IMPACTITES ON MARS: WHAT SHOULD WE EXPECT AND WHAT IS THE ROLE OF VOLATILES?

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Introduction: Mars possesses the most diverse impact cratering record of any planetary object in the Solar System [1]. Impact craters are also one of the most common geological landforms on Mars. Furthermore, impact craters offer a window into the subsurface, and their characteristics provide insights as to the composition, structure, and physical characteristics of the martian crust and its volatile inventory.

The diversity of martian impact craters and their associated deposits (impactites) have been attributed, in part, to the widespread presence of volatiles in the martian subsurface. It is well known that volatiles play an important role in the impact cratering process; in particular, with respect to impact melt generation and ejecta deposition. The terrestrial impact cratering record currently provides the only ground-truth data on the effects of impacts into volatile-rich (i.e., sedimentary) targets.

The aim of this paper is to provide an up-to-date assessment of the processes and products of impacts in to volatile-rich targets on Earth and to apply this knowledge to the martian impact cratering record. Some predictions as to the type of impactites that should be found on Mars will also be made.

Classification of impactites: The classification of impactites is still the topic of ongoing debate within the impact community; however, the most widely accepted and standardized scheme is that proposed by "The Subcommission on the Systematics of Metamorphic Rocks of the IUGS" [2] (Table 1). It is generally believed that the type of target rocks governs the type of impactite(s) produced during an impact event. This will be discussed below.

Crater-fill deposits: It has generally been accepted that coherent impact melt rocks and impact melt sheets are not generated in impact structures formed in sedimentary (i.e., volatile-rich) targets [e.g., 3]. This is despite the fact that, theoretically at least, impacts into sedimentary rocks should produce as much or more melt than impacts into crystalline rocks [3]. This anomaly has been attributed to the formation and expansion of enormous quantities of sediment-derived vapour (e.g., H_2O, CO_2, SO_2), resulting in the unusually wide dispersion of shock-melted sedimentary rocks [3]. Instead, in impact structures formed in predominantly sedimentary targets, the resultant impactites have been referred to as lithic impact breccias that are supposedly melt free (Table 1).

However, recent work at the 23 km diameter, ~23 Ma Haughton impact structure, Canada, has shown that the crater-fill impactites are not lithic impact breccias as previously thought but are, in fact, impact melt rocks [4–6]. Haughton occurred into a ~1.7 km thick sedimentary target sequence overlying crystalline basement rocks. Impact melts derived from sedimentary rocks have also been found at the Ries [7–9] and Chicxulub impact structures [e.g., 10]. Thus, it is apparent that impact melting in volatile-rich targets is much more common than previously thought. It follows that *impact melt sheets should be common on Mars*, even in impact craters that comprise volatile-rich targets.

Proximal ejecta deposits: Two of the most unusual aspects of martian impact craters are the presence of lobate or so-called 'fluidized' ejecta deposits, and the layered nature (often two or more layers) of the ejecta [1]. Two conflicting mechanisms have been proposed to account for these features: (1) interaction of ejecta with volatiles in the subsurface [e.g., 11], or (2) ejecta interaction with the atmosphere [e.g., 12].

Ejecta deposition is one of the least understood aspects of impact cratering, which is due, in part, to the lack of preservation of ejecta deposits at the majority of terrestrial impact sites. The ~24 km diameter, ~14.5 Ma Ries impact structure, Germany, is one of the exceptions. The Ries target sequence comprises volatile-rich sedimentary rocks (~500–800 m thick) overlying crystalline basement. In addition, three main proximal ejecta deposits have been recognized at the Ries: (1) Bunte breccia, (2) surficial, or 'fallout', suevites, and (3) coherent impact melt rocks. The latter two lithologies overlie Bunte breccia. Thus, the Ries ejecta deposits may provide a good analogy to fluidized, layered martian ejecta deposits.

What are the emplacement mechanisms for the Ries ejecta deposits and what can they tell us about ejecta deposition on Mars? It is generally accepted that the Bunte breccia represents what remains of a continuous ejecta blanket that is consistent with ballistic emplacement [e.g., 13].

