MORPHOMETRIC AND PETROCHEMICAL CHARCTERIZATION OF IMPACT MELT SPHERULES FROM LONAR CRATER, MAHARASHTRA, INDIA.

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Introduction: Planetary bodies have been subjected to intense meteoric bombardments and these impacts had been an important geological process in shaping the planetary surfaces and landforms. The Lonar crater, Buldana district, Maharashtra, India [Bounded by latitudes 19°58′06″N and 19°59′06″N and longitudes 76°29′55″E and 76°31′05″E, falls in the Survey of India (SOI) toposheet no. 56A/9], is a bowl-shaped, simple, hypervelocity impact structure, one of the youngest and best preserved impact structures on the planet Earth [1]. The 1.88 km diameter simple crater formed entirely within the basalts of Deccan traps, making it a useful analogue for small craters on the basaltic surfaces of the other planets and the Moon [2]. Several authors reported glassy objects (impactite glasses?), tektite-like bodies, impact shperules from the Lonar carter [3,4,5,6,7]. These glassy objects are likely the direct evidences of impact, and several multivariant types of studies have been carried out so far. Here we have attempted to categorize them, based on their morphology, petrography, mineralogy and whole rock (major oxides, trace elements and REE) chemistry.

Methodology and Results: Mineral chemical data were acquired by CAMECA SX-100 electron microprobe (EDS + WDS) analyser at the EPMA Laboratory, GSI, NCEGR Kolkata. An accelerating voltage of 15 kV and beam current of 12 nA with ~ 1 µm beam diameter were used in all cases. These data were corrected internally (PAP) and a set of natural standards was used to control analysis results, with synthetic standards being used for Mn and Ti.

Impact melt glasses and spherules are the most abundant along the crater rim that appear to be unaltered by human activity or mass wasting. More than hundreds of samples of basaltic impact glasses and spherules have been collected systematically from the southeastern (SE), northeastern (NE), northwestern (NW) and southwestern (SW) parts of crater rim, restricted within several hundred meters from outer crater rim, and also from the southwestern rim of Little Lonar depression (a small lake at north of the Lonar crater; refer sample locations in [2]). Many of the smaller melt glasses are aerodynamically and rotationally sculpted and might have solidified during their flight. Circular and elliptical vesicles are common, particularly towards the center of glassy objects. Pitch black colored, low specific gravity, perforated/vesiculated impact or melt glasses and spherules have been observed at several places around the crater rim. Such occurrences of impact melt glasses and spherules within the ejecta blanket indicate its impact origin. Impact melt spherules / glasses are of different sizes (~1-2 mm to 1 cm) and shapes (circular, near elliptical – spherical, disc shaped, tapered – horn shaped, bifurcated – branching type, dumbbell shaped etc.) observed within ejecta sediments. Dull to lustrous, pitted (vesiculated) and dark greyish-black variety of aerodynamically shaped impact melt spherules mostly exist along the SE and eastern (E) part of ejecta. These smaller melt glasses and spherules primarily have splash forms with compositional flow lines (Figure 1a & b). Their rounded habits indicate that they are fläden, and impact spherules possibly formed from molten ejecta that cooled in mid-air while subjected to rotational and aerodynamic forces, during post impact time.

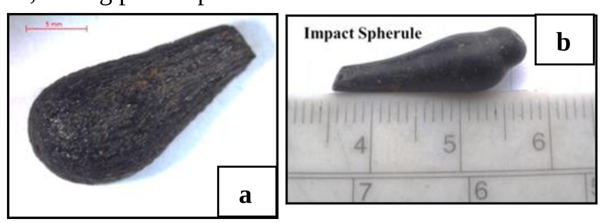

Figure 1a & b: Impact melt spherules (with compositional flow lines) and splash form from Lonar crater.

