ROLE OF IMPACT CRATERS IN THE ORIGIN OF PHYLLOSILICATES AND SURFICIAL MATERIALS ON MARS – NEW UNDERSTANDING FROM EARTH ANALOG STUDIES

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Introduction: The discovery of abundant phyllosilicates on Martian impact crater walls and central peaks [1, 2] is leading to renewed examination of terrestrial analog impact craters to evaluate the Martian examples. Current and future rovers including the upcoming MSL mission will be studying materials produced by impacts on Mars, including ejecta, mega-breccia, and hydrothermally altered basement materials. Recent studies on phyllosilicate formation in terrestrial impact craters in basaltic and sedimentary targets and related impactite formation and atmospheric effects are providing information that could be directly applicable to surface studies on Mars.

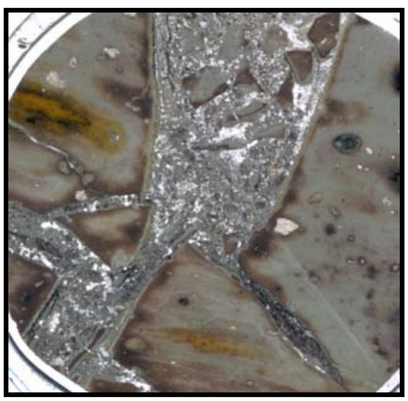

Figure 1. Image of thin section from the lower impactites of the Yaxcopoil-1 drill core, Chicxulub crater. Solidified impact melt has been fragmented in a puzzle piece relationship. The clay-rich matrix clay filling the cracks is interpreted to have precipitated from a hydrothermal fluid at temperatures > 300 ^{o}C [5]. This deposit contains smaller fragments of the melt clasts (usually dark from iron oxide), and calcite (white). Image width 2 cm.

Macroscopic phyllosilicate vein deposits and hydrothermal processes: The nature and temperature of phyllosilicate formation is being explored at several craters. At the 20 km diameter Ries Crater (comparable to a well studied crater south of the Mawrth MSL landing site), stable oxygen and hydrogen isotope studies have shown that phyllosilicate formation occurred at ambient temperatures in the suevite ejecta, and the alteration in the crater-filling sequence from the Nördlingen drill core in the central impact deposits occurred in the presence of meteoric water-dominated fluid circulation at temperatures of 40 to 105 °C [3, 4]. These deposits are also being studied with boron and lithium isotopes to further constrain their origin.

At the 180 km diameter Chicxulub impact structure (similar in size to Gale or Holden craters on Mars), studies on the phyllosilicates deposited in the lower impact-melt deposits of the Yaxcopoil- 1 drill core in the mega-breccia zone are revealing the deposition of clays as precipitates from hydrothermal fluids at much higher temperatures [5](Fig.1). The discovery of andradite garnet in the clays has confirmed the relatively high temperature (>300 ^{o}C) of the hydrothermal system in the Yax-1 drill core [5]. Geochemical evidence of Li-enrichments from the more extensive hydrothermal system originating in the buried impactites in the center of the crater has been identified within the post impact sedimentary deposits inside the crater [6]. Similar veins containing phyllosilicates and enrichments of fluid-mobile elements like Li could be detected and studied in Martian crater deposits with the MSL instruments.

Macroscopic shock effects: Recent studies of shocked basaltic materials at Lonar crater are revealing physical characteristics at the mm to cm size that will be visible from rovers [7]. The macroscopic response of basalt to hypervelocity shock at levels below that required to produce impact melts includes a reduction in density and the production of characteristic fractures (**Fig. 2.**). Spectroscopic indication of shock in Lonar samples has also been recently studied [8].

Figure 2. Natural and cut sides of a Class 2 (20-40 GPa) shocked basalt or maskelynite-bearing basalt [7] showing "decompression cracks" and the resulting weathering style likely resulting from the release of the shock wave by the rarefraction wave. Red hematite and white quartz are alteration products in this basalt (LC09-275) before shock metamorphism, and are now shocked [7]. Images 5 cm across.

Basement features related to impact are being documented at craters like the new Santa Fe structure and the Rochechouart structure. A familiar macroscopic feature of hypervelocity shock events are shatter cones, which can range up to meters in size and are located beneath the transient cavity of an impact crater. Related features due to impact include ubiquitous fracturing of target rocks and a variation on shatter cones called "shatter texture"[9]. On Mars these are expected to be present in mega-breccia as seen in Holden Crater [10].

