CONTRASTING AERODYNAMIC MORPHOLOGY AND GEOCHEMISTRY OF IMPACT SPHERULES FROM LONAR CRATER, INDIA: SOME INSIGHTS INTO THEIR COOLING HISTORY.

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Introduction: The ~570 ka old Lonar impact crater, India, is one of the few known terrestrial impact craters that was excavated in the basaltic targets of the Deccan Traps (65 Ma) [1, 2]. This impact crater of ~1.8 km diameter is a unique terrestrial analog for the large number of craters on planetary bodies in our solar system having basaltic crusts. The typical Lonar impact glasses that occur only within the ejecta around the rim of the Lonar crater include impact-melt bomb and spherules [3]. The impact spherules from this crater can primarily be classified into two fundamental types depending on their sizes, e.g. sub-mm sized spherules and mm-sized spherules, which is quenched from basaltic silicate liquid droplets [4]. Recently, a variety of sub-mm sized Lonar spherule has been described, which contains cores consisting of conglomerates of ash-sized mineral grains, shocked basalt or solidified melts and adhering rims with ash-sized materials [5]. However, detailed petrochemical information on this variety of spherule is yet to come.

Although, the Lonar crater has been extensively studied in terms of geochemistry [3, 4, 6] during the last decade, complete petrochemical information on the mm-sized spherules is still inadequate. In this work, we report our preliminary observation on the petrography and geochemistry of the mm-sized spherules from the Lonar crater.

Sampling and analytical techniques: The mm-sized spherules for the present work were collected from a pit within the ejecta at the southeastern part of the rim of the Lonar crater [4]. A Cameca SX 100 electron microprobe was used for analyses of major oxides and some trace elements (Cr, Co, Ni, Cu and Zn) of our samples. The instrument is equipped with wavelength dispersive spectrometers (WDS) with large crystals (LPET and LLiF). Quantitative major element analyses were done at 15 keV accelerating voltage, 20 nA sample current, 1 µm beam with PAP correction routines. Long peak counting time (up to 350s) was used to achieve the low detection limits for trace elements at 15 keV accelerating voltage, 80 nA sample current and 15 µm broad beam. The detection limits for Cr, Co, Ni, Cu and Zn were achieved up to 42, 52, 55, 78 and 99 ppm respectively. Uncertainties of trace element analyses were as follows: Ni (7%), Cr (2%), Co (6%), Cu (8%) and Zn (10%).

Internal morphology: The aerodynamically shaped, mm-sized spherules are characteristically black, spherical to ellipsoidal droplets and vary in size from 2-5 mm (Fig. 1). The BSE image of a whole spherule shows that it is almost homogeneous, non-crystalline at the central part but vesicular towards the margin, and the size of vesicles becomes larger (~0.4mm) close to the margin. The vesicles generally contain secondary infillings of quartz. Spherules with sparse distribution of vesicles are also not uncommon. The xenocrystic population within the spherules includes mainly titaniferous magnetite and plagioclase, which are noticed only along the marginal part of the spherule. The partially digested plagioclase xenocrysts are highly vesicular (Fig. 2). The central part of the spherules are generally devoid of any remnant of partially-melted plagioclase, which is commonly present towards the marginal part of the grains. These spherules characteristically show growth of minute dendritic euhedral titaniferous magnetites within the homogeneous matrix, which sometimes form dis-continuous rims along the periphery of the plagioclase xenocrysts. However, these millimeter-sized spherules do not contain any well-defined schlieren trails defined by minute euhedral magnetites that were observed in the sub-mm sized spherules [4].

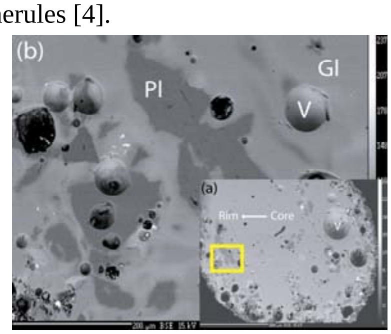

Fig. 1. BSE images of (a) mm-sized spherules (inset), (b) enlarged view of marginal part of spherule (yellow box in figure a) shows partially digested anhedral plagioclase, abbreviations: Plagioclase (Pl), Glass (Gl), Vesicle (V).

Geochemistry: The average mm-sized Lonar impact-spherules are marginally enriched in SiO_2 and significantly in K_2O, and depleted in MgO and Na_2O over target-basalt (Table 1, Fig. 3), these spherules have ~1.5 times higher Ni over the target basalt [3]. In comparison to sub-mm sized spherules [4], the mm-sized spherules are generally acidic and enriched in SiO_2, Na_2O, K_2O and P_2O_5, and depleted in FeO_t, MnO, MgO, and in all transitional trace elements (Cr, Co, Ni) and Zn.

