CONSORTIUM STUDY OF LUNAR METEORITES YAMATO-793169 AND ASUKA-881757:
GEOCHEMICAL EVIDENCE OF MUTUAL SIMILARITY, AND DISSIMILARITY VS. OTHER MARE BASALTS

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Compositions of bulk powders and separated minerals from two meteorites derived from the mare lava plains of the Earth's Moon, Yamato-793169 and Asuka-881757, indicate a remarkable degree of similarity to one another, and clearly favor lunar origin. However, these meteorites are unlike any previously studied lunar rock. In both cases, the bulk-rock TiO₂ content is slightly greater than the level separating VLT from low-Ti mare basalt, yet the Sc content is much higher than previously observed except among high-Ti mare basalts. Conceivably, the Sc enrichment in A881757 reflects origin of this rock as a cumulate from a mare magma of "normal" Sc content, but this seems unlikely. Mineral-separate data suggest that most of the Sc is in pyroxene, and a variety of evidence weighs against the cumulus hypothesis as a major cause for the high Sc. The remarkable similarity between Y793169 and A881757 suggests the possibility that they were derived from a single source crater on the Moon.

As described in a companion abstract [1], the samples allocated for this study include homogenized powders generated from a large mass (indirectly 14 g) of the coarse-grained A881757, and from a smaller mass (0.51 g) of the relatively fine-grained Y793169; and also small chips, used to obtain mineral separates, from A881757. The bulk samples were studied by INAA and electron probe fused bead analysis at JSC and UCLA, and by RNAA at UCLA. Mineral separate analyses are exclusively from INAA at the JSC lab. In an earlier study [2], bulk analyses were also obtained (at JSC) for pieces of a 0.25-g chip of A881757, but in many respects the newer, powder samples are probably more representative of the composition of this extraordinarily coarse-grained mare gabbro.

In the TiO₂-based classification system for mare basalts, our averaged new data indicate that Y793169 (2.2 wt%) and A881757 (2.4 wt%) are both low-Ti. Earlier analyses (of distinct chips) reported by Yanai and Kojima [3] indicate 1.55 and 1.66 wt%, respectively. Considering all of the available evidence, it appears that these meteorites have higher TiO₂ than the customary upper bound for VLT (1.5 wt%), yet lower TiO₂ than nearly all previously known "low-Ti" mare basalts. Viewed in relation to the extraordinarily low mg ratios of these meteorites (by all accounts ~33 mol%), their TiO₂ contents are marginally consistent with kinship to previously-studied VLT (very-low-Ti) mare basalts. In another popular classification system, our averaged new data indicate that A881757 is low-Al (10.3 wt% Al₂O₃), and Y793169 (11.1 wt%) is marginally high-Al. The ambiguities posed by these two mare meteorites suggest that the traditional major element system for mare basalt classification cannot always be relied upon to effectively delineate affinities among the various mare materials.

Lindstrom et al. [2] noted that A881757 is uncommonly Sc-rich. On a plot of Sc vs. Ti (Fig. 1), Y793169 and A881757 plot near one another, and at roughly 2x the Sc content of most Apollo/Luna low-Ti mare basalts. At least in A881757, most of the Sc apparently resides in pyroxene. Two 32–35 mg pyroxene separates were found to contain 138–143 μg/g, which is much higher than the bulk-rock, and 3.6x higher than an opaque separate that appears to consist mainly of chromian ulvöspinel (Ti was not directly measured in these separates; the values used in Fig. 1 are based on analyses by Yanai [4]). The texture of A881757 is in some ways similar to those of cumulate eucrites [4]. Thus, conceivable the extraordinarily high Sc content arose through accumulation of pyroxene (and possibly other Sc-rich phases) from a relatively "normal" mare basaltic melt. However, by analogy with the compositions of Apollo 15 partial cumulates, especially the olivine-free 15388 [5], and cumulate eucrites, and moreover based on available crystal/melt distribution coefficients, it seems unlikely that a plausible (probably <=40 wt%, inferred from REE and mg evidence) cumulus component in A881757 could account for most of the separation between it and "normal" mare basalts on Fig. 1 [6]. Moreover, in the opinion of Takeda et al. [7], A881757 is "not a cumulate rock"; and Y793169, which is much finer grained than A881757, appears similar on Fig. 1. The high Sc contents of these meteorites probably reflect partial melting of a Sc-rich source (or sources) in the lunar mantle.

Rare earth element (REE) concentrations in A881757 and Y793169 are generally higher than those of
VLT mare basalts and in the range of low-Ti mare basalts. However, the unfractionated middle-REE/heavy-REE ratios of these two meteorites resemble the typical pattern of VLT mare basalt and contrast with the convex REE patterns of most low-Ti mare basalts. Mineral analyses show that the bulk of the middle-heavy REE are in pyroxene and not symplectite.

A881757 and Y793169 resemble VLT mare basalts in having high Sc/Sm ratios despite moderate Ti/Sm (Fig. 2). These meteorites resemble low-Ti basalts in terms of moderate overall REE contents and V/Sm and Cr/Sm ratios, and they even resemble high-Ti basalts in having high Sc coupled with low V. Neither meteorite shows the enrichments in K and Ge that remain peculiar to mare basalts from Apollo 14, apparently due to assimilation of the K-rich granitic and Ge-rich KREEPy materials that are uncommonly abundant in the Apollo 14 region.

A set of remarkable similarities between Y793169 and A881757 (from our data: their extraordinarily high Sc despite low Ti, and extraordinarily low mg; other workers [1,8–10] have demonstrated similar ages, $^{238}U/^{204}Pb$, and times of blast-off from the Moon) suggests that these two meteorites might be paired, in the sense of having left the Moon in a single cratering-ejection event. The geochemical contrasts between this duo and previously available mare basalts show that the full diversity of the lunar maria, and the factors that govern variability among mare basalts, are still poorly understood. The diversity and lack of systematics among lunar mare basalt compositions, reinforced by Y793169 and A881757, are consistent the magma ocean cumulate model for genesis of the mare source regions. The relationship between geochemistry and age among mare basalts seems more complex that previously supposed, perhaps because the compositional stratification that develops in the pile of magma ocean cumulates is too disorderly to conform with any model for depth-time-temperature evolution of the lunar interior.

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