IMPACT CRATER LANDING SITES FOR THE 2003 MARS EXPLORER ROVERS – ACCESSING LACUSTRINE AND HYDROTHERMAL DEPOSITS

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Introduction: Five craters larger than 100 km diameter, including Gale with its spectacular lake deposits, have been identified as possible landing sites for the Mars Explorer Rovers (MER) 2003 missions [1]. These craters are important locations where lacustrine, fluvial, and hydrothermal processes occurred on Mars, they have exciting landscapes, and these missions represent the first chance to visit a large crater on another planet [2,3,4]. Lakes probably formed in these craters, with water supplied from aquifers or surface sources, resulting in deposition of water-lain sediments and evaporites [3,5,6,7]. Lake waters derived from broad regional aquifers, can potentially collect biological material from a wide region and provide environments for possible life forms to flourish. Hydrothermal systems, which formed in the craters due to heat from impact melt and uplifted basement, are highly sought after targets because terrestrial life probably originated in such systems. Studying hydrothermal and aqueous processes in large craters on Mars will allow us to:

- Identify and characterize environments for the origin and evolution of life on Mars.
- Understand the history of water at the Martian surface, including hydrothermal systems, lake formation, and the nature of ancient climates.
- Study the contributions to the Martian soil from hydrothermal and evaporite processes [8].

The location of fluvial and lacustrine deposits are often evident from geomorphic evidence, such as layering and delta structures, but the location of hydrothermal deposits is less obvious. However, continuing research including study of MGS MOC imagery (**Fig. 1**), hydrothermal modeling, and terrestrial analogue studies provide strong guidance on where such deposits can be found, and on the processes that may have exposed or delivered this material to the landing sites.

MER impact crater landing sites: Possible landing sites on the floors of five craters were identified during early assessment of MER landing sites. These craters include Gusev (EP55A, -1.9 km elev., 160 km diam.), Gale (EP82A, -4.5 km elev., 170 km diam.), Boeddicker (EP64A, -2.1 km elev., 110 km diam.), an unnamed crater in Elysium Planitia (EP69A, -1.7 km elev., 100 km diam.), and an unnamed crater in Terra Meridiani containing two sites (TM15A, north site, TM16A, south site, -1.9 km elev., 150 km diam.). Unfortunately, there are virtually no MOC high-resolution images of the landing sites on the floors of these craters. Evidence for fluvial and lacustrine deposits have been identified in Gale (Viking and MOC), and the unnamed EP crater (Viking data) [4,6,7], and such deposits have a good chance of being present at the surface in their landing sites. Gusev crater was thought to be a good candidate, but unreleased MOC images do not reportedly show evidence of lake deposits or evaporites on the crater floor [9]. For the Unnamed TM crater, there appears to be a channel leading into the crater from the south, however no deltas have been identified, and no evidence for sedimentary layering is obvious in the two released MOC images. Evidence for lacustrine activity has not been reported for Boeddicker, but there are no released MOC images.

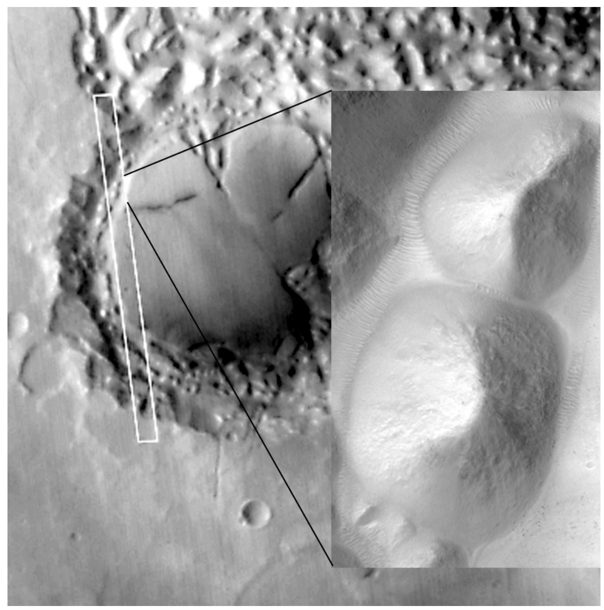

Figure 1. This picture illustrates the high permeability at the rim of a buried crater on Mars. This chaos region formed in a buried 50 km diameter crater at 1^{o} N, 26^{o} W, due to erosion of blanketing deposits by emerging groundwater. The localization of the outflow was probably due to bedrock fracturing, and hydrothermal alteration due to focusing of fluid flow around an impact melt sheet following crater formation. The inset image is a portion of a high resolution MOC image. (Context image M0307651, picture width 85 km, inset M030750, width 2.1 km).

Location of hydrothermal deposits: In large craters the nature and geometry of the heat sources and the zones of higher permeability controls the location of hydrothermal deposits. The heat sources are the impact melt sheet on the crater floor, and the uplifted basement [2,10,11]. Recent results by Thorsos et al. [11] indicate that these two sources of heat were approximately equal during the formation of large craters in the southern highlands. Numerous studies of terrestrial hydrothermal systems and theoretical studies of Martian systems by Gulick [12] and Rathbun and Squyres [13] shows that focusing of hydrothermal fluids occurs at the edge of planar heat sources. Both geological evidence and modeling suggest that the flow of hydrothermal fluids in large craters will be concentrated at the edges of the melt sheets in zones of higher permeability present in the crater rim and central uplift.

