NEW EVIDENCE FOR IMPACT-INDUCED HYDROThermal ALTERATION AT THE LONAR CRATER, INDIA: IMPLICATIONS FOR THE EFFECT OF SMALL CRATTERS ON THE MINERALOGICAL AND CHEMICAL COMPOSITION OF THE MARTIAN REGOLITH.  J. J. Hagerty and H. E. Newsom, University of New Mexico, Institute of Meteoritics, Dept. of Earth & Planetary Sciences, Albuquerque, NM 87131 U.S.A. Email: jh2713@unm.edu

Introduction: The 50,000 year old, 1.8km diameter Lonar crater is located in Maharashtra, India (19°58'N, 76°31'E) [1]. This relatively small crater is of particular interest because of its unique morphological and mineralogical properties, which make it a valid analogue for similar craters on the surface of Mars [2, 3]. We show that even in this relatively small crater, substantial hydrothermal alteration has occurred, probably due to the thermal effects of the impact event. The results of the Lonar study are used to draw conclusions about similar craters on Mars.

Results from this study along with other lines of evidence now suggest that hydrothermal alteration at small craters will be an important process on Mars. For example, as impact-induced hydrothermal systems react with the surrounding host rock, alteration products will be produced, and mobile elements will be transported to the surface. In turn, these alteration products and associated mobile elements may make a significant contribution to the martian regolith [4].

Evidence for substantial hydrothermal activity in small martian craters is indicated by the amount of analogous alteration observed at the Lonar crater. The availability of water on Mars, even in small craters, is suggested by the evidence for near-surface reservoirs of liquid water and ice [5]. There is also a strong potential for the production of liquid water by shock melting of ice during crater formation [6].

Analytical methods: A JEOL 733 electron microprobe was used to determine the chemical composition of several altered Lonar samples. The alteration materials were analyzed with a 15kV accelerating voltage, a 20nA beam current, counting times of 20 seconds for major element peaks, and a 5-10µm spot size. A ZAF correction was used during all microprobe analyses.

A JEOL 5800LV scanning electron microscope was used to image several alteration textures in the Lonar samples. The SEM was optimized for high-resolution imaging, which requires a 20 kV acceleration voltage, a sample current of 20 nA, a spot size of 8-10 µm, and a working distance of 8-16 mm. Elimination of the background X-ray spectra is accomplished by a method of filtered least squares.

Stable isotope data were obtained when carbonate materials were powdered and then reacted under vacuum for one hour with purified orthophosphoric acid at 50°C. The CO₂ that was evolved was cryogenically purified and its isotopic composition was measured on the Finnigan MAT Delta E isotope ratio mass spectrometer. The resulting isotope ratios were corrected for ¹⁷O contribution/contamination. Oxygen isotope data were corrected using the carbonate-phosphoric acid fractionation factor of 1.00931 for calcite at 50°C.

Results: The microprobe results from this study were compared with the averages of multiple points from several reference clays [7, 8, 9] plotted on a SiO₂, MgO, and Al₂O₃ ternary diagram. The excellent correlations suggest that the majority of the clay materials in the Lonar samples are saponites and celadonites. The identification of these materials is important for demonstrating the hydrothermal nature of the alteration. Both saponite and celadonite are produced during the hydrothermal alteration of basalt, typically at temperatures of 130-200°C [7, 9].

The production of these “hydrothermal” clays was further established through geochemical modeling of the alteration process. For instance, the modeling clearly demonstrated that similar clay minerals should be produced at elevated temperatures; whereas ambient alteration appears to produce a completely different alteration assemblage.

SEM images of the altered Lonar samples show that there is abundant textural evidence for post-impact hydrothermal alteration, including classic replacement textures (Figure 1), ubiquitous pockets of alteration (Figure 2), and multiple generations of carbonate growth. These textures compare favorably with hydrothermal textures that have been observed at the Valley of Ten Thousand Smokes, Alaska [10] and the Ries crater in Nördlingen, Germany [11]. The hydrothermal nature of the alteration is supported by the isotopic analyses of carbonate material, which gave a δ¹³C_PDB value of -13.4 °/oo and δ¹⁸O_SMOW value of 19.6 °/oo. These data compare favorably with the data derived from well-defined hydrothermal carbonates.

Implications for Mars: Newsom [12] and Newsom et al. [13, 14] showed that hydrothermal processes associated with the formation of large craters (> 50 km diam.) early in martian history could have produced abundant alteration minerals and transported mobile elements onto the martian surface. However, during the past 3.5 billion years, small craters similar in size and character to the Lonar crater have begun to
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Although crater population studies by the BVSP [15] suggest that 1-2 km diameter craters occur once every $10^5$ km$^2$ on the surface of Mars. If this is an accurate estimate, there should be 145,000 martian craters that are 1-2 km in diameter. This large number suggests that hydrothermal processes involving craters the size of Lonar and larger, could have had a significant effect on the chemistry and mineralogy of the martian surface. In contrast to low water/rock volcanic processes, the hydrothermal processes involved in the formation of small craters can provide brecciated and altered deposits that are easily eroded by aeolian and fluvial processes.

The degree of alteration at the Lonar crater was used to estimate the amount of alteration that can be produced by a similar crater on Mars. For example, if we assume that 1% of the area affected by hydrothermal activity is actually altered to clays, then approximately 0.067 km$^3$ of alteration clays could be produced at the Lonar crater. If this value is extrapolated to Mars, then 1-2 km diameter craters will have produced 9,715 km$^3$ of alteration clays. If 15% of that altered material is in the form of saponite (e.g. 16) there will be 1,457 km$^3$ of saponite on the martian surface, which is equivalent to a global layer of saponite that is 6.7 cm thick.

These alteration clays, which contain volatile, mobile elements, will become mechanically weak when exposed to ambient martian conditions [17]. Over long periods of time the dominant martian wind will distribute the alteration material on a global basis [18, 19]. These wind blown alteration products will accumulate on the martian surface for billions of years due to the absence of mechanisms that would recycle them back into the crust. This process could be the most important time averaged weathering mechanism on Mars as long as water is present in some form [19].

If this process has been sustained for long periods of time, large volumes of mobile, volatile elements will have been introduced into the martian soil via the erosion of hydrothermal alteration products. In fact, soil formation models proposed by Newsom et al. [14] have suggested that the observed abundances of volatile elements in the martian soil can be explained by contributions from hydrothermal systems in addition to volcanic aerosol contributions.

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**References:**


**Figure 1.** BSE image of classic replacement textures in the Lonar basalts. The image is 140 µm across.

**Figure 2.** BSE image of two alteration pockets surrounded by hydrothermal carbonate material. The image is 800 µm across.