IMPACT CRATER HYDROTHERMAL NICHES FOR LIFE ON MARS: A QUESTION OF SCALE.
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Introduction: A major focus in the search for fossil life on Mars is on ancient hydrothermal deposits [1, 2]. Nevertheless, remote sensing efforts have not found mineral assemblages characteristic of hydrothermal activity [3]. Future remote sensing work, including missions with higher spatial resolution, may detect localized hydrothermal deposits, but it is possible that dust mantles will prohibit detection from orbit and lander missions will be required. In anticipation of such missions, it is critical to develop a strategy for selecting potential hydrothermal sites on Mars. Such a strategy is being developed for volcanogenic hydrothermal systems [4], and a similar strategy is needed for impact hydrothermal systems.

Terrestrial Impact Craters: Hydrothermal deposits in terrestrial impact craters <100 km in diameter are limited to fracture and cavity fillings representing minor, short-lived hydrothermal circulation. In contrast, hydrothermal deposits in the ~200 km diameter Sudbury crater in Canada include an extensive basin-wide system and a system focussed along faults that fed a long-lived subaqueous vent complex (carbonate and chert) [5, 6]. The Sudbury vent system is similar to modern deep sea vent systems, known be excellent niches for thermophilic bacteria [7]. Preliminary studies of the ~200 km diameter Chicxulub crater indicate that it too may have had an extensive hydrothermal system [8]. We propose that large craters on Mars hold the most promise for preserving vestiges of extensive, long-lived hydrothermal systems and possibly life.

At Sudbury crater, hydrothermal circulation was driven by the 2.5-km-thick coherent melt sheet (melt mostly free of large unmelted clasts) within the crater. Smaller craters, with significantly thinner impact melt sheets, have minor hydrothermal activity, suggesting direct correlation between melt sheet thickness and the magnitude of the hydrothermal system. Furthermore, data from terrestrial craters indicate that there is an exponential relationship between crater size and coherent melt sheet thickness, and that there may be a size threshold for coherent melt sheet formation (Fig. 1). Most terrestrial craters <35 km in diameter have only mixtures of melt and unmelted clasts. To explain this phenomenon, Cintala and Grieve [9] have suggested that mixing of melt with unmelted clasts is a function of the ratio of melt volume/crater volume. Initially the melt is smeared on the bottom of the crater, and when the melt volume/crater volume is large, the mixed zone is a small fraction of the melt.

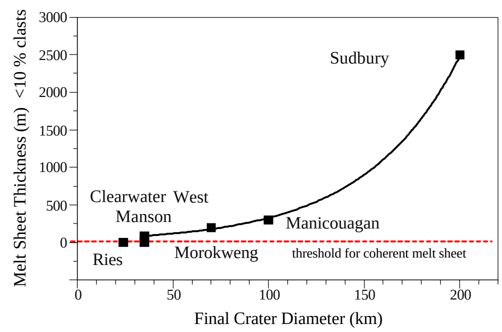

Figure 1. Melt sheet thickness and crater diameter.

When the melt volume/crater volume is small, erosional mixing of melt and clasts results in little to no clast-free melt. This is important because the incorporation of unmelted clasts in the melt can cool it quickly, greatly reducing the longevity of the hydrothermal system that develops.

Scaling for Mars. Before beginning the search for Martian analogues of the Sudbury Crater we must consider several aspects of crater formation that are gravity dependent, since Mars has about 1/3 the gravity of Earth. Due to this gravity difference, craters on Mars are about 1.24 times larger than craters on Earth (given impactors with the same mass and velocity). Another factor is projectile velocity. Typical velocities of asteroids and comets that impact Mars are ~ 19 km/s and 42 km/s, vs. ~25 km/s and 53 km/s on Earth [10]. Thus, for average craters with similar impact energies on Earth and Mars, Martian craters were formed by lower velocity (greater mass) projectiles. This is important because the mass of impact melt generated scales with V^2. When this relationship is coupled with the one above relating to larger craters on Mars, comparisons between crater size and melt can be made using the following equation [11]:

$$\frac{Mm}{Md} = 1.6 \times 10^{-7}(gDt)^{0.83}Vi^{0.33}$$

where Mm is the mass of impact melt, Md is the mass of rock displaced from the crater cavity, Dt is transient crater diameter (~0.5-0.6 final diameter), g is gravity, and Vi is the impact velocity.

We combined the empirical data on coherent melt thickness and gravity scaling to predict which craters on Mars are likely to have melt sheets capable of driving a long-lived hydrothermal system. The threshold final crater diameter for the formation of a coherent melt sheet on Earth is ~ 35 km, which corresponds with a Mm/Md = 0.11 (asteroid impact). Such a Mm/Md on Mars corresponds with a final crater diameter ~ 100 km (Fig. 1).

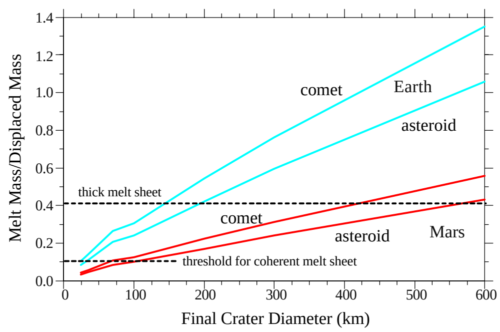

Figure 2. Scaling of Mm/Md for Earth and Mars.

Terrestrial craters with a thick coherent melt sheet such as Sudbury have a Mm/Md = 0.42, which on Mars corresponds with a final crater diameter of ~ 600 km (asteroid impact) or 440 km (comet impact).

Conclusions. We conclude that only very large craters on Mars have a high potential for developing long-lived hydrothermal systems. Martian craters < 100 km in diameter can probably be ruled out completely because they would produce melt mixed with a large number of clasts and therefore cool quickly. Craters < 200 km in diameter are tenuous, but may develop coherent melt sheets a few hundred meters thick (analogous to Manicouagan on Earth), which could drive a large, albeit short-lived, hydrothermal system. Martian craters capable of forming a Sudbury-like hydrothermal vent system fall in the 400 – 600 km size range. Such craters are rare on Mars (excluding ancient basins formed during the heavy bombardment period), which greatly limits the search. Candidates include Huygens (460 km), Schiaparelli (470 km) (Fig. 3), and Cassini (430 km).

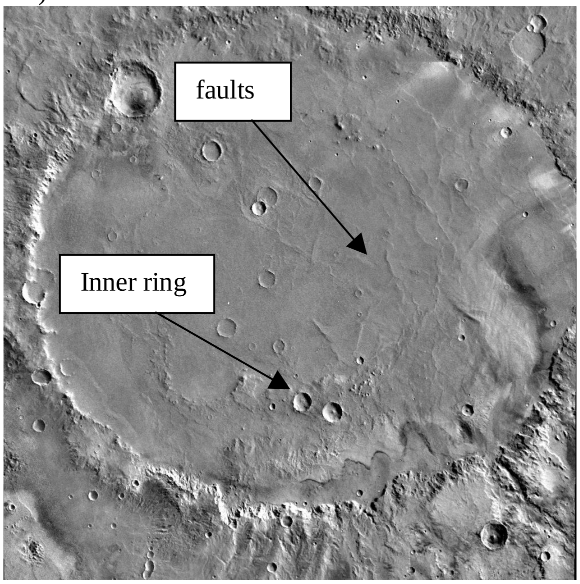

Figure 3. Schiaparelli crater, Mars (470 km diameter). By anaolgy to Sudbury, hydrothermal depoists may be found associated with faults inside the inner ring.

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