**IMPACT EJECTA EMPLACEMENT: OBSERVATIONS FROM EARTH, MOON AND MARS.** G. R. Osinski, Canadian Space Agency, 6767 Route de l'Aeroport, St-Hubert, QC J3Y 8Y9, Canada (osinski@lycos.com).

**Introduction:** One of the most characteristic, but poorly understood, aspects of meteorite impact events is the generation of ejecta deposits. The lack of understanding is due, in part, to the scarcity of ejecta at the majority of the world's impact structures. Observations of impact ejecta deposits on other planetary bodies provide a complementary data set with which to study the emplacement of impact ejecta; however, ground-truthing is not possible and information is only available about the surface morphology and properties of the ejecta deposits. The aim of this paper is to summarize and discuss observations of impact ejecta deposits from terrestrial, lunar, and martian impact structures and the role of target lithology in their formation.

**Proximal versus distal impact ejecta:** Proximal impact ejecta deposits are found in the immediate vicinity of an impact crater (<5 crater radii from the point of impact); whereas distal ejecta deposits are found distant from the crater (>5 crater radii) and may be dispersed globally depending on the magnitude of the impact event. It is important to note that for complex impact craters, proximal ejecta deposits do not only occur outside the final crater rim (as in simple impact craters), but also within the collapsed crater rim region (i.e., they occur external to the original transient cavity and up to the outer limit of the continuous ejecta blanket, up to ~5 crater radii from the point of impact).

**Proximal impact ejecta:** Proximal ejecta deposits are rare on Earth due to post-impact erosional processes, but are common on other planetary bodies. It is generally accepted that proximal ejecta deposits on airless bodies, such as the Moon, are emplaced *via* ballistic sedimentation [1]. In this model, the ballistic emplacement of primary crater-derived ejecta results in secondary cratering and the incorporation of local material (so-called "secondary ejecta"), and considerable modification of the local substrate [1].

Studies of the continuous ejecta blanket (Bunte Breccia) at the Ries impact structure strongly support the importance of ballistic sedimentation during ejecta emplacement on Earth [2]. An important observation is that the Bunte Breccia consists of two main components: (1) primary ejecta excavated from the initial transient crater (~31 vol%; [2]); and (2) local material or "secondary ejecta" (~69 vol%; [2]). The incorporation of large amounts of secondary ejecta clearly indicates that after primary ejecta is initially deposited, it then continues to be transported radially-outwards along the surface.

It is apparent that target lithology plays an important role in the formation of continous ejecta deposits. At the Ries structure, the volatile content and cohesiveness (e.g., resistant limestone bedrock versus unconsolidated clays and sands) of the uppermost target outside the transient cavity governed the maximum radial extent of ground-hugging flow following ballistic deposition [2].

An important observation is that one, or more, layers of ejecta may overlie the continuous ejecta blanket around complex impact structures. This is particularly common on Mars, where so-called double and multiple layered ejecta structures are observed [3]. This is also true for several terrestrial craters, including the Chicxulub (e.g., [4, 5]), Haughton [6], and Ries (e.g., [7]) impact structures. On the Moon, impact melt deposits overlying the continuous ejecta blanket may also be thought of as ejecta deposits [8].

Some of the best-preserved and exposed ejecta deposits occur at the Ries structure, where a series of impact breccias (polymict crystalline breccias), impact melt-bearing breccias (suevites), and impact melt rocks overlie the continuous ejecta blanket (Bunte Breccia) [7]. Early workers suggested that these impactites were deposited subaerially from an ejecta plume [7, 9]. More recently, it has been suggested that the proximal suevites were emplaced as surface flow(s), either comparable to pyroclastic flows (e.g., [10, 11]), or as ground-hugging impact melt-rich flows that were emplaced outwards from the crater center during the final stages of crater formation [12]. This has also been suggested for the impact melt rocks at the Ries [13]. Such a mechanism for the emplacement of this suevite ejecta is consistent with several field observations [12] and the clear temporal hiatus between emplacement of the ballistically-emplaced Bunte Breccia and the overlying suevites/impact melt flow deposits [2], which requires a two-stage ejecta emplacement mode. This is supported by observations made at the Haughton structure, where two layers of proximal ejecta also occur [6]. As at the Ries, the properties of the lower layer (which represents the continuous ejecta blanket) are consistent with emplacement *via* ballistic sedimentation during the excavation stage, with the upper layer being emplaced as ground-hugging flows during the modification stage of crater formation. For the upper layers, target lithology appears to play a fundamental role in determining the amount of melt and vapour generated, which affects the amount of fluidization and flow.

At the larger Chicxulub structure, several layers of ejecta are present, both within and exterior to the final crater rim. Evidence from the Yaxcopoil-1 drill hole suggests complex emplacement mechanisms involving ground surge and ballistic sedimentation; however, the limited thickness of impactites available for study (~90 m) and the evidence for reworking renders it difficult to place these observations in the wider context of impact ejecta emplacement in general [4]. Exterior to the final crater rim, Chicxulub possesses two main types of proximal ejecta deposit [14] (cf., the Haughton and Ries structures): (1) polymict impact breccias up to ~300 m thick, interpreted as the continuous ejecta blanket (cf., Bunte Breccia at the Ries structure); and (2) suevite deposits up to ~150 m thick that overlie the Bunte Breccia-like deposits. Unfortunately, the emplacement mechanism(s) of these impactites has not been addressed in any detail due to poor exposure.

The outer portion of the continuous ejecta blanket has been termed the Albion Formation and comprises a basal spheroid bed and an upper diamictite bed (e.g., [15]), which preserve features such as cross bedding and internal shear planes, indicative of lateral flow outwards from the crater center [15, 16]. Kenkmann and Schönian [16] proposed the following depositional model: following ballistic deposition at <<3 crater radii, ground-hugging flow occurred driven by the water content of the flow itself. At distances of >3.5 crater radii, the incorporation of local clays further fluidized the flow and allowed it to continue moving for greater distances than would have been possible if the substrate was resistant bedrock. Thus, target lithology played a key role in fluidizing the ejecta deposits.

Emplacement of impact ejecta *via* a combination of ballistic sedimentation and ground-hugging flow during different stages of crater formation, is broadly consistent with observations from other planetary bodies. For example, exterior impact melt-rich ejecta flows have been recognized around lunar and venusian impact structures [8, 17, 18]. It is also widely accepted that the layered ejecta deposits of many martian impact craters were emplaced as highly fluidized relatively thin ground-hugging flows [19-21].

**Distal impact ejecta:** Distal ejecta deposits, collectively termed air fall beds typically comprise two main types: strewn fields of glassy tektites and microtektites, and spherule beds comprising (formerly) glassy impact spherules and fragments of shocked target rocks. Of the four tektite strewn fields, two (the Ivory Coast and Central European fields) have been linked to source craters [22]. In addition, several Phanerozoic to Cenozoic spherule layers have been documented in the rock record [23]. It is typically assumed that distal ejecta gradually settles out from the atmosphere; however, it has also been suggested that distal impact ejecta falling into the atmosphere may clump together into density currents that flow to the ground much more rapidly than might be expected for single particles themselves [24].

**Summary:** In summary, while many aspects of ejecta emplacement remain unclear, it is apparent that target lithology plays an important role in this aspect of the impact cratering process, for example in constraining the amount of fluidization and surface flow and the amount and properties of entrained impact melt. Further work, however, is required on this subject, including numerical modeling and greater use of planetary datasets for comparative studies.

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