

COMPOSITIONAL EVIDENCE FOR LAUNCH PAIRING OF THE YQ AND ELEPHANT MORAINÉ LUNAR METEORITES.

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Introduction: Arai and Warren [1] provide convincing evidence that QUE (Queen Alexandra Range) 94281 derives from the same regolith as Y (Yamato) 793274 and, therefore, that the two meteorites were likely ejected from the Moon by the same impact. Recently discovered Y981031 is paired with Y793274 [2,3]. The “YQ” [1] meteorites (Y793274/Y981031 and QUE 94281) are unique among lunar meteorites in being regolith breccias composed of subequal amounts of mare volcanic material (a VLT [very-low-Ti] basalt or gabbro) and feldspathic highland material [1,3,4,5].

EET (Elephant Moraine) 87521 and its pair EET 96008 are fragmental breccias composed mainly of VLT basalt or gabbro [5–10]. Warren, Arai, and colleagues [1,3,5,7,8] note that the volcanic components of the YQ and EET meteorites are texturally similar – more similar to each other than either is to mare basalts of the Apollo collection. Warren and colleagues address the issue of possible launch pairing of YQ and EET, but note compositional differences between EET (black squares of Fig. 1) and the volcanic component of YQ, as inferred from extrapolations of regressions such as those of Fig. 1 (red) to high FeO concentration [1,4,5]. We show here that (1) EET 87/96 consists of fragments of a differentiated magma body, (2) subsamples of EET represent a mixing trend between Fe-rich and Mg-rich differentiates, and (3) the inferred volcanic component of YQ is consistent with a point on the EET mixing line. Thus, there is no compositional impediment to the hypothesis that YQ is launch paired with EET.

Samples and analysis: We have used INAA (instrumental neutron activation analysis) to determine concentrations of 25 elements in 24 subsamples of EET 87/96 (mean mass: 37 mg) and 6 subsamples of Y-981031 (30 mg) to complement our previous data on 28 subsamples of QUE 94281 (17 mg).

Results and Discussion: EET is heterogeneous and subsamples are highly variable in composition [9], ranging over more than a factor of 2 in FeO concentration and almost a factor of 8 in Sm (Fig. 1). The low-FeO subsamples have high Mg/Fe, high Cr/Sc, high Ca/Na, and low concentrations of incompatible elements compared to the high-FeO subsamples. High-FeO splits are rich in fayalite-hedenbergite-silica assemblages (symplectites) and clasts of K and Si-rich glass with rare-earth-merrillite (whitlockite) [8,11,12]. We have made a preliminary petrographic study of one of the low-Fe, high-Mg splits and find it to be dominated by a pigeonite (En_{50-60})-plagioclase assemblage. Our results are consistent with those of Lindstrom et al. [9], who attribute the heterogeneity to “variations in proportions of primitive and more-evolved basaltic samples.” We

agree that the source of the EET meteorites is either a shallow differentiated gabbroic intrusion or a thick, ponded basalt flow [5–7], but one in which there was physical separation (mm?, cm?, m?) of early and late crystallized phases. The EET meteorite is a breccia composed of fragments of the solidified differentiation products.

Our new data for Y981031 overlap with our previous data for QUE 94281 [4] but our Y981031 sample is more feldspathic than most samples of Y793274 [13–15]. As with EET, subsamples of the YQ meteorites are variable in composition, but for a different reason. The compositions plot along a mixing line (dotted red, Fig. 1) between a feldspathic (low FeO) highlands component (off scale of Fig. 1), probably a regolith, and a mare volcanic component (high FeO) with the composition of VLT mare basalt [1,4,5]. For the purpose of estimating the composition of the mare component of YQ, we previously assumed that it had 19% FeO [4]. Arai and Warren assumed 18% [1]. Fig. 1 shows that if the volcanic component of YQ has ~17% FeO, then the composition is consistent, within uncertainty, to a composition plotting on the EET mixing line.

Because of the large variability among subsamples, the mean composition of EET is not known well. The intersection point of the two mixing trends of Fig. 1 corresponds to the low-FeO end of the 95% confidence range for the EET mean, based on our own samples (thick part of solid blue lines of Fig. 1). The two large EET 87521 samples of Warren and Kallemeyn [16] plot at the high-FeO end of the range. Arai and Warren [1] question a relationship between EET and YQ in part on the basis of a high V concentration in EET compared to the YQ extrapolation. Although we did not determine V, Cr is consistent with our interpretation (Fig. 1), so we expect that V is, too.

If YQ and EET were ejected from a common source crater, it is likely that EET 87/96, a fragmental breccia, originated from a deeper position than Y79/98 and QUE 94281, which are regolith breccias. Thus, highland material likely overlies mare volcanics at the launch site. If the volcanic body is vertically differentiated, we would expect the upper, less dense portion to have a lower FeO concentration, which would account for the low-FeO concentration of the YQ volcanic component compared to the EET component (Fig. 1). Finally, we note that one of our EET 87521 subsamples, the one with the anomalously low-FeO concentration (11.6%), is compositionally indistinguishable from the most feldspathic of the YQ subsamples (Fig. 1). This similarity provides weak evidence that the nonmare component of EET is the same as that of YQ.

