Eu ANOMALIES OF LUNAR BASALTS REFLECT BOTH SOURCE CHARACTERS AND MAGMATIC FRACTIONATION. S. Misra[1] and D. Ray[2], [1]SAEES, University of KwaZulu-Natal, Durban-4000, South Africa (misras@ukzn.ac.za), [2]PLANEX, Physical Research Laboratory, Ahmedabad- 380 009, India (dwijesh@prl.res.in).

Introduction: The lunar basalts, which constitute ~1 vol% of the lunar crust, are believed to have evolved from Lunar Magma Ocean (LMO) in essentially anhydrous condition [1]. The LMO hypothesis, however, has recently been questioned [2-5], and alternative hypotheses, e.g. serial magmatism [4, 6-8] or asteroid impact [9], are proposed. The recent discovery of H_2O in lunar rocks [10-12] further favours hydrous evolution of Lunar crust, and hence re-evaluation of mare basalt geochemistry becomes important for better understanding of Lunar rock petrogenesis.

An important foundation of the LMO hypothesis is the positive and negative Eu anomalies of Lunar anorthosite and basalt respectively [13]. However, recent studies show that positive Eu anomaly is no longer an essential feature of Lunar anorthosites [2]. Lunar anorthosites with low total REE have positive Eu anomaly, however as the concentration of total REE increases the Eu anomalies in these rocks become non-existent or negative. The existing studies on mare basalts and picritic glasses suggest that these rocks have negative Eu anomalies, and positive and negative LREE and HREE slopes respectively [14, 15]. Consequently, more critical studies of the REE properties of these basalts are required for re-evaluation of their petrogenesis. In the present study, we re-interpret the REE properties of Lunar High (H)-Ti and Low (L)-Ti basalts using literature data [10, 13, 15, 16]. These findings are compared with examples of terrestrial MORBs (PetDB online) and the least crustally contaminated samples of Continental Flood Basalts (CFB) [17-19].

REE chemistry: The H-Ti and L-Ti mare basalts have almost flat REE pattern with negative Eu anomalies [20]. In Ce_N versus La/Sm_N plot, L-Ti mare basalts show restricted variation, and there could be a decreasing linear trend for La/Sm_N (~1.17 to 0.62) with marginal increase in Ce_N from 19 to 38 (Fig. 1). This variety of mare basalts show overlapping field with the majority of terrestrial MORBs. The H-Ti mare basalts show lower La/Sm_N (~0.80 to 0.32) and higher Ce_N values, in general, than those of the terrestrial basalts; maximum variation in Ce_N between ~20 and 140, and gentle linear increase of La/Sm_N ratios with increasing Ce_N. The examples of terrestrial CFBs have higher La/Sm_N and Ce_N values comparable to a small group of terrestrial MORBs, and their field in this diagram is almost non-overlapping with either of the Lunar basalts or the majority of terrestrial MORBs. The terrestrial CFBs also show a linear increase of La/Sm_N with increasing Ce_N.

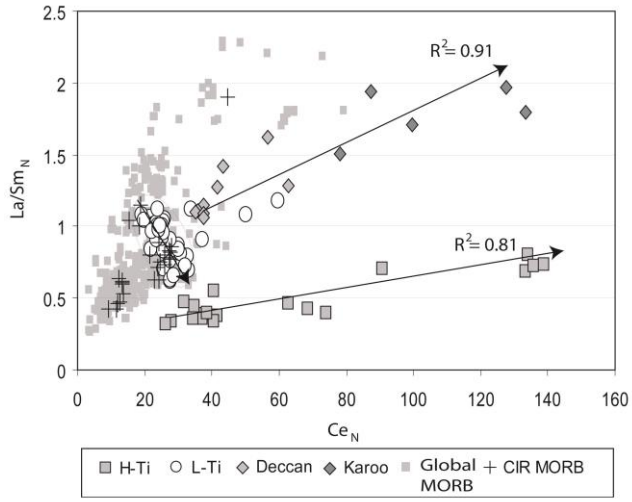

Fig. 1. Ce_N versus La/Sm_N plots of lunar basalts and example of terrestrial basalts, abbreviations: H-Ti- High Ti mare basalts, L-Ti- Low-Ti mare basalt, Deccan- uncontaminated Deccan Traps basalt, Karoo- uncontaminated Karoo basalts, CIR- Central Indian Ridge MORBs.

The Gd/Yb_N ratios of L-Ti mare basalts are marginally higher than those of the terrestrial MORBs, although some overlap exists (Fig. 2). The H-Ti mare basalts have Gd/Yb_N ratios similar to those of the terrestrial MORBs but show almost no variation of this ratio with increasing Ce_N. The terrestrial CFBs have the highest Gd/Yb_N ratios than all other basalts and show a broad linear increase of Gd/Yb_N with increasing Ce_N.

