A SEARCH FOR TERRESTRIAL ANALOGUES TO MARTIAN LAYERED EJECTA STRUCTURES G. R. Osinski and H. J. Melosh, Lunar and Planetary Laboratory, University of Arizona, 1629 E. University Blvd., Tucson, AZ 86721-0092, USA (osinski@lycos.com).

Introduction: Hypervelocity impact craters are one of the most common geological landforms on Mars. Their nature provides insights as to the composition, structure, and physical characteristics of the martian crust and its volatile inventory. It is notable that the martian impact cratering record is more diverse than for the other terrestrial planets [1]. One of the most unusual aspects of martian impact craters is the presence of lobate or fluidized ejecta deposits, often comprising two or more lobes or layers of ejecta [e.g., 1], collectively termed "layered ejecta structures" [2]. These features have been attributed to either (1) interaction of ejecta with volatiles in the subsurface [e.g., 3], or (2) ejecta interaction with the atmosphere [e.g., 4]. The former theory is the most widely accepted and has been used as evidence for the presence of H_2O in the martian subsurface [1]. However, exactly how H_2O is incorporated into the ejecta, at what stage in the cratering process this occurs, and in what state (i.e., solid or liquid), H_2O occurs in the subsurface, still remains unclear.

Given that Earth possesses an atmosphere and volatile-rich target rocks (i.e., sedimentary rocks), in theory, lobate or fluidized ejecta deposits should also be present around terrestrial impact structures. Field and analytical studies of such deposits would then enable the necessary ground-truthing of the various models for the formation of fluidized ejecta blankets.

Unfortunately, there are no impact craters >0.5–1 km diameter on Earth with pristine ejecta deposits, due to post-impact erosional processes. Nonetheless, several relatively young (<20–30 Ma), well preserved complex impact structures, developed in volatile-rich target rocks, are known from the terrestrial impact cratering record. Two of the best and most studied examples are the Ries impact structure, Germany, and the Haughton impact structure, Canada, which are both ~24 km in diameter and that possess well preserved ejecta deposits, particularly in the case of the Ries. Other, younger terrestrial impact structures developed in sedimentary target rocks may also provide good analogies to Mars (e.g., Zhamanshin); however, the lack of detailed field studies hampers such comparisons. The Haughton and Ries impact structures, in contrast, have been intensively studied over the years. Furthermore, recent work in the past few years has shed more light on the role of volatiles in ejecta formation and deposition. In this work, we present a summary of the results of these recent field and allied analytical studies on the ejecta deposits of these two craters, discuss the models put forward for their origin, and evaluate the potential of using these structures as analogues for martian layered ejecta deposits.

Ries impact structure: The ~24 km diameter, ~14.5 Ma old Ries impact structure, Germany, is one of the best preserved terrestrial impact structures. The Ries target sequence comprises ~500–800 m of sedimentary rocks (carbonates and sandstones) overlying crystalline basement [10]. The structure possesses a thick sequence of crater-fill impactites ("crater suevite" and three main types of proximal ejecta [10]: (1) Bunte Breccia, (2) surficial, or "fallout", suevites, and (3) coherent impact melt rocks. The latter two lithologies overlie Bunte Breccia, with a very sharp contact between the to formations (i.e., two layers of ejecta are present at the Ries).

Fig. 1. Field photograph showing the Bunte Breccia (red/brown) overlain by surficial suevites (grey/green) at the Aumühle Quarry. Note the sharp contact between the two lithologies.

It is generally accepted that the Bunte Breccia represents what remains of a continuous ejecta blanket that is consistent with ballistic emplacement [e.g., 11]. The emplacement mechanism(s) of the suevites is less well understood. It was generally accepted that these impactites were deposited subaerially from an ejecta plume [e.g., 10]. However, recently, it has been shown that surficial suevites were emplaced as surface flow(s) [12–14], either comparable to pyroclastic flows [12, 13], or as a ground-hugging impact melt-rich flows that were emplaced outwards from the crater centre during the final stages of crater formation [14]. This has also been suggested for the impact melt rocks at the Ries [15]. 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-bearing melt-rich flows) [14]. It is notable that the volatiles were incorporated into the suevites in the form of hydrous impact melts that later devitrified to clays [14].

Haughton impact structure: The ~24 km diameter, 23 Ma old Haughton structure is situated on Devon Island in the Canadian High Arctic and is well preserved and well exposed due to the prevailing polar desert environment. The target stratigraphy consists of a ~1880 m thick series of sedimentary rocks, predominantly carbonates with minor evaporites, sandstones, and shales, overlying Precambrian crystalline basement [5]. Contrary to the previous interpretation of a single impactite lithology [6], combined field, optical and analytical scanning electron microscopy studies have revealed the presence of a series of impactites at Haughton [7–9].

Two principal impactites have been recognized in the near-surface crater rim region of Haughton. Pale yellow–brown allochthonous impact melt breccias and megablocks are overlain by pale grey impact melt breccias [9]. The former are interpreted as remnants of the continuous ejecta blanket. The pale grey impact melt breccias are analogous to the surficial suevites at the Ries structure and are interpreted as ground-hugging surface flows [9]. These studies reveal that carbonates, evaporites, sandstones, and shales underwent melting during the Haughton impact event [7–9].

Discussion: 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 and, by analogy, may provide important information about the products and processes associated with impacts into volatile-rich targets on Mars.

Using the terminology of Barlow et al. [2] for martian impact craters, the Ries and Haughton structures are double-layer ejecta structures. Can the information gained from studying these structures tell us anything about ejecta deposition on Mars?

One of the main conclusions from recent studies is that ejecta interaction with the atmosphere was unimportant during the Haughton and Ries impact events [9, 14]. This lends credence to the theory that the presence/absence of volatiles is the most important parameter in determining the morphology of ejecta around martian impact structures.

It is clear that the lower layer of ejecta at Haughton and Ries represent ballistic ejecta. At the Ries, this unit (the Bunte Breccia) consists of two main components [11]: (1) “primary ejecta” excavated from the initial crater, and (2) local material or “secondary ejecta”, derived from where the primary ejecta was initially deposited and, then, mobilized and incorporated by the secondary cratering action of the primary ejecta. This so-called secondary ejecta can comprise >90 vol% of the total volume of the Bunte Breccia in many places, particularly where the underlying substrate at the time of impact was unconsolidated clays and sands [11]. Thus, it appears that the incorporation of volatile-rich sediments was important in the formation of the Bunte Breccia at the Ries structure.

The upper layer of ejecta at the Haughton and Ries structures represent ground-hugging flows, which has also been suggested for Mars [e.g., 3]. A substantial component of these terrestrial flows are impact-generated melts derived from sedimentary, volatile-rich target rocks [7–9, 14]. By analogy, it is suggested that substantial amounts of volatiles could be incorporated in to martian ejecta deposits in the form of volatile-rich melts.

Further comparative studies using Haughton and Ries as terrestrial analogues for martian impact structures are planned. It is hoped that this paper will stimulate discussion and a transfer of ideas between the martian and terrestrial impact cratering communities.

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