TERRESTRIAL ANALOGS: LAYERED EJECTA CRATERS AND THEIR IMPLICATIONS.

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Introduction: Terrestrial impact craters have provided a wealth of analog information that has helped to understand the processes that go into producing the morphologies of impact craters on other bodies. However, the study of terrestrial impact craters only has provided scant information about ejecta because most ejecta deposits are either highly eroded or missing altogether. Recent detailed analysis of the geology and geometry of ejecta at Ries crater in Germany by [1] and Lonar crater in India by [2] are noted exceptions. Based on these data, [3] suggests that Lonar crater is a single layer ejecta (SLE) crater, and [1] that Ries is a double layer ejecta (DLE) crater (see [4, 5] for definition). Consequently, these craters may provide the first reliable terrestrial analog data for the ejecta of layered ejecta craters.

The study of the ejecta from these analog craters should fill in important pieces missing to our understanding of processes that control formation of the morphologic elements of layered ejecta. This is important to Mars history because these studies may help to answer the question of the role of water in development of these craters. Here, we test the morphometric data (specifically ejecta run out distance and rampart width) for the Ries and Lonar craters [1, 2] against similar data for Martian layered ejecta craters from [3] in an effort to further verify they are layered ejecta craters. In addition, some preliminary thoughts of the implications of these data are discussed.

Morphometry: Based on the morphometric data from [2, 3] for Lonar, its diameter [D] is 1.88 km; average ejecta run out distance to edge of the rampart is 1.4 km, the average width of the ramparts [W_{av}] is 0.15 km, the average ejecta mobility (EM) or average run out distance to crater radius ratio is 0.15, and WR or average rampart width to crater radius ratio of the rampart is 0.16. These values suggested to [3] that Lonar crater is a single-layered ejecta crater morphologically similar to those on Mars, Ganymede, and Europa (see 3, and 5). Using the morphometric parameters for the inner ejecta layer of Ries crater (D = 26 km) measured by [1] for the inner ejecta layer where the average run out distance = 14.6 km, average EM = 1.12, W_{av} = 8.7 km, and the WR = 0.67. The furthest extent outward of the Bunte ejecta [6, 7] is used as a minimum value for ejecta run out distance of the outer ejecta layer of Ries (i.e., 32 km from the rim) resulting in an EM = 2.46. These values are plotted in Fig. 1 – 3 with similar data from [3] for layered ejecta craters on Mars.

Results: To a first order, Figures 1-3 show that the widths of ramparts and run out distance of ejecta of layered ejecta deposits on Mars and Earth fall into major groups. Furthermore, the ejecta of Lonar and Ries plot in groups consistent with the suggestions of [1, 2, and 3], that Lonar is a SLE and Ries is DLE crater.

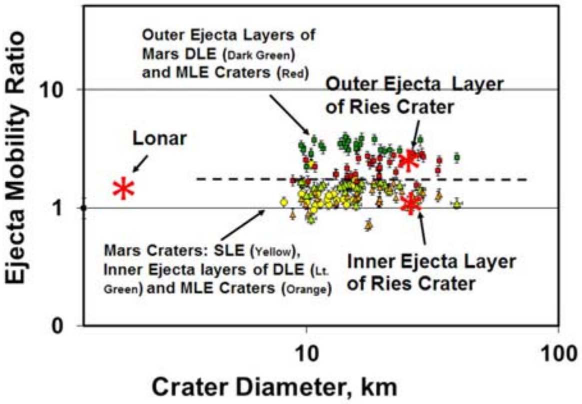

Fig. 1; Ejecta Mobility as a function of crater diameter. The dashed line separates inner layer and outer layer EM values.

The EM data shown in Fig. 1 suggest that the ejecta layers of Ries are similar to Mars DLE and MLE craters of similar sizes. Although, Lonar is too small for its growth to be gravity dominated and hence its ejecta layer run out distance does not scale in a self-similar way, its small size and limited ejecta run out distance still makes it similar to Martian SLE craters.

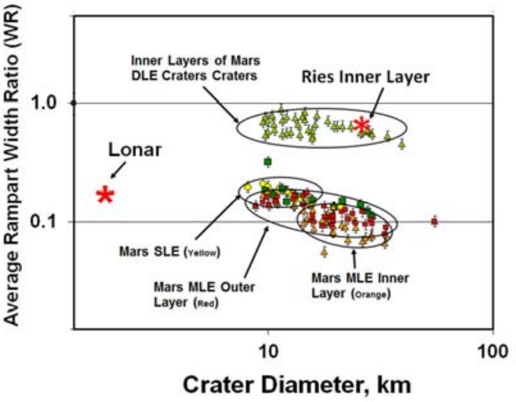

Fig 2: In this scatter diagram of WR as a function of D, the Ries inner layer clearly falls in the DLE inner ejecta layer group.

