**IMPACT CRATERS AS PROBES OF FLUIDS ON DIFFERENTIATED BODIES.** G. R. Osinski[1], L. L. Tornabene[1], D. W. G. Sears[2,3], S. S. Hughes[4] and J. L. Heldmann[3]. [1]Centre for Planetary Science and Exploration/Depts. Earth Sciences/Physics and Astronomy, University of Western Ontario, London, ON Canada. [2]Bay Area Environmental Research Institute, 596 1st St West Sonoma, CA USA. [3]NASA Ames Research Center, Mountain View, CA 94035, USA. [4]Dept. of Geosciences, Idaho State University, Pocatello, ID USA. (gosinski@uwo.ca)

**Introduction:** The differentiated bodies of the Solar System vary greatly in terms of size, surface characteristics, and presence/absence of an atmosphere, reflecting their different geological histories and active processes. There is, however, one major geological process common to all these bodies and that has acted upon them from the birth of the Solar System to the present day – impact cratering. Indeed, it is now recognized that the impact of asteroids or comets with planets and other Solar System bodies and the associated formation of meteorite impact structures is a fundamental geological phenomenon.

In the absence of widely distributed samples from known locations on differentiated bodies other than Earth and, to a certain extent, the Moon, we suggest that two fundamental attributes of meteorite impact craters – impact ejecta and impact melt deposits – can be used as proxies for comparing the crustal abundance of fluids between different planetary bodies and in different geographic regions of individual bodies.

**Impact Melt Deposits:** One of the most distinctive processes to occur during an impact event is rapid shock-induced melting of target rocks directly beneath the impact point, which produces impact melt rocks and impact melt-bearing breccias [1, 2]. These impact melt deposits vary greatly in terms of their physical and chemical properties – e.g., ranging from crystalline to glassy – and can be found as dykes intruding crater floors, as continuous layers or semi-continuous lenses in crater interiors (crater fill deposits) and as individual fragments, semi-continuous lenses, or continuous layers in the rim region, both within and without impact craters (ejecta deposits) (Fig. 1A).

Historically, it was thought that impact melts were not generated, or were generated in such small amounts that they were not generally observable, in targets containing significant volatiles (e.g., Mars [3] and sedimentary rocks on Earth [4]). However, it is now clear that this is not the case and that significant deposits of impact melts are generated from impacts into volatile-rich targets [5, 6]. Melts generated from volatile-poor and -rich rocks are, however, very different in terms of their physical and chemical properties and their overall appearance (e.g., compare Fig. 1B with 1C and D). In Table 1, we synthesize observations based on satellite observations of Mars, Moon, and Vesta, with data from studies of meteorites and Apollo samples, together with ground-truth data from impact craters on Earth from both the field and laboratory analysis of samples from known locations and context.

As an example, one of the most exciting recent discoveries on Vesta has been the discovery of pitted deposits within the interior of impact craters [7]. Such deposits were discovered just prior to this on Mars [8]. The best current explanation for the formation of these pits in Martian craters is the explosive release of gas from volatile-rich impact melt deposits [8, 9]. This hypothesis is strongly supported by the presence of so-called degassing pipes in impact melt-bearing breccias ('suevites') at the Ries impact structure (Fig. 1C), and phreatic craters associated with volcanic flows. The Ries impactites contain silicate impact glasses and clays (Fig. 1C) derived from melting a mixture of sedimentary and crystalline rocks. Notably, impact melt-bearing breccias are minor and degassing pipes are lacking in crystalline and purely sedimentary targets on Earth. Similarly, pitted materials, which likely represent suevites, are lacking in volatile-free and very rich regions on Mars (e.g., ice-rich regions of the northern plains) (Table 1) [8].

