IMPACT CRATER HYDROTHERMAL PROCESSES IN TERRESTRIAL ANALOG CRATERS AND THEIR IMPLICATIONS FOR PHYLLOSILICATES IN IMPACT CRATERS ON MARS. H. E. Newsom[1], [1]Institute of Meteoritics, Dept. of Earth and Planetary Sciences, Univ. of New Mexico (UNM), Albuquerque, NM 87131, (newsom@unm.edu)

Introduction: The discovery of abundant phyllosilicates on Noachian Martian crater walls and central peaks [1-3] is leading to renewed examination of terrestrial analog impact craters to understand the Martian deposits. Recent studies of phyllosilicate formation in terrestrial impact craters and related impactite formation are providing information directly applicable to surface studies on Mars. For example, most terrestrial craters larger than 1.8 km diameter have at least some evidence of aqueous or hydrothermal processes in the form of aqueous alteration minerals [4]. In particular, these studies can address the question of whether the clays in Martian craters represents altered Martian crust excavated by impacts versus in situ formation by crater-related hydrothermal processes. Furthermore, in the near future there is a chance that examination of early crustal material from the Gale crater rim by the Mars Science Laboratory may help answer this question for craters on Mars [5].

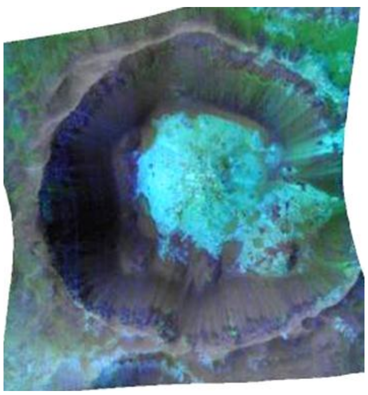

Figure 1. CRISM image of an impact crater on Mars. Iron-magnesium clays are mapped in blue, olivine in green, NASA PIA14764. Image width 10 km.

Phyllosilicate vein deposits and hydrothermal processes: Prior to the discovery of extensive clay deposits in ancient martian terrains, the use terrestrial impact craters as martian analogs for hydrothermal processes has raised objections, including the neutral instead of acidic aqueous environments on the Earth and the composition of the targets, which can include sedimentary overburdens. Although those objections may not be relevant to early Mars, comparisons can still be difficult because of scale issues, as many terrestrial craters with evidence of hydrothermal activity, e.g. Lonar, Haughton, Ries etc., are smaller than the Martian craters with phyllosilicate signatures [1-3].

The nature and temperature of phyllosilicate formation is being explored at several terrestrial craters. At the 20 km diameter Ries Crater, oxygen, hydrogen, and boron stable isotope studies show that phyllosilicate formation occurred at ambient temperatures in the suevite ejecta, but 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 elevated temperatures of 40 to 105 °C [6, 7]. Evaluation of temperatures derived from stable isotopes and mineralogy must keep in mind that impact deposits begin hot, but have an extended cooling period during which alteration phases can back react to low temperature phases with corresponding stable isotope signatures.

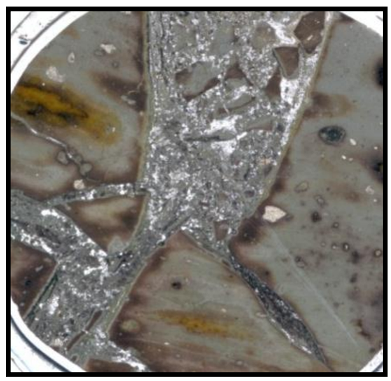

Figure 2. Thin section image from the lower impactites of the Yaxcopoil-1 drill core, Chicxulub crater. Silicate impact melt has been fragmented in a puzzle piece relationship. The fractures are filled with an Mg-rich clay matrix containing calcite and are interpreted to have precipitated from a hydrothermal fluid at temps. > 300 ^{o}C [8]. Image width 2 cm.