Fig. 2 shows that there are two major morphologic groups based on rampart width, i.e., 1) relatively narrow ramparts that occur around single, multi-layered ejecta layers and the outer layer of double layered ejecta, and 2) relatively wide ramparts that occur at the distal edges of the inner ejecta layer of double layered ejecta. Figure 2 shows that WR of the inner ejecta layer rampart of Ries is consistent with being a member of group # 2 from above, and WR for the Lonar layer is consistent with being in group # 1.

The values of EM and WR in Fig. 1 and 2 are plotted against each other in Fig. 3. This figure shows distinct groups, with the ejecta of Ries falling in the group that includes the inner ejecta layer of Martian DLE craters, and the ejecta of Lonar falling within the group that includes SLE and the inner ejecta layer of MLE craters.

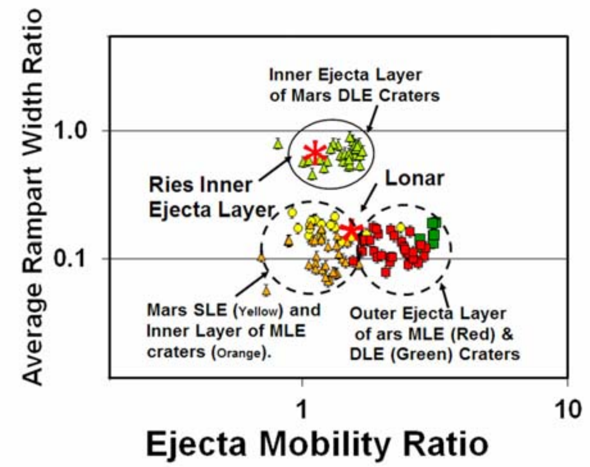

Fig. 3: This scatter diagram shows EM plotted against WR for Martian layered ejecta craters, Ries inner ejecta layer and Lonar ejecta layer.

Discussion: These data provide morphologic evidence that layered ejecta craters, like those on Mars, form on Earth, and add confidence to the supposition that Lonar and Ries can be used as terrestrial analog for understanding emplacement of layered ejecta. One first order question about the ejecta deposits around these two craters that would be of great value to approach is why Lonar is a SLE crater and Ries is a DLE crater? While this study has just begun, we offer a few speculative points about an answer to this question.

First, it is unlikely that these different ejecta types are a result of crater size difference alone. This is because Martian DLE and SLE craters of the same size are common, and can be found in the same vicinity. Hence, size alone does not control whether a crater will be a SLE or DLE, although it may influence it.

Second, the physical environment (e.g., the amount of water in the target rock and on the surface at the time of impact; the relief and roughness of the surface) may have a substantial effect on the ejecta deposits. For example, one hypothesis to explain why the inner layer of Ries has relatively wide rampart is that the impact was in a particularly water-rich environment. This would increase the ejection angle [8, 9], which would result in relatively greater erosion of the impacted surface by the ejecta. This would result in incorporation of a higher volume of local material in the outward flowing ejecta compared with lower angle ejecta. This added bulk likely would affect rampart dimensions by piling up behind the flow front as it slowed by friction as it propagates forward. This hypothesis is supported by observation that the Bunte breccia contains a substantial amount of local material (increasing outward in relative proportions up to 90%) that is mixed throughout the ejecta [7], and that the ejecta of Lonar contains little local material [2].

However, it is clear that there are problems with this hypothesis. For example, [2] suggest that because of the difference in size of these two craters, the comparatively low-velocity of Lonar ejecta should result in less erosion of the surface, and hence inclusion of less local material. In addition, increasing the ejection angle also decreases the horizontal velocity of the ejecta. This should result in shorter run out distance for the inner ejecta layer of DLE craters compared with SLE and the inner ejecta layer of MLE craters. This does not appear to be the case (see Fig. 1 and 3)

Conclusions: There is reasonable evidence that Ries and Lonar are layered ejecta craters, and that Ries is a DLE and Lonar a SLE. These craters offer an opportunity for first hand study of the ejecta of two important types of layered ejecta craters. In concert with Mars data, these studies should provide considerable insight into the processes and conditions required for their formation.

Reference: [1] Sturm, S., et al., 2012, *LPSC* # 1705-1706 ; [2] Maloof, A., et al., 2010, *GSA, Bull*., 122; 1/2; p. 109–126; [3] Boyce, J., et al., 2010, *MAPS*, 45, 239, 4, 638–661; [4] Barlow, N., et al., 2000, *JGR*, v. 105, no. E11, p.233 26733–26738; [5] Barlow, N., 2005, *GSA SP* 384, 433-442; [6]; Pohl et al., 1977, *In Impact and Explosion Cratering*, LPI, 343-404; [7] Horz, F., et al., 1983, *Rev. Geophys.*, 21, 8,1667–1725; [8] Greeley, R., et al., 1980, *11th LPSC*. pp. 2075–2097: [9] Senft L., and Stewart S., 2008, *MAPS*, 43:1993–2013.