LA-ICP-MS TRACE ELEMENT GEOCHEMISTRY OF SUB-MILLIMETER SIZED IMPACT SPHERULE FROM LONAR CRATER, INDIA. D. Ray[1] , S. Misra[2], H. Newsom[3] and D. Upadhyay[4], [1]PLANEX, Physical Research Laboratory, Ahmedabad 380009, India (dwijesh@prl.res.in), [2]SAEES, University of KwaZulu-Natal, Durban 4000, South Africa (misras@ukzn.cn.za), Institute of Meteoritics and Department of Earth and Planetary Sciences MSC03 2050, University of New Mexico, Albuquerque, NM 87131, USA (newsom@unm.edu), [4]Department of Geology and Geophysics, Indian Institute of Technology, Kharagpur 721302, India (dewashish@gg.iitkgp.ernet.in).

Introduction: The ~50 or 570 ka old Lonar crater, India (19°59′N, 76°31′E), was formed on a basaltic target belonging to the Deccan Traps (~65 Ma) by an oblique impact of a chondritic meteorite from the east [1-5]. After more than four decays of search, three different types of impact spherules e.g. mm- and sub-mm sized impact spherules [2, 6], and a sub-mm sized mantled lapilli [7], were identified from the ejecta blanket around the crater. However, detailed major and trace element analyses are available only for the mm-sized spherule at present [6, 8]. In this report, we present the major and detailed trace element compositions of the sub-mm sized spherule to evaluate the possible impact-induced chemical process(es) operated during the Lonar impact.

Analytical Techniques: The major and minor element analyses of the Lonar spherules were carried out using an Electron Probe Micro Analyzer with wavelength dispersive spectrometers (CAMECA SX 100) at Physical Research Laboratory, India [8]. In situ trace element analyses of the sub-mm sized spherule were done on a LA-ICP-MS at the Department of Geology and Geophysics, Indian Institute of Technology, Kharagpur, India, using a Cetac 213 nm Nd-YAG laser ablation system coupled to a Varian 820 quadrupole ICP-MS. The ablation parameters used were the following: 10 Hz pulse frequency, 60 µm spot size and 730 V energy. The analyses were performed in time-resolved peak hopping mode with each analysis consisting of a 20 s background measurement with the laser turned off and 40 s peak signal measurement with the laser turned on. External standardization was done by bracketing groups of eight unknowns with two measurements of the NIST 612 reference glass. Data was reduced using the Glitter© software using Ca as an internal standard.

Analyitcal results: The population of sub-mm sized Lonar spherule under investigation are mostly melt-rich, however, both the melt- and magnetite-rich varieties were reported earlier [2]. These samples are also homogeneous and devoid of xenocrysts (Fig. 1).

Both the mm- and sub-mm sized Lonar impact spherules are characteristically depleted in Na_2O (~0.3-0.5 times respectively) and P_2O_5 (~0.3-0.6 and 0.2-0.4 times) compared to those values in the target basalt. Additionally the sub-mm sized spherule has relatively higher average $Fe_2O_3^T$ and MnO (~1.2 times), marginally lower Na_2O (~0.8), and variable K_2O (~0.7-1.9) as compared to those values in the mm-sized spherule.

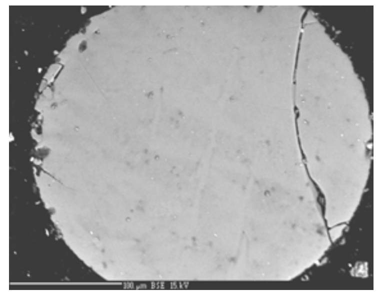

Fig. 1. BSE image of Lonar sub-mm spherule, note homogeneous, almost vesicle-free glassy spherule without any xenocrystic component.

The average incompatible trace element composition of the Lonar sub-mm sized spherule is compared with those of target-basalt, impact-melt bomb and mm-sized spherules in figure 2. Among these elements, only Rb shows maximum variation in abundance (RSD: 41%), followed by U (RSD: 26%). The variability of rest of the trace elements are within ±5%. The sub-mm sized impact spherule has average incompatible trace element composition similar to that of the target basalt except that the former is marginally depleted in U and Zr. The average Lonar impact-melt bomb and mm-sized impact spherule are relatively enriched in Rb, Ba, Th, U, La, Ce and Zr compared to those in the target basalt.