Terrestrial geological evidence for the concentration of hydrothermal fluid flow at the rims of craters comes from the Ries crater, where evidence exists for intense hydrothermal alteration of suevite associated with nearby carbonate spring mounds of probable hydrothermal origin on the western rim [14]. Evidence from the Sudbury structure includes the occurrence of hydrothermal ore deposits at the contact of the basement rim material with the crater fill. Evidence from Mars for the high permeability of central uplifts consists of the images of recent channel formation on pole-facing slopes of the central uplifts of large craters [15]. Evidence for permeability in the rims of large craters on Mars comes from the circular pattern of erosion in the cover of preexisting craters in chaos regions (e.g. **Fig 1**).

The hydrothermal potential for the candidate craters can be estimated from the total heat available from impact melts and uplifts. The smallest crater, the 100 km diameter Unnamed EP crater, will have 3,000 km^3 of impact melt, corresponding to a layer almost 400 m thick on the crater floor, while the largest craters, Gale and Gusev nearly 170 km in diameter may have as much as 20,000 km^3 of impact melt, corresponding to a layer almost 900 m thick. The total heat available in these craters, assuming equal amounts from uplift and impact melt, ranges from 2×10^{22} up to 2×10^{23} Joules. In terms of possible volcanic hydrothermal activity, Gusev is the only crater with a near-by large volcanic construct, Apollinaris Patera., and a near-by area of chaos.

Discussion: Of the crater landing sites, Gusev at 14.2° S, 184.8 ° W, and Boeddicker at 14.8° S, 197.5 ° W, are only accessible to MER A, while the other craters are accessible to either lander. Only one of the craters in the Eleysium Planitia area, can be targeted because landing sites must be located 37° from each other, Because the MER B lander has a larger footprint, it would be logical to send this lander to the Western Hematite location at 0.5^0 to 0.8^0 west, and use MER A for one of the five craters in Elysium Planitia.

Some conclusions can be drawn regarding the potential accessibility of hydrothermal deposits from the central uplifts and crater rim materials based on the probable geometry of the landing site ellipses and the available imagery. With the possible exception of Gale, the floors of the large craters are likely to be covered by fluvial and aeolian deposits, making access to the underlying melt sheets very unlikely. The ejecta blankets of superimposed craters provide a way to distribute samples from the rim and central uplift onto the floor of the craters. A superimposed crater, 18 km in diameter, is present on the rim of the Boeddicker crater adjacent to the EP64A site, and a 16 km diameter crater is located on the floor of the unnamed TM crater, adjacent to the southern, TM16A site. Unfortunately, none of the five candidate craters have the combination of strong evidence for lacustrine activity, and ejecta from a large superimposed crater, although the released MOC imagery is limited or nonexistent. Alternative mechanisms for delivering material to the floors of the craters include ejecta from small craters and fluvial transport. In terms of proximity, landing sites in Boeddicker and Gale may have material from both central peaks and rims that have been transported to the landing sites, but high-resolution MOC images are needed to verify this.

Summarizing, the Gale landing site (EP82A) may have outcrops of lacustrine deposits, and hydrothermal deposits transported from the central uplift and crater wall. The landing sites in Boeddicker (EP64A) and the unnamed TM crater (TM16A) contain ejecta from large superimposed craters, providing the best chance of finding impact melt and crater wall material, but they have no evidence of lacustrine material in the limited available imagery. Landing in a large crater has a great potential for addressing the goals of the MER missions, but acquisition of better imagery is essential.

References: [1] http://marsoweb.nas.nasa.gov/ [2] Newsom H.E. (1980), *Icarus, 44,* 207. [3] Newsom H.E. et al. (1996) *JGR 101*, 14951. [4] Malin, M.C. and Edgett, K.S. (2000) *Science 290*. [5] Cabrol, N. et al. (1996) *Icarus 123*, 269. [6] Cabrol N. et al., (1999) *Icarus 139*, 235. [7] Cabrol N. and Grin E. (2000) *Icarus*, in press. [8] Newsom H.E. et al. (1999), *JGR 104*, 8717. [9] Edgett K.S. and Malin M.C. (2000) *EOS Transactions AGU*, Suppl. #P52C-09, F774. [10] McCarville, P.J. and L.J. Crossey (1996) *G.S.A. Special Paper, 302*, 347. [11] Thorsos I.E. et al. (2000) *AAS Bulletin.* [12] Gulick V. (1998) *JGR, 103* 19365. [13] Rathbun, J.A. and Squyres, S. W. (2000) *Lunar and Planet. Sci. XXXI*, # 1111. [14] Graup, G. (1998) personal communication. [15] Malin, M.C. and Edgett, K.S. (2000) *Science 288*, 2330.