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Conclusions: Cosmic-ray exposure data allow that EET 87541/96008 was ejected from the Moon by the same impact that launched YQ (Yamato 793274/981031 and QUE 94281) [1, citing K. Nishiizumi, pers. comm.]. Our data show that the inferred volcanic component of YQ has a composition consistent with that of EET and, thus, there is no significant compositional obstacle to the hypothesis that YQ and EET are launch paired. If they are, then EET, which is dominated by the shallow, differentiated mafic components, likely derives from deeper in the crater whereas YQ, which has admixed nonmare components, consists of regolith at the surface of the impact site.

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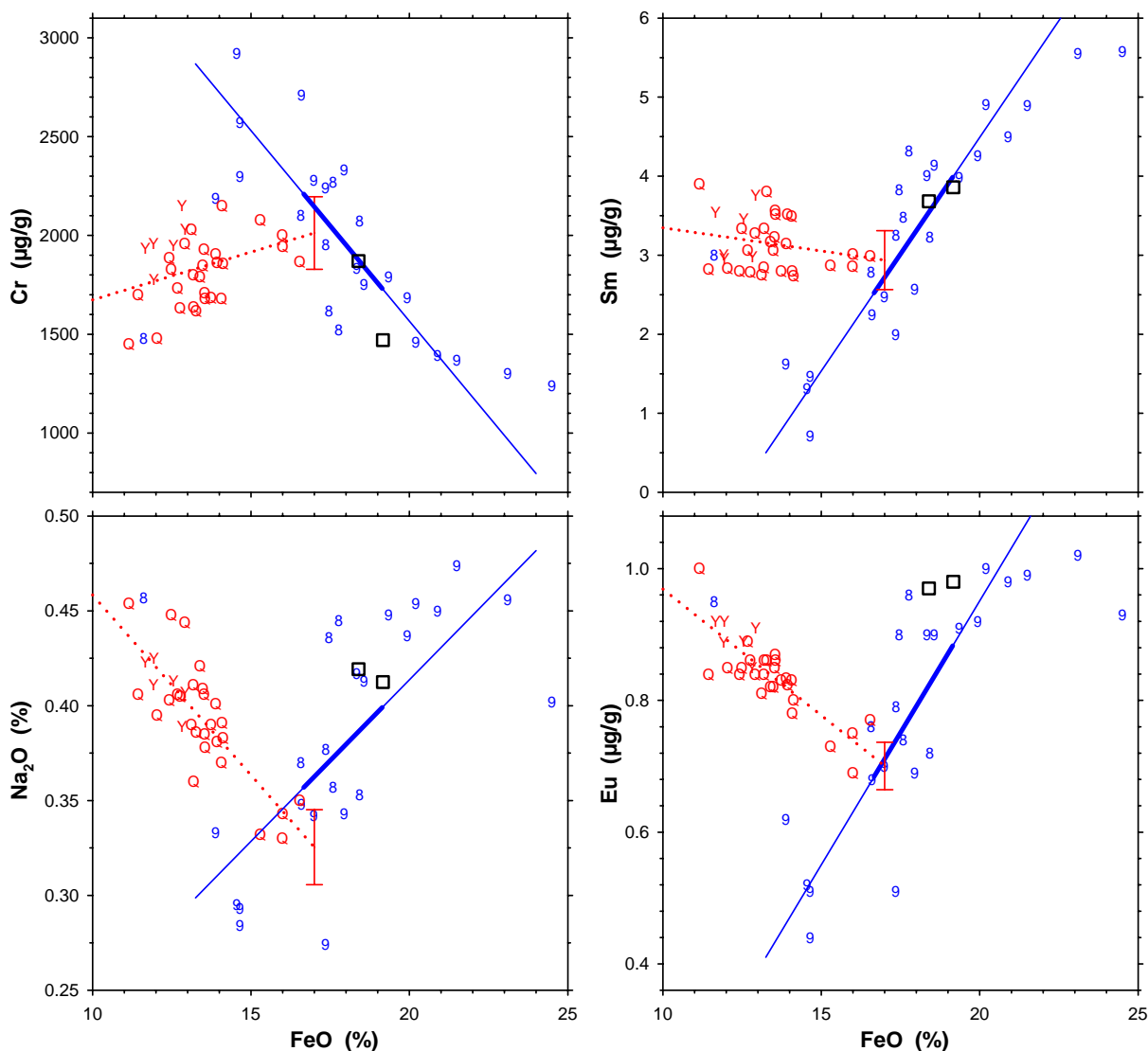


Figure 1. Subsamples of EET 87521/96008 (8 & 9) are highly variable in composition. The blue line is a simple linear regression to the blue data points (8 & 9), and the thick part represents the 95% confidence limit on the mean concentrations. Subsamples of Yamato 981031 (Y) and QUE 94281 (Q) are also variable in composition. The dotted red line is a simple linear regression to the Q & Y data, and the error bar represents the 95% confidence limit on the predicted value at 17% FeO. All data from this lab, except that the black squares are EET 87521 data of [16].