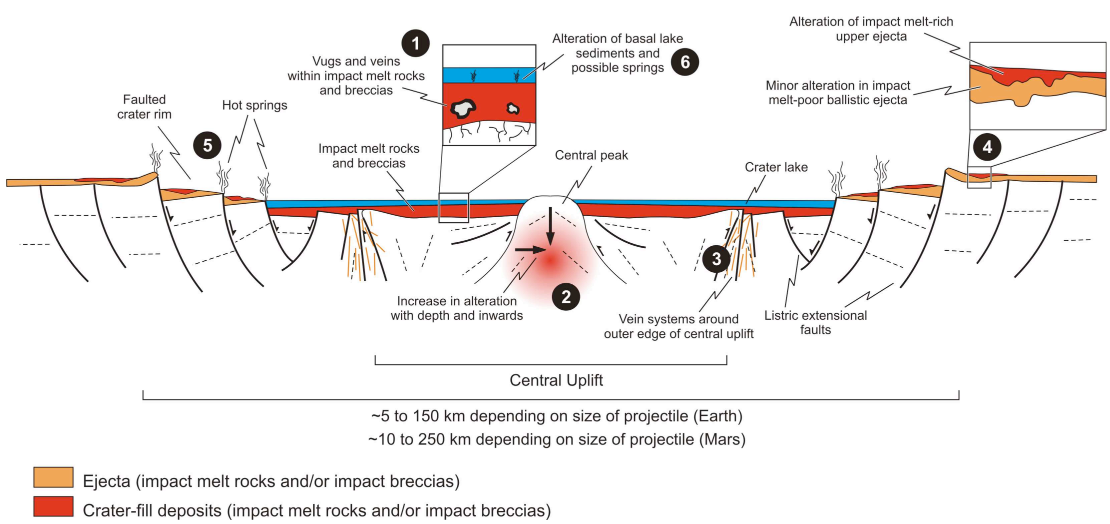

Fig. 1. Distribution of hydrothermal deposits within and around a typical complex impact crater. The six settings are highlighted and numbered in the order in which they are discussed in the text.

Thus, impact craters, once formed on Early Earth – and by analogy on Mars and other planets – may have represented prime sites that served as protected niches where life could have survived and evolved and, more speculatively, perhaps originated. Importantly, all of these habitats for life are expected to have been generated by impacts on Mars. We will now focus on one particular and, likely, the most adundant and important habitat: impact-generated hydrothermal systems.

Impact-generated hydrothermal systems: It has long been suggested that hydrothermal systems might have provided habitats or "cradles" for the origin and evolution of early life on Earth, and possibly other planets such as Mars.

We have conducted a review of hydrothermal alteration in terrestrial impact structures, which builds upon earlier works [8]. Evidence for impact-induced hydrothermal activity is recognized at over 70 of the ~180 terrestrial craters, from the ~1.8 km diameter Lonar Lake structure, India [9], to the ~250 km diameter Sudbury structure, Canada [10]. It is notable that very few simple craters display evidence for hydrothermal alteration, which accounts for ~50 craters in the terrestrial record. Thus, it seems highly probable that any hypervelocity impact capable of forming a complex crater (>2–4 and >5–10 km diameter on Earth and Mars, respectively) will generate a hydrothermal system. Consideration of the terrestrial record suggests that the presence of an impact crater lake is critical for determining the longevity and size of the hydrothermal system.

Distribution of hydrothermal deposits within impact craters: We show that there are six main locations within and around an impact crater where impact-generated hydrothermal deposits can form: 1) crater-fill impact melt rocks and melt-bearing breccias; 2) interior of central uplifts; 3) outer margin of central uplifts; 4) impact ejecta deposits; 5) crater rim region; and 6) post-impact crater lake sediments. Alteration ranges from discrete vugs and veins to pervasive alteration depending on the setting and nature of the system.

Impact-generate hydrothermal systems on Mars? In terms of the Martian impact cratering record, we suggest that the same six locations within and around terrestrial impact craters where impact-induced hydrothermal deposits can form will also hold true for Mars. Evidence for impact-generated hydrothermal activity is growing and requires detailed studies using high-resolution imagery and multispectral information. Such detailed studies have only been done in detail for a handful of Martian craters. The best example so far is from Toro crater [11]. We also present new evidence for impact-induced hydrothermal deposits within an unnamed ~32-km diameter crater ~ 350 km away from Toro and within the larger Holden crater.

Conclusions: Consideration of the impact cratering record on Earth suggests that hydrothermal activity will be commonplace after the impact of an asteroid or comet into H_2O-rich planetary surfaces. Hydrothermal systems represent sites where water, warmth, dissolved chemicals and nutrients may have been available for extended lengths of time. As such, they are prime locations suitable for colonization by thermophilic microorganisms. Synthesizing observations of terrestrial and Martian impact craters, we suggest that if there was life on Mars early in its history, then hydrothermal deposits associated with impact craters may provide the best, and most numerous, opportunities for finding preserved evidence for life on the Red Planet.

Acknowledgements: This work is supported by the Natural Sciences and Engineering Research Council of Canada (NSERC) Industrial Research Chair in Planetary Geology sponsored by MDA Space Missions and the Canadian Space Agency (CSA) to GRO.

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