DISCOVERY OF MANTLED SUB-MILLIMETER LAPILLI FROM THE LONAR CRATER, INDIA

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Introduction: The Lonar crater (19°58′N, 76°31′E) in the state of Maharashtra, India is a simple, near-circular impact crater, 1830 m across, in Deccan Trap basalt (~65 Ma) [1, 2]. The crater was recently dated at ~650,000 years by the whole rock ^{40}Ar-^{39}Ar method [3]. Melt spherules and impact melt have been known at Lonar for decades but we have recently discovered two new classes of sub-millimeter to millimeter size particles in samples of the ejecta blanket. These particles display a layering of fine-grain material similar to accretionary and armored lapilli found in the vicinity of volcanic as well as other impact craters.

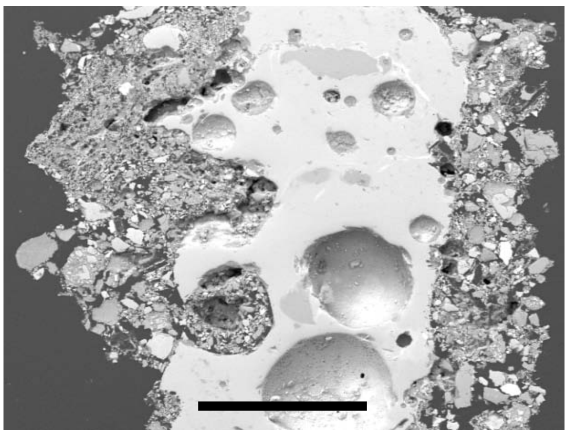


Fig. 1 BSE image of a vesicular, impact melt core with a fine-grain rim composed of mineral grains and scoriaceous melt. Max particle size in rim ~50 µm. Scale bar ~250 µm.

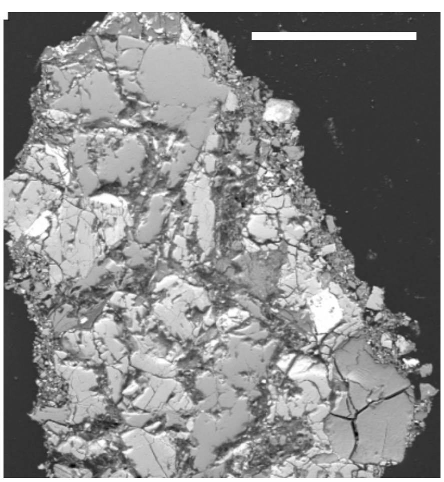


Fig. 2 (left) BSE image showing a shocked basaltic core with fine-grain, rim composed of mineral fragments. Max particle size in rim 25 µm. Scale bar ~250 µm.

Sampling and analytical procedures: The samples of Lonar ejecta blanket were collected by H. Newsom, S. Wright, and S. Misra between 2002 and 2008. These samples were studied with a binocular microscope for the purpose of extracting impact glass melt spherules and splash forms. The new types of particles are roughly spherical and appear to have a coating of fine-grain mineral fragments (Figs. 1-6). The fine-grain mantles are resistant to cleaning with alcohol and the grain-size of the mantling material is often finer than the loose ejecta in which the particles are found. These samples were mounted and polished in thick sections, and backscattered electron (BSE) images and EDS spectra were obtained with the JEOL 5800LV at 20 KV at the University of New Mexico.

Fig. 3 (right) BSE image showing a basaltic, vesicular core surrounded by a fine-grain rim composed of mineral fragments. Max clast size in rim 50 µm. Scale bar ~200 µm.

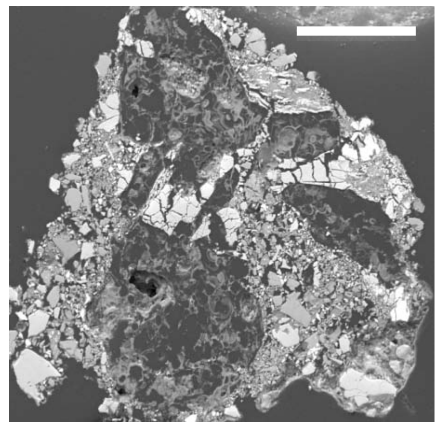
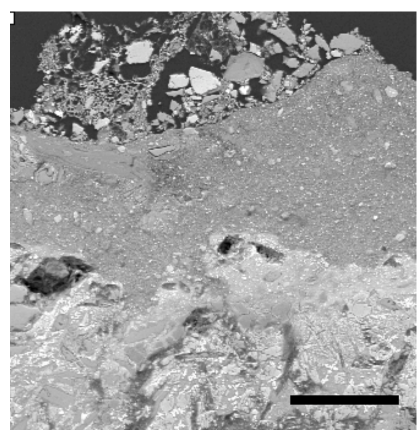


Fig. 4 (right) BSE image showing a shocked mineral core (bottom), topped with a zone of melted material high in feldspar component and a fine-grain rim. Max clast size for melt and rim is 50 µm. Scale bar ~250 µm.



Petrography and chemistry of particles: BSE images show continuous or nearly continuous coatings of fine-grain material on almost all particles. Two new distinct types of particles were found in the ejecta blanket. The most common type has a central core of glass or highly shocked basalt surrounded by a fine-grain rim of mineral fragments (Figs. 1-5). The second type is similar to accretionary lapilli and contains only ash-size particles (<63 µm)(Fig. 6).