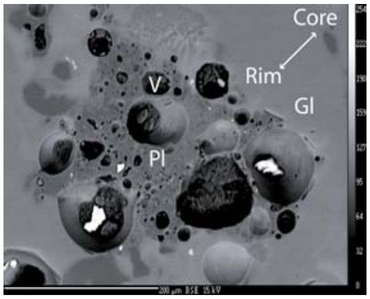

Fig. 2. Partially digested xenocrystic plagioclase at the marginal part of spherule showing vesicles. Abbreviations same as Fig. 1

Table 1. Average bulk chemical compositions of target- basalt, impact-melt bomb, sub-mm and mm-sized spherules from Lonar crater

	Unaltered Lonar basalt[3]	Impact-melt bomb[3]	Sub-mm sized spherules[4]	mm-sized spherules
No. of samples	16	7	18	12
No. of analyses			36	64
SiO_2 (wt%)	47.82	50.15	48.27	51.77
TiO_2	2.26	2.26	2.32	2.29
Al_2O_3	12.96	13.52	13.67	13.22
FeO_t	14.22	13.85	15.29	13.64
MnO	0.19	0.21	0.24	0.17
MgO	6.07	5.67	6.85	5.23
CaO	9.87	9.47	9.24	9.84
Na_2O	3.00	1.98	1.80	2.32
K_2O	0.38	0.67	0.33	0.60
P_2O_5	0.27	0.30	0.07	0.24
Total	97.04	98.08	98.08	99.32
Mg#	0.43	0.42	0.44	0.41
Cr (ppm)	117	128	313	119
Co	48	45	115	bdl
Ni	90	84	1296	bdl
Cu	220	193	na	175
Zn	131	133	211	135

Mg# mole Mg/mole ($Mg+Fe^{2+}$), bdl: below detection limit, na: not analyzed.

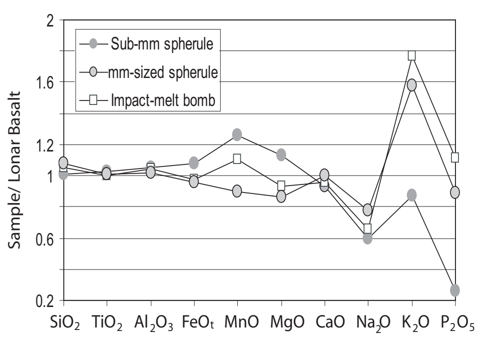

Fig. 3. Average Lonar basalt normalized bulk chemical composition of impact-melt bomb, sub-mm and mm- sized impact spherules from Lonar crater, India.

Discussion: Generally the absence of vesicles and smooth surface texture characterize the sub-mm sized spherules [4], whereas presence of vesicles could be taken as a characteristic feature of the mm-sized spherules (Fig. 1). Occurrence of vesicles especially along the marginal zone of the mm-sized spherules suggests the evolution of these quenched liquid droplets (that solidified in atmosphere during their flight) must be associated with high volatile pressure. The vesicular nature of the partially-melted xenocrystic plagioclase (Fig. 2) suggests possible loss of Na, an important constituent of the plagioclase of the target Lonar basalt [7] and has relatively low volatility temperature (T_{cond}=970K) [8]. The glassy nature of the spherules and vesiculations in xenocrystic plagioclase within these spherules suggest that the peak shock pressure during impact varied between 60-80 GPa when compared with experiments [7]. The characteristic absence of schlieren trails of minute dendritic magnetites in the mm-sized spherules suggest that the temperature during the formation of these spherules could be lower than those of the sub-mm sized spherules that enhanced the viscosity of these silicate droplets to resist the formation of schlieren by flowage.

Both mm-sized spherules and Lonar impact-melt bomb share similar average bulk composition but differs significantly wrt sub-mm sized spherules (Table 1). Therefore, both mm-sized spherules and impact-melt bombs were likely to have been produced by plagioclase-dominated melting of the target-basalt [7, 9]. The only impactor component that could be present within the mm-sized spherules is Co [10].

The morpho-chemical differences between the sub-mm and mm-sized spherules suggest different modes of their formation from the impact plume. Predominance of schlieren and impactor components, and nearly absence of vesicles in the sub-mm sized spherules suggest these quenched liquid droplets could have been produced from the impactor-rich, hotter central part of the plume, whereas the morpho-chemistry of the mm-sized spherules suggests possibility of their formation from the relatively cool outer part of the same plume. Further studies are in progress.

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