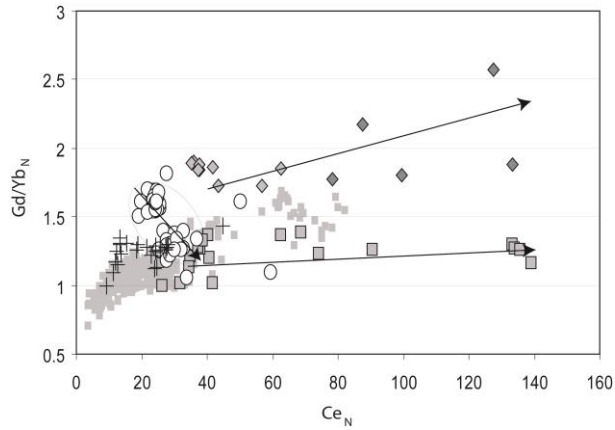

Fig. 2. Ce_N versus Gd/Yb_N plots of lunar basalts and example of terrestrial basalts, symbols as in figure 1.

The Eu/Eu* values for all terrestrial MORBs and CFBs have an average close to 1 (standard deviation: 0.06) (Fig. 3). The terrestrial MORBs show no important variation of Eu/Eu* with increasing Ce_N from ~4 to 80. The examples of terrestrial CFBs along with few of the MORBs show a very gentle linear increase of Eu/Eu* with increasing Ce_N. The Eu/Eu* values for the lunar samples are always lower than 0.8, the value for the L-Ti mare basalts varies between ~0.8 and 0.4 with a sharp linear decreasing trend with minor increase of Ce_N. The H-Ti mare basalts have Eu/Eu* values between ~0.5 and 0.2 and show a gentle linear decrease with increasing Ce_N.

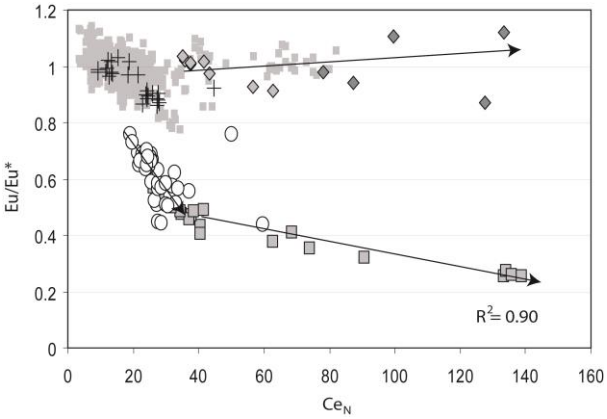

Fig. 3. Ce_N versus Eu/Eu* plots of lunar and terrestrial basalt samples, symbols as in figure 1.

Discussion: Previous observations on bulk compositions of Lunar basalts suggest that these basalts evolved through crystal fractionation from different parent magmas with a common but distinct iron enrichment trends [13, 21]. If the variation in Ce content in mare basalts is taken as an index of crystal fractionation, the H-Ti mare basalt (Ce_N ~20-140) exhibits maximum extent of REE fractionation to account for marginal increase in La/Sm_N ratios and important decrease in Eu/Eu* ratios, however their Gd/Yb_N values do not show any important variation with fractionation (Fig. 1-3). The effect of fractionation on REEs in L-Ti mare basalt is less, Ce_N shows very limited variation (~19-38) although there are definite sharp decreases of La/Sm_N, and perhaps Gd/Yb_N and Eu/Eu* ratios with fractionation of this basalt.

Although it is believed that negative Eu anomaly is an intrinsic property of the pyroxene-bearing cumulate source of lunar basalts, which was acquired during fractionation of plagioclase from the LMO to form the floated anorthositic crust [1, 13], our present observation shows that fractionation in both the L-Ti and H-Ti mare basalts facilitate significant increase in the existing negative Eu anomalies (Fig. 3). The effect of increasing negative Eu anomaly with fractionation in both groups of mare basalts indicates the possibility of an early separation of calcic plagioclase from their respective parent magmas during fractionation, a phenomenon perhaps not noticed before.

The H-Ti and L-Ti mare basalts are relatively depleted in Al_2O_3 as indicated by their low Al_2O_3/TiO_2 and high CaO/Al_2O_3 ratios [22] and also in SiO_2 and (Na_2O+K_2O) [21]. In addition, these basalts are also depleted in Rb, Pb and Sr beside Eu [20], indicating a depleted mantle source, in general, for the lunar basalts. Relatively low Pb/Nd and U/Nd ratios [20] along with lower Eu/Eu* values (maximum ~0.5) for the H-Ti mare basalt (Fig. 3) confirm that the source rock of this group of basalts was more depleted compared to that of the L-Ti mare basalt. As all these major and trace elements are compatible to plagioclase structure, it could be hypothesized that the lunar mantle could have experienced a phase of hydrous melting prior to the formation of basaltic magmas when a feldspathic melt was produced and extracted, leaving behind a relatively residual lunar mantle as a source of subsequent basaltic magmatism [21].

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