Individual spot analyses on the Lonar sub-mm sized spherules (n=7) show very restricted variations in incompatible trace element proportions except for Rb, U and Pb, and the spidergrams involving these elements have $(Ba/Lu)_N$ between 2.95 and 3.39 with an average=3.10 (standard deviation=0.15). Compositionally, core and rim of the sub-mm sized spherules are indistinguishable in terms of incompatible trace element chemistry. The studied samples show variations in Rb from ~0.5 to 5 times to that in the chondrite, slightly positive to moderately negative U anomaly (U/U* ~0.5-1.17), both positive to strongly negative anomalies for Pb (Pb/Pb* ~0.06-2.30), and negative anomaly for Sr (Sr/Sr*~0.58-0.60).

In terms of compatible trace element composition, the average sub-mm sized spherule is distinctly enriched in Cr (~ 8 times), Co (~ 7 times) and Ni (~12 times) over the target basalt (Fig. 3), while the target basalt, impact-melt bomb and mm-sized spherule share similar average compositions.

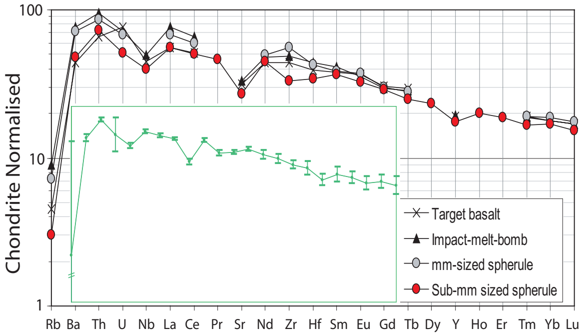

Fig. 2. Chondrite normalized average incompatible trace element spidergrams of Lonar target basalt and impactites. Inset shows variations in element concentrations in %RSD.

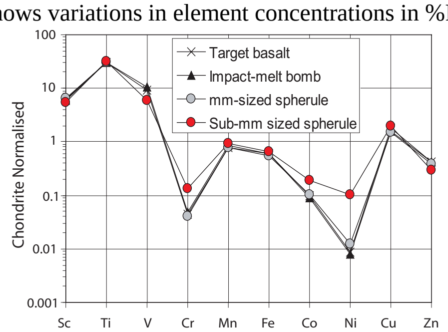

Fig. 3 Chondrite normalized average compatabile trace element spidergrams of Lonar basalt and impactites.

Discussion: Among the Lonar impactites, the sub-mm sized spherules are only significantly enriched in FeO^T (~ 0.2 times over the target basalt), MnO (~0.3 times), MgO (~ 0.1 times), and Cr (~ 6 times), Co (~ 2 times) and Ni (~10 times) (Fig. 3) confirming fractionation of impactor asteroid components only within this variety of impactite [2, 8]. The sub-mm sized spherule has the lowest K_2O among the Lonar impactites, and are also equally depleted in Na_2O and P_2O_5 suggesting significant loss of volatiles from their parent liquid droplets during their formation. The condensation temperature of K close to ~1001°K [9] constrains the lower temperature limit of formation of these spherules. The predominance of schlieren and nearly absence of vesicles in the sub-mm sized spherules [2] further suggest relatively low viscosity of their parent liquid droplets, confirming relatively higher temperature of their formation.

The reason for the fractionation of the impactor components between the smaller and larger sized impact glasses is not yet fully understood [10-12]. It has been suggested that this fractionation could be related to air burst mechanism [13, 14]. An alternative hypothesis is that the impact plume generated immediately after the Lonar impact gradually became inhomogeneous in terms of impactor components and temperature during its expansion at the end of the excavation stage of formation of the crater [8]. The central plume close to its top became relatively hot and impactor component-rich, whereas the peripheral plume was relatively cool and depleted in impactor components. Relatively high temperature of formation and high concentration of impactor components within the sub-mm sized spherules confirm that these spherules were formed within the hot central part of the plume, whereas the morphochemistry of the mm-sized impact spherule and impact-melt bomb suggest that these impactities solidified within the peripheral plume, which was devoid of impactor components and had relatively lower temperature.

It was suggested before that the groundwater underlying the Lonar crater was heated by remnant impact energy and could have resulted post-impact hydrothermal activity [15]. Following studies on drill core impact breccias from the base of this crater also supported this hypothesis [16]. Further studies on Lonar ejecta [17] and the basalt flows from the base of the Lonar crater [18] also suggest evidences of hydrothermal activity in and around the Lonar crater. Our data shows that the sub-mm sized Lonar spherules shows a very restricted incompatible trace element chemistry (Fig. 2). However, they display significant variations in the concentration of Pb and U. These elements tend to be mobile in oxidizing hydrothermal fluids, providing further evidence of the possibility of impact-induced hydrothermal activity in and around the Lonar crater. Further studies are in progress.

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