MINERALOGICAL AND PETROLOGICAL INVESTIGATION OF LUNAR METEORITE REGOLITH BRECCIAS: Y-981031, Y-983885 AND Y-86032.

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Introduction: The lunar surface records the geological history of Moon and its interaction with the dynamic solar system environment. Remote sensing missions have revealed the compositional variation across the lunar surface, which has led to the classification of three distinct geologic terranes. These are: the Procellarum KREEP Terrane (PKT), which was sampled during the Apollo and Luna missions; the South Pole-Aitken basin (SPA), the largest impact basin on the Moon; and the Feldspathic Highlands Terrane (FHT) [1]. Lunar regolith breccia meteorites that could have potentially been launched from anywhere on the Moon, provide insight into major processes that have shaped the lunar surface, such as meteoroid impacts and volcanism [2,3]. These meteorites reflect the amalgamation of a variety of lithologies and can act as important sources of information regarding the compositional diversity of the lunar crust, especially outside the sampled PKT regions.

Here, we perform detailed petrological and mineralogical investigations of three lunar regolith breccia meteorites Yamato(Y)-981031, Y-983885 and Y-86032, and discuss their lithological makeup. Our bulk major and trace element analysis, similar to previous studies, suggest that these samples were derived from regions outside the PKT. The variety of clasts and their compositional variations highlights the diversity in the lunar crust.

Methodology: Back-scattered electron imaging, X-ray mapping and mineral chemical analysis were carried out at Physical Research Laboratory (PRL), Ahmedabad, using an electron probe microanalyser (EPMA; JEOL JXA-8530F Plus Hyperprobe). The bulk major and trace element analyses were performed on the powdered bulk rock using an *iCAP-Q* ICPMS at the Scripps Isotope Geochemistry Laboratory (SIGL).

Results and Discussions: ***Y-981031*** is a polymict regolith breccia. Although, initially classified as an anorthositic regolith breccia [4], our studied section shows a dominance of basaltic mineralogy, compared to feldspathic, in the matrix fragments. The meteorite contains numerous basaltic, troctolitic, anorthositic and glassy lithic fragments along with mineral fragments of pyroxene, olivine, plagioclase, glass spherules, Fe-Ni metal, ilmenite, symplectites and silica. The clasts range in size of up to a few mm (Fig. 1). The studied section also has a vesicular fusion crust with variable composition. The modal abundance of highland clasts is ~15%. The pyroxenes show a large compositional variation from En$_{4.1}$ to En$_{65.4}$ and Wo$_{4.6}$ to Wo$_{43.3}$. Pyroxene present as both clasts and lithic fragments show coarser exsolution lamellae than typical Apollo mare basalts (Fig. 1). Most of the plagioclase has been maskelynitized with a compositional range from An$_{88}$ to An$_{99}$. Olivine composition varies from Fo$_{58}$ to Fo$_{80}$.

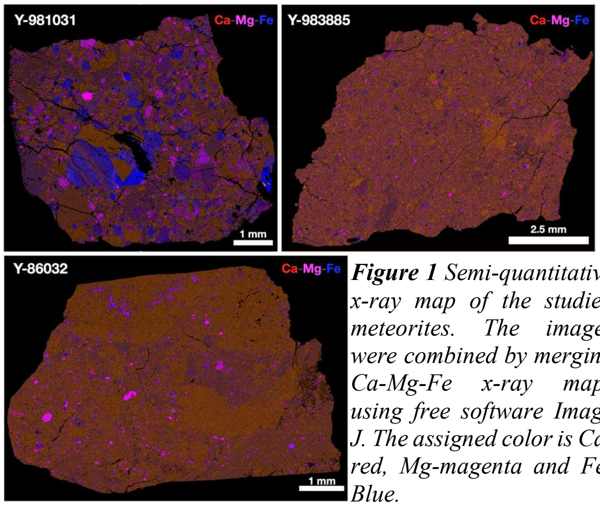

Figure 1 *Semi-quantitative x-ray map of the studied meteorites. The images were combined by merging Ca-Mg-Fe x-ray maps using free software Image J. The assigned color is Ca-red, Mg-magenta and Fe-Blue.*

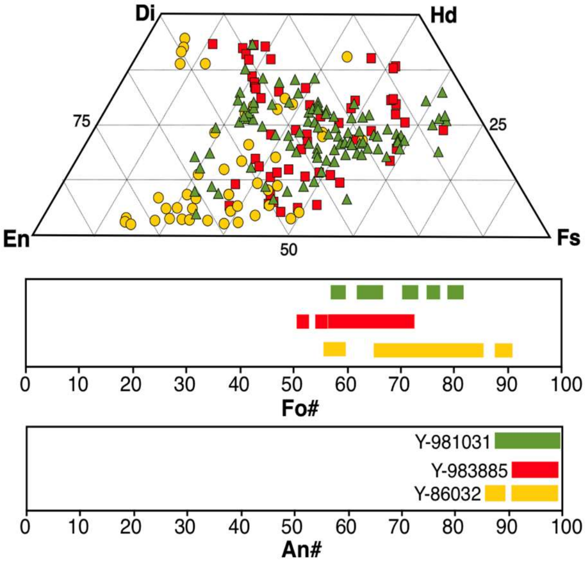

Figure 2: *Compositional variation in pyroxene, plagioclase and olivine in the meteorite Y-981031(green), Y-983885 (red) and Y-86032 (yellow).*

The bulk FeO, Al_2O_3, Sm and Th content suggest it to be mixture of highland and mare basalt components with overall dominance of a mare component. The bulk rock rare earth element (REE) content shows LREE enrichment suggesting a possible KREEP component in the sample (Fig. 3c). Nickel (153 µg/g) and Co (41 µg/g) concentration in the meteorites show high values when compared to the end-member mare basalts.