The emplacement mechanism(s) of the suevites is less well understood. It is generally accepted that these impactites were deposited subaerially from an ejecta plume. However, recently, it has been suggested that the suevites represent impact melt flows that were emplaced outwards from the crater centre during the final stages of crater formation and that they were never airborne [9]. This has also been suggested for the impact melt rocks at the Ries [14] and for proximal ejecta deposits at Haughton [4–6]. Importantly, the Ries impact melt rocks were derived entirely from the crystalline basement, whereas the volumetrically dominant suevites incorporated substantial amounts of volatiles from the sedimentary cover (i.e., the Ries suevites represent volatile-rich impact melt flows) [9]. It is, therefore, suggested that some of the fluidized ejecta deposits on Mars may represent volatile-rich melt flows. Where ground ice was in the near subsurface, it is likely that volatiles could have subsequently been incorporated into these flows, extending their runout distances considerably, as proposed by Carr et al. [11]. In terms of the type(s) of impactites expected in proximal ejecta deposits on Mars, if these analogies with terrestrial impact craters are correct, *suevite-like deposits* and patches of more *coherent impact melt rocks* would be expected.

Distal ejecta deposits: As suggested by Schultz and Mustard [15], it is probable that clasts of impact-generated glass will be present in distal ejecta deposits on Mars (i.e., in ejecta deposited >5 crater radii away from the source crater).

Summary: Impact melt rocks and glasses are likely to be much more common on Mars than previously thought. By analogy with the terrestrial impact cratering record, it is expected that massive impactites in the form of coherent impact melt rocks and suevite-like deposits will be found within and around martian impact craters (see Table 1). In addition, as proposed by Schultz and Mustard [15], impact melts are likely to be found in distal ejecta deposits. Finally, some of the fluidized ejecta deposits on Mars may have originated as volatile-rich impact melt flows.

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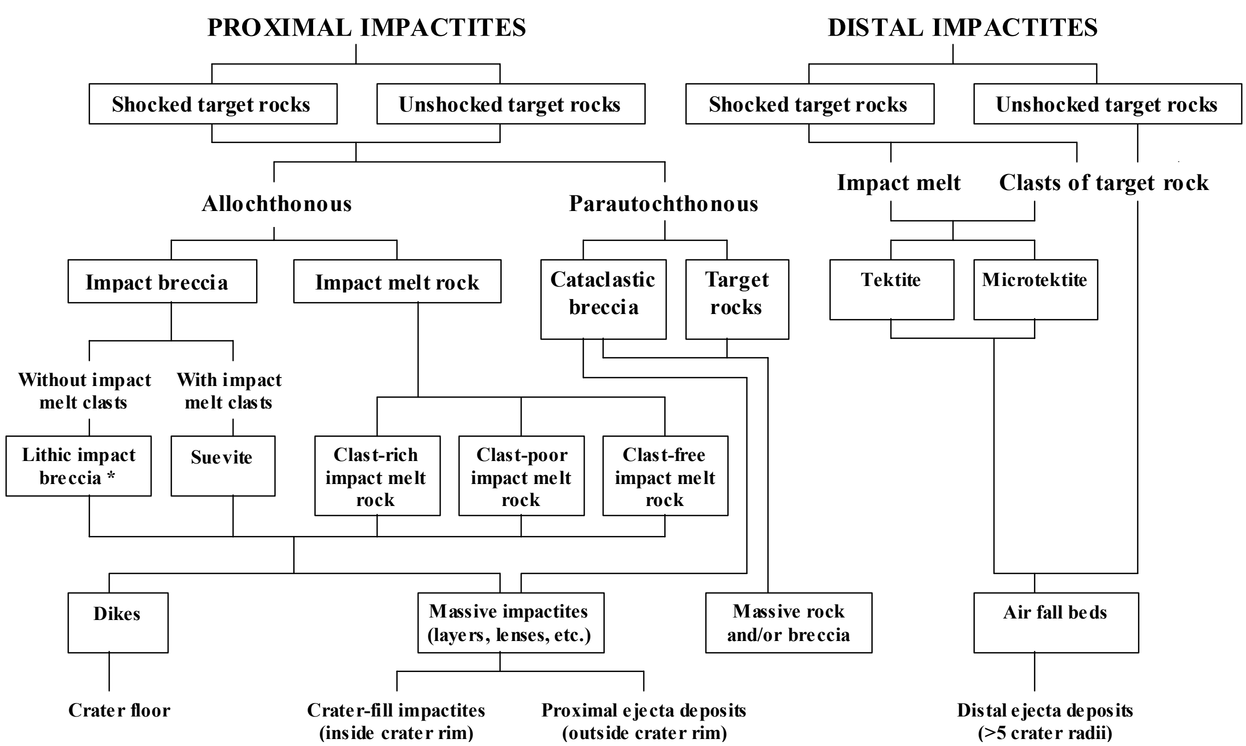
Table 1. Classification of impactites from a single impact event [2]. Although this scheme was drawn up based mainly on the terrestrial impact cratering record, most of these impactite types should also be expected on Mars.



* Lithic impact breccias have been referred to as clastic matrix breccias or fragmental breccias at many impact sites.