Characteristics and classification: Accretionary lapilli in impact craters are spheroidal aggregates of ash-size material, sometimes with a nucleus interpreted to be derived from the target rock [4,5]. Volcanic accretionary lapilli are classified as C-type or R-type [6]. The C-types have an ash core without a rim, and R-type display a fine-grain rim. Armored lapilli are a variety of accretionary lapilli containing a nuclei of minerals or melt particles derived from the basalt target, covered by fine or coarse-grain ash [7,8]. The Lonar particles have characteristics of both the accretionary and armored types, and usually have a single, fine-grain mantling layer. The EDS spectra indicate that the accretionary rim materials of the lapilli are consistent with pyroxene, plagioclase and iron oxides derived from Lonar target basalt. In some cases, lapilli show evidence of minor post accretionary devitrification and alteration. The particles from Lonar are similar to volcanic lapilli found at Laacher See and other volcanoes [6]. Accretionary lapilli have also been found at other impact craters such as Ries [4] and Bosumtwi [5].

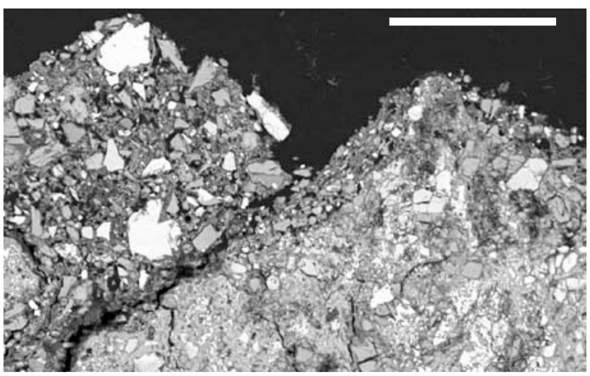


Fig. 5 BSE image of a particle with a fine-grain ash size core surrounded by a rim that is much thicker on the left. The rim consists of subrounded ash-size ilmenite, plagioclase and augite fragments. Rim max clast size 100 µm. Scale bar ~250 µm.

Discussion: The origin of the particles apparently began with the impact ejection of target basalt fragments that ranged from unshocked to completely molten droplets. The melts had time to solidify in the plume above the crater before accretion of fine-grain fragments of basaltic minerals. In some cases the core consists of an aggregate of coarser-grain minerals covered by a fine-grain outer layer. Some particles exhibit evidence of transport into a high-temperature zone within the impact plume, with accretion of plastic scoriaceous melt particles and some evidence for partial melting of the accretionary layers. The particles subsequently became part of the fallout material at the top of the ejecta blanket.

Given the small size of the Lonar crater, the presence of lapilli and evidence for melting of plume material is surprising. However, the partial or complete breakup of a projectile in the atmosphere can produce a high-temperature jet of expanding gas that can produce melting and substantially enhance the atmospheric effects of a cratering event [9-11]. The evidence for a chondritic impactor at Lonar [12] is consistent with an air blast contribution to the plume. Furthermore, the high temperatures from the air blast coupled with the heat associated with the crater formation, can explain the high-temperature formation of the armored lapilli cores, including glassy melt spherules and partially melted basalt fragments. There is also evidence for accretion of molten scoriacious melts onto the surfaces of the cores (e.g., **Fig. 1**) and possible melting of armored lapilli prior to additional accretion of fine-grain mantles.

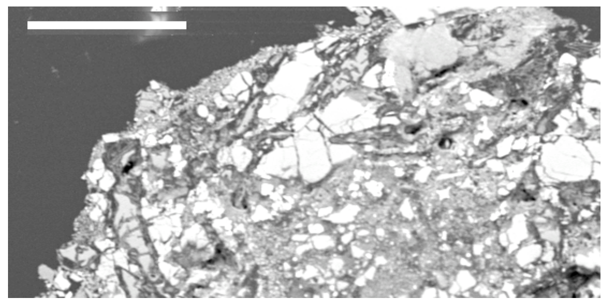


Fig. 6. BSE image of a particle consisting of a conglomerate of ash size fragments of ilmenite, augite, and glass surrounded by a fine-grain rim of the same composition. Rim max clast size 50 µm. Scale bar ~250µm.

Conclusions: (1) A new type of layered particle has been found in Lonar crater ejecta, with cores consisting of conglomerations of ash-size mineral grains, shocked basalt, or solidified melts. Adhering rims consist of ash-size mineral grains. (2) These particles are interpreted to be accretionary and armored lapilli. (3) The formation of lapilli at Lonar may have been enhanced by atmospheric heating due to energy from an airburst process associated with the crater-forming event. (4) The presence of lapilli in impact crater ejecta is becoming a commonly observed and possibly diagnostic feature of both large and small impact craters and could also be a feature of impacts on Mars [13].

References: [1] Fredriksson et al (1973) *GSI 43*, 921-927. [2] Nayak (1972) *EPSL* 14, 1-6 [3] Jourdan et al (2010) 41st *LPSC* abs no. #1661 [4] Graup (1981) *EPSL 55*, 407-418. [5] Koeberl et al (2007) *MAPS 42*, 709-729. [6] Schumacher & Schmincke (1991) *Bull. Volc.* 53, 612-634. [7] Warme et al (2002) *GSA Special Paper 356*, p. 489-504. [8] Fischer & Schmincke (1984) *Pyroclastic Rocks* p 239. [9] Melosh & Collins (2005) *Nature 434,* 157. [10] Boslough & Crawford (2008) *Int. J. Impact Eng 35*, 1441-1148. [11] Newsom et al (2010) *GSA meeting* # 69-13. [12] Misra et al 2009 *MAPS 44,* 1001-1018. [13] Newsom et al. (2011), *LPSC 42* # 1298. *Acknowledgements*: PG&G grant NNH07DA001N (HEN). Thanks to L. Burkemper and F. McCubbin for sample preparation help.