At the 180 km diameter Chicxulub impact structure (similar in size to Gale or Holden craters on Mars), studies of the lower impact-melt deposits (**Fig. 1**) of the Yaxcopoil-1 drill core in the mega-breccia zone reveal the deposition of phyllosilicates clays as precipitates from hydrothermal fluids at high temperatures [8]. The discovery of andradite garnet in the clays has confirmed hydrothermal temperatures >300 ^{o}C in the Yax-1 drill core samples [8, 9]. 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 [10]. Similar veins containing phyllosilicates and enrichments of fluid-mobile elements like Li could be detected and studied in Martian crater deposits with the MSL ChemCam instrument which is sensitive to Li.

Localization of impact hydrothermal processes by the available heat and water supply: Terrestrial studies suggest that hydrothermal processes in both terrestrial volcanic and impact settings are localized and depend on the distribution of heat sources and availability of water. Impact melts in crater fill and ejecta blankets provide heat that can produce hydrothermal alteration if water is available [11].

The sources of heat for powering hydrothermal processes in impact craters come from several sources including the presence of impact melt. Central uplifts represent the bottom of the transient cavity and can be highly shocked and contain impact melt. The uplifted geothermal gradient can be as important a heat source as shock effects. Mineralogical evidence for high-temperature fluids (> 350 ^{o}C) is present in the central uplift of the Manson structure for example [12]. The walls of smaller craters (e.g. **Fig. 1**) may have shed their impact melt onto the crater floor, as suggested for the impact melt-bearing breccias in the terrestrial Ries crater drill core. The amount of impact melt in ejecta can also be highly variable. An example from the Moon (**Fig. 3**) shows an impact melt flow on top of other ejecta, which would produce a local thermal maximum.

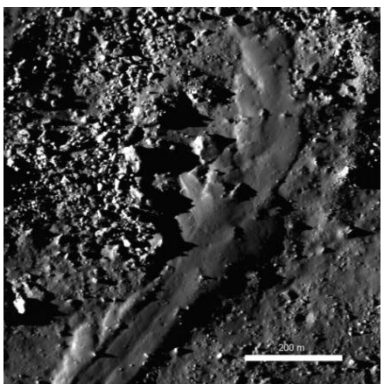

Figure 3. Flow of impact melt on the surface of the Byrgius A lunar crater ejecta 3.2 km from the crater's rim. (LRO website, scale 200m).

The availability of water and transport of hydrothermal fluids can also be important in localizing the effects of hydrothermal processes. Self-sealing of hydrothermal systems can also affect the transport and expression of hydrothermal systems. This is seen at many terrestrial volcanic hydrothermal settings, including Yellowstone, where surface expressions of hydrothermal activity are highly localized. In mid-ocean ridge settings fluids can also be transported many kilometers from their source. In terrestrial impact craters hydrothermal fluids can also travel long distances from their sources (e.g., the Yaxcopoil site in the Chicxulub crater [13]) and are often localized to faults or porous breccias (e.g. Sudbury), producing alteration zones that are spatially limited.

Implications for Martian impact craters: The lessons from terrestrial hydrothermal systems for Martian craters suggests that: A) Extensive hydrothermal alteration requires large craters (>10 km diam.), with heat from basement uplift, and the presence of shocked and melted material in crater fill and ejecta. B) Assuming water is available from precipitation; ice, or groundwater, hydrothermal fluids (on Mars any water above freezing might be considered hydrothermal) can be generated in impact melt sheets, melt-bearing ejecta, and central uplifts. C) Hydrothermal fluids can contribute to the formation and deposition of evaporites (e.g. **Fig. 4**), and impact crater lakes with accompanying and alteration of materials on the lake floors. D) Hydrothermal fluids derived from hot central uplifts and melt sheets may also migrate into porous megabreccias and faulted rocks associated with crater walls and central uplifts leading to formation or precipitation of alteration minerals. C) Outside of large craters or basins, alteration of melt-bearing ejecta can only occur if the ejecta is relatively thick (> 100 m) or consists largely of impact melt, and water is available.

Figure 4. Veins of Ca-sulphate, probably gypsum on the rim of Endeavor Crater, Mars. The large vein is ~ 2 cm wide.

Conclusions: The 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 [14, 15]. Phyllosilicates are formed in impact craters as vein fillings in impact melt deposits, central uplifts, 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. 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. In conclusion, based on terrestrial analog studies, impact hydrothermal processes are a plausible explanation for the alteration phases observed in association with Martian craters.

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