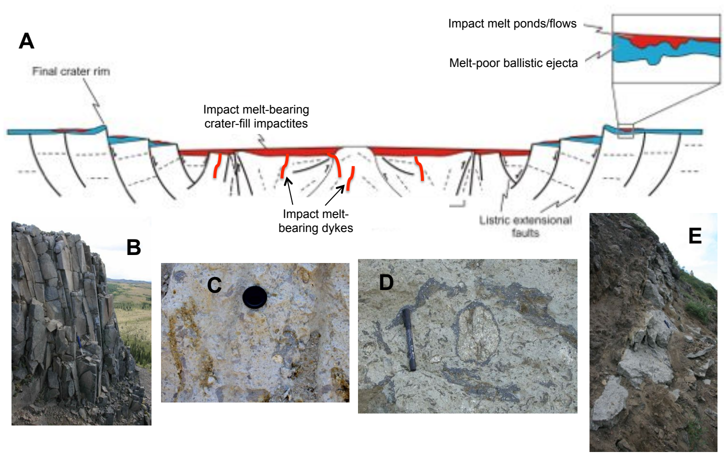


**Fig. 1A.** Schematic cross section of a typical complex impact crater showing the distribution of impact melt-bearing impactites. **B.** Volatile-free/poor impact melt rocks from the ejecta of the Mistastin Lake impact structure, Canada. **C and D.** Volatile-rich impact melt-bearing breccias from the Ries impact structure, Germany (D) and the Mistastin structure (D). The sub-vertical orange features at the left of C are degassing pipes. **E.** Volatile-rich impact melt-bearing breccia dyke intruded into the crater floor at the Mistastin structure.

We thus propose that pitted materials – which we suggest would have the appearance of impact melt-bearing breccias from terrestrial craters on Earth – form from impacts into differentiated planetary bodies that contain moderate amounts of volatiles (Table 1). Exact numbers cannot be determined at present, but the range of 10 to 15–20 volume % fluids seems reasonable based on models for pit formation on Mars [9], considerations of the volatile content of the target rocks at the Ries structure [10], and estimates from Vesta (~9%) based on spectral observations of carbonaceous chondrite bodies [7].

**Impact Ejecta Deposits:** In addition to impact melting, the formation of ejecta deposits is a characteristic feature of impact events (Fig. 1A). On Mars, the presence of so-called fluidized or layered ejecta structures has long been proposed as an indicator for subsurface volatiles [11]. In a recent paper, a multi-stage model for impact ejecta emplacement on all the terrestrial planets has been proposed [12]. Based on this model, in Table 1, we link the previous discussion of impact melts to the potential morphology of ejecta deposits that could be observed from orbit.

**Summary and Outlook:** In this contribution we hope to have demonstrated that the physical properties and morphologies of impact melt and ejecta deposits within and around impact structures can be used as proxies for fluid abundance within the subsurface of differentiated planetary bodies. Further work to quantify better the abundance of fluids required to form a particular feature/product and integration with meteorite data – in particular from the HED group from Vesta – will hopefully yield further results.

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**Table 1.** Link between fluid/volatile content of parent body, impact melt deposits, and ejecta morphology.

| **Fluid content of target** | **Impact melt deposit properties** | | | **Impact ejecta morphology in satellite data** | **Found where?** |
|---|---|---|---|---|---|
| | **Appearance in outcrop/hand specimen** | **Appearance in satellite data** | **Mineralogy (in situ, orbital, laboratory)** | | |
| Volatile-free | Coherent crystalline rock with igneous textures and features (e.g., Fig. 1B) | Veneers, ponds and flows, indistinguishable from lava flows | Typical igneous mineralogy (olivine, pyroxene, feldspars, depending on target) | Continuous layer of ballistic ejecta with/without patchy melt deposits on top | **Moon** |
| Volatile-poor (<5%) | As above + minor impact melt-bearing breccias with silicate glass fragments (e.g., Fig. 1D) | As above | As above + trace amounts of hydrous phases (e.g., clays, sulfates, carbonates, depending on target) | Continuous layer of ballistic ejecta with/without patchy melt deposits on top | **Earth** (crystalline targets); **Mars** (volatile-poor volcanic terrains – e.g., Pangboche Crater [7]) |
| Volatile-rich (<10–20%) | Impact melt-bearing breccias with silicate glass fragments and degassing pipes (e.g., Fig. 1C) | Pitted deposits; some observations of clasts in high resolution image | Abundant hydrous phases (e.g., clays, sulfates, carbonates, depending on target) | Continuous layer of ballistic ejecta with patchy melt ponds on top | **Mars** (low to mid-latitudes); **Vesta**; **Earth** (mixed sedimentary-crystalline targets) |
| Volatile-rich (>>20%) | Impact melt-bearing breccias | Smooth crater fill deposits? Continuous ejecta layer? | Abundant hydrous phases (e.g., clays, sulfates, carbonates, $H_2O$ and other ices, depending on target) | Two or more continuous layers of ejecta (e.g., double or multiple layered ejecta structures) | **Mars** (high latitudes); **Earth** (purely sedimentary targets with carbonate- and sulfate-rich targets) |