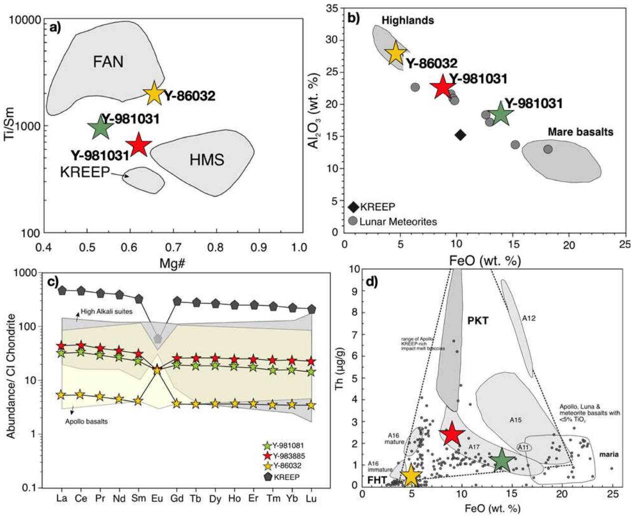

Figure 3: *The measured bulk major and trace element composition of studied samples. a) plot of Mg# (Mg/Mg+Fe) vs. Ti/Sm ratio for the bulk of Y-981031, Y-983885, Y-86032 and other highland lithologies [5,6]. b) bulk composition of* Al_2O_3 *and FeO in studied samples compared with highland and mare region [2]. c) CI normalized REE pattern of studied meteorites compared with Apollo mare basalts, KREEP and high Alkali suites [7,8]. d) Bulk FeO and Th concentration of studied sample compared with Apollo soils ("A11", etc) and lunar meteorites [2].*

Y-983885 is a fine grained polymict regolith breccia with clasts of < 1 mm grain size. The lithic fragments comprise low-Ti basalts, high-Al basalts, troctolite, granulites and KREEP basalts. Small clasts of minerals such as olivine, pyroxene and plagioclase are embedded in a fine grained matrix. Pyroxenes in Y-983885 show wide compositional range from $En_{8.1}$ to $En_{58.1}$ and $Wo_{5.4}$ to $Wo_{54.6}$. The measured plagioclase composition follows typical lunar range from An_{91} to An_{99}. Olivine in the sample range from Fo_{51} to Fo_{72}.

The bulk rock TiO_2 (0.49 wt.%) composition shows dominance of a VLT component. The concentration of FeO, CaO and Al_2O_3 is higher than for Y-981031. The LREE enrichment in the REE pattern and an overall high REE abundance suggest the presence of a KREEP component in this meteorite. Among other basaltic meteorites, Y-983885 is also unique because of its compositional similarity to the SPA basin especially because of high Si, Ca and Fe [9]. The meteorite shows highest concentration of Ni (403 µg/g) among the studied meteorites. Its high Ni/Co ratio may indicate meteoritic contribution from a chondritic impactor.

Y-86032 is the finest-grained sample among the studied meteorites. It is classified as a fragmental breccia composed largely of feldspathic clasts [10]. The clasts include granulite and impact melt of compositions ranging from feldspathic to mafic. A small amount of fine-grained mineral clast of olivine, plagioclase and pyroxene is found imbedded in glass rich matrix. The compositional range of pyroxenes ($En_{18.6}$ to $En_{80.4}$ and $Wo_{2.6}$ to $Wo_{40.5}$) is more limited when compared to Y-981031 and Y-983885. Plagioclase ranges from An_{86} to An_{99}. Olivine clasts in Y-86032 are few in number and show a compositional range from Fo_{58} to Fo_{90}. The measured whole rock composition of Y-86032 shows resemblance to other feldspathic lunar meteorites. The low bulk FeO (4.76 wt. %) and Th (0.13 µg/g) abundances suggest that Y-86032 is from a locality that away from the PKT (Fig. 3). The bulk REE abundance of the meteorite is the lowest among the studied samples and show a positive Eu anomaly, in contrast to other studied samples. With low concentration of incompatible elements, the Y-86032 can be classified as a KREEP-free sample variety.

Conclusion: The studied samples Y-981031, Y-983885 and Y-86032 show varied degree of mixing of highland and mare materials. The bulk Th and FeO concentration in the studied samples suggest their derivation from three distinct locations in the lunar surface. The preliminary study of sample Y-981031 and Y-983885 show comparatively larger proportions of basaltic materials than anorthositic materials, in contrast to previous studies. The different textures and sizes of exsolution lamellae in pyroxenes suggests varied degree of cooling of the clasts, and crystallization in a range of environments from surface to shallow subsurface or a under a thick lava flow. We will target the individual clasts in these meteorites for detailed study.

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