Under optical microscope, these impact melt spherules are translucent, uniformly brown to greenish black coloured, although in cases showed schlieren between colourless and brown colour layers along with partially melted mineral inclusions. Characteristic flow-banding is indicated by contorted schlieren, and by trails of minute cross-shaped crystallites, apparently magnetite. The BSE images of a representative cm-sized melt spherule show it is almost homogeneous in composition and glassy, non-vesicular at the central part but vesicular in majority towards the margins, where the maximum size of the vesicle varies from 0.3 – 0.5 mm. In a few cases, the vesicles contain secondary infillings of quartz. The central parts of the spherules are devoid of any xenocrystic mineral phases like plagioclase, clinopyroxene or magnetite, which are components of target basalt. The plagioclase xenocrysts are mostly subhedral and highly vesicular, and locally transformed into vesiculated feldspar glass. Shock-induced anhedral plagioclase glasses or melted plagioclase are also noticed along the marginal part of the mm-sized spherules (Figure 2). The mm-sized spherules characteristically show growth of minute, dendritic, euhedral, magnetite within the homogeneous matrix. These magnetite grains generally form fine trails that encircle undigested plagioclase xenocrysts present at margin of the spherule. The xenocrystic clinopyroxenes are also present and mostly associated with relict plagioclase and Ti-magnetite at the marginal part of the spherule. However, the xenocrystic pyroxenes are relatively smaller in size and less common as compared to the melted plagioclase glass. Importantly, these mm-sized spherules lack well defined schlieren trails formed by minute euhedral magnetite grains. However, these trails of magnetite are typically present in the sub-mm sized spherules. Skeletonised growth of magnetite crystals indicates rapid cooling. Lustrous, often pitted and dark greyish-black variety of impact glasses and melt spherules occasionally show flow banding with mineral compositional variation (in terms of major oxides) as revealed from EPMA data. Electron Microprobe analyses confirm that the micro-xenocrystic components are plagioclase, clinopyroxene and titano-magnetite belonging to the target basalt. The xenocrystic magnetite mostly occurs as subhedral grains, size ranges up to 50 µm. Crystallization of fibrous plagioclase glass, droplets of tiny magnetite – titanomagnetite crystals and devitrified basaltic glasses suggest sudden quenching from basaltic molten droplets. Melt glasses (both irregular and splash form) with characteristic flow banding having high silica content (SiO_2 = 50-62%, Na_2O = 1.6-3%, Al_2O_3 = 5.5 – 14%, MgO = 4.5-6%, FeO = 11-21%, CaO = 2-10% and TiO_2 = 2% as derived from mineral chemical data) suggests post-impact chemical fractionation.

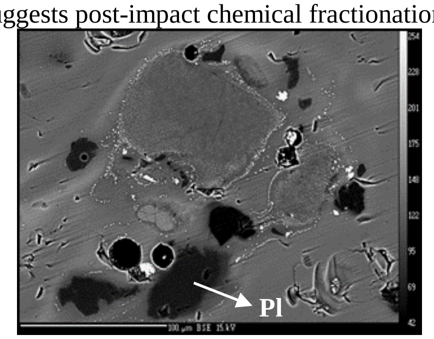

Figure 2: Shock melted anhedral plagioclase observed along the marginal part of melt spherules. Note the compositional flow banding rimmed by tiny magnetite + Ti-magnetite (BSE image).

Chains or array of tiny dendritic and octahedral shaped magnetite ± ulvospinel ± titanomagnetite crystals are also observed indicating quenching from liquid droplets (Figure 3). Moreover, the geochemical data (major oxides, trace elements and REE) plot of these impact glasses and melt spherules suggests they are the derivative of basaltic melting, belong to tholeiilite series. These are characteristically depleted in Na_2O, K_2O and MnO, and having relatively higher concentration of FeO^T, MgO and CaO in comparison to the target basalts.

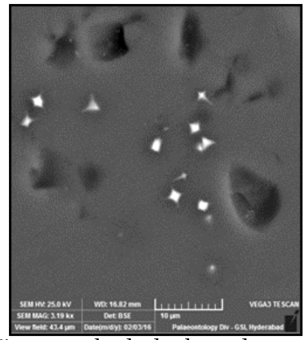

Figure 3: Tiny octahedral shaped magnetite crystals within impact melt spherule (in SEM).

The chondrite-normalized trace elements (TEs) and rare earth elements (REEs) distribution patterns indicate that the Lonar impactites (impact melt glasses and spherules) show nearly similar patterns with slightly enriched LREE over HREE trends, as comparable with the basalt flows (Figure 4).

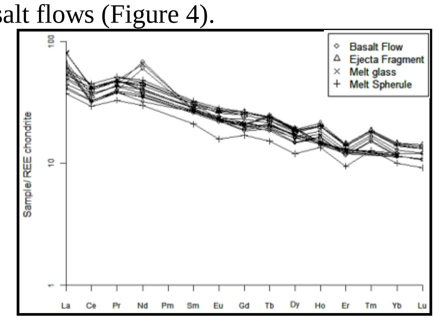

Figure 4: Chondrite-normalized REEs distribution pattern in Lonar crater samples [8].

Discussion: Detailed petrography, textures, mineral phase chemistry and geochemical data of impact melt glasses and spherules suggest these were derived from target basaltic rocks due to impact. These Lonar impactites shouldn't be referred as 'tektites' inspite of having close morphological resemblance as they have restricted spatial occurrence within the ejecta sediment, and geochemical discordance with sensu-stricto tektites [3].

References: [1] Fredriksson K. et al. (1973) *Science 180*, 62–864. [2] Maloof et al. (2010) *Geol. Soc. Am. Bull. 122*, 109–126. [3] Fudali R. F and Fredriksson K. (1992) *Meteoritics 27*, 99-100. [4] Nayak V. K (1972) *Earth and Planetary Science Letters*, *14*, 1-6. [5] Misra S. et al. (2009) *Meteoritics & Planetary Science 7*, 1001–1018. [6] Ray D. and Misra S. (2014) *Earth Moon Planets 114*, 59-86. [7] Weiss B. P. et al. (2010) *Earth and Planetary Science Letters 298*, 66–76. [8] Nakamura N. (1974) *Geochim. Cosmochim. Acta 38*, 757-775.