Spherules and accretionary lapilli: Impact-melt spherules and accretionary lapilli are likely to be encountered on the surface of Mars in the sedimentary record of the ancient crust, for example in places like Mawrth Vallis. Impact spherules have been documented in distal ejecta from the large Sudbury and Chicxulub impacts down to the 1.8 km diameter Lonar crater. Accretionary lapilli are also known from impacts such as the ~25 km Ries [11] and ~11 km Bosumtwi [12] and have recently been described from the basaltic Lonar crater (**Fig. 3**)[13]. Distinguishing spherules of impact origin from other types of spherical materials will be assisted by the studies of the detailed characteristics of the analog materials.

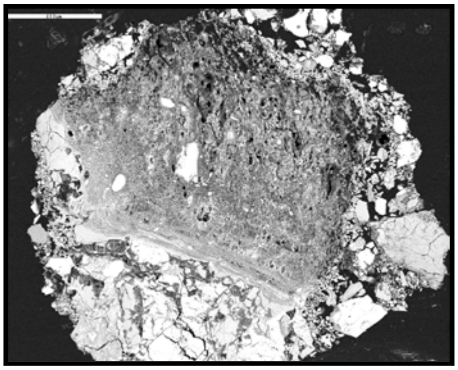

Figure 3 BSE image of an armored lapillus from Lonar ejecta showing fine-grain basaltic mineral fragments adhering to a vesicular impact melt core. Scale bar 200 µm.

Air blast effects due to impactor breakup: The breakup of incoming objects in an atmosphere transfers energy to form an impinging jet of hot gas on the surface [13]. Early in Mars history when atmospheric densities were higher, this process would operate in a fashion similar to the Earth today. Even in recent eons a large number of "type II" events will occur on Mars, which are equivalent to the high altitude breakup of meteoroids on the Earth. For example, 2 m objects enter Earth's the atmosphere several times per year and can completely disintegrate in the upper atmosphere, generating a high-altitude airburst with an explosive energy exceeding 1 kiloton. [14]. Recently, evidence for this process has been found in materials from very small craters like Henbury in Australia; the evidence includes siderophile element enrichments in melts and macroscopic evidence in the form of melt-covered rocks [15]. On Mars, both the chemical and physical evidence can be studied using the instruments on the MER and MSL rovers. Atmospheric breakup has also been called upon to explain features of the Barringer Meteor Crater [16]. The airburst evidence implies that heating and melting of the surface can occur with or without the formation of a crater. Furthermore, the energy of a given impact event may be much larger than implied by the size of the crater. This can accentuate processes discussed before, including formation of accretionary lapilli, and production of dust.

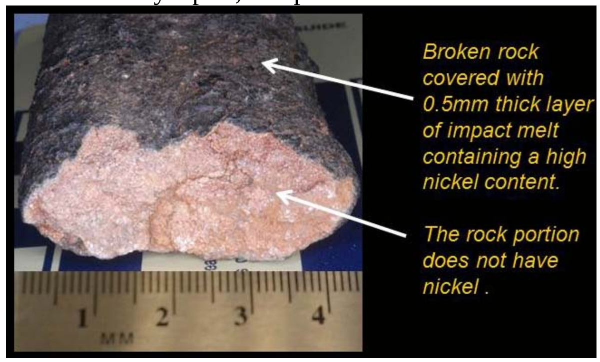

Figure 4 Image of a melt-covered rock from the Henbury, Australia crater field. The chemical data and morphology support an origin by an air blast.

Conclusions: The rapid pace of research on terrestrial impact craters is producing information about cratering processes and materials directly applicable to both orbital and in situ investigations of the surface of Mars. The aqueous and hydrothermal processes involving impact craters and the search for life has been well documented [17, 18]. Phyllosilicates are formed in impact craters as vein fillings in impact melt deposits, central uplifts and crater walls, and as disseminated clays in suevite ejecta. These occurrences will be recognizable by rover instruments, along with mobile element enrichments from impact hydrothermal systems recorded in impact crater lake deposits. Studies of the Lonar crater shocked basalts are providing an understanding of the processes that affected much of the martian surface and martian meteorites, and are revealing features due to shock recognizable by a rover.

Sedimentary rocks on Mars can contain distal and proximal impact ejecta. Distinguishing these materials from other volcanic, aeolian and fluvial deposits will be important for assessing habitability and this may be accomplished through the recognition of features, such as accretionary lapilli and the presence of shocked material.

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