

THE CHRONOLOGY AND PETROGENESIS OF THE MARE BASALT CLAST FROM LUNAR METEORITE DHOFAR 287: Rb-Sr AND Sm-Nd ISOTOPIC STUDIES. C.-Y. Shih¹, L.E. Nyquist², Y. Reese¹, H. Wiesmann¹, M.A. Nazarov^{3,4} and L.A. Taylor⁴. ¹Lockheed-Martin Space Operations, Mail Code C-23, 2400 NASA Road 1, Houston, TX 77058; ²SR, NASA Johnson Space Center, Houston, TX 77058; ³Vernadsky Institute, RAS, Moscow-11975, Russia; ⁴Planetary Geoscience Institute, University of Tennessee, Knoxville, TN 37996.

Introduction: Lunar meteorite Dhofar 287, found in the desert of Oman, consists of ~95% mare basalt (287A) and <5% of regolith breccia (287B) [1,2]. Preliminary mineralogical and chemical studies suggest that the basalt resembles the Apollo 12 olivine basalts but has higher REE abundances and also is enriched in LREE [1]. The REE characteristics suggests it is a unique low-Ti mare basalt type not sampled by the previous Apollo and Luna missions. We analyzed Rb-Sr and Sm-Nd isotopic compositions for this basalt clast in order to determine mineral isochron ages and to assess alteration effects on isochrons under the hot-desert environment. Also, using the Rb/Sr and Sm/Nd ratios calculated for the source region from a two-stage isotope evolution model, we evaluate the mantle source mineralogy for this unusual low-Ti mare basalt.

Samples and experiments: Several chips weighing ~1g were allocated for the study. The entire sample was gently crushed to less than 149 μ m. A bulk sample (WR1) was taken. A second bulk sample (WR2) was washed with warm 2N HCl and sonicated for 10 min. Both residue (r) and leachate (l) samples were analyzed. A large, finer (<44 μ m), bulk sample (WRf) was also washed with 2N HCl. The residue sample was analyzed for Sm isotopic composition to evaluate the possible neutron effects for the meteorite. Four mineral separates were separated from the 74-149 μ m size fraction by the Franz magnetic separator and handpicking. The purities of the mineral separates - clear plagioclase (Plag), white Ca-pyroxene (Px1), brown Fe-pyroxene and olivine (Px2+Ol) and black opaques (Opq) - were good (95-99%). In order to eliminate desert alterations, all the minerals were subjected to aggressive leaching by 4N HCl and 0.5% HF, except the Plag by 4N HCl only. The acid leachates were not analyzed. Sm and Nd isotopic measurements for bulk samples were of Sm⁺ and Nd⁺, whereas those for the mineral separates were of SmO⁺ and NdO⁺, respectively.

Sm-Nd isotopic results: Sm-Nd results for bulk rock and mineral separate samples are shown in Fig. 1. The Sm isotopic composition for an "unspiked" sample shows that secondary neutron effects on the Sm/Nd ratio measured for the basalt are insignificant. Our Sm and Nd abundance data for the bulk sample confirm the basalt is unique in its higher REE content and LREE-enriched character, which were noted

previously [1]. Data for terrestrial river and aeolian particulates [3,4] are also plotted to show compositions of probable terrestrial contaminants. The Plag and Opq data seem displaced towards these compositions, suggesting that they were significantly contaminated. Excluding the Plag and Opq samples, four bulk rock (leachates and residue) and two pyroxene-rich samples yield a good linear array corresponding to an age of 3.46 \pm 0.03 Ga. The Sm-Nd isochron age probably represents the original crystallization age of the basalt because the isochron is defined by samples of REE-rich bulk rock leachates (mesostasis) and pyroxenes, which are most resistant to alterations in the Sm-Nd isotopic system [e.g. 5]. The age is slightly older than for Apollo 12 low-Ti mare basalts but within the age range for Apollo 15 low-Ti mare basalts. It is also noted that A-15 green glasses of age ~3.32 Ga, plot within \sim 1 ϵ of the basalt isochron. The initial ϵ_{Nd} ratio calculated for the basalt at 3.46 Ga is -0.63 ± 0.32 , which is very different from those for all of the common high-Ti or low-Ti mare basalt samples studied so far. Most of the mare basalts originated from depleted mantle sources of superchondritic ¹⁴⁷Sm/¹⁴⁴Nd ratios, whereas this basalt was derived from an enriched source of subchondritic ¹⁴⁷Sm/¹⁴⁴Nd ratio.

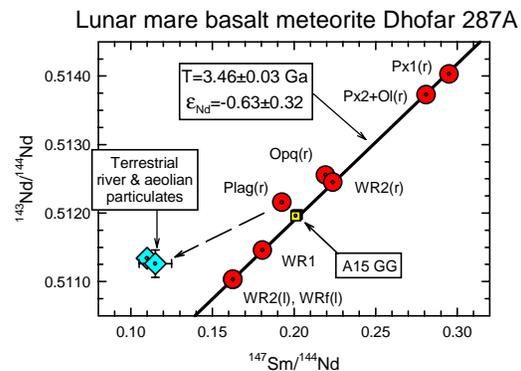


Figure 1. Sm-Nd isotopic data for Dhofar 287A.

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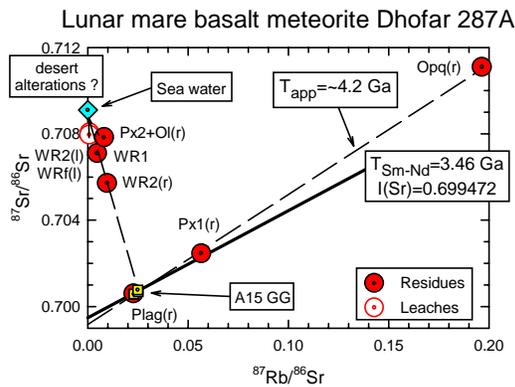


Figure 2. Rb-Sr isotopic data for Dhofar 287A.

Rb-Sr isotopic results: Rb-Sr results for bulk rock and mineral separate samples are shown in Fig. 2. All four bulk samples and Px+Ol, cluster near an area of high $^{87}\text{Sr}/^{86}\text{Sr}$, but very low $^{87}\text{Rb}/^{86}\text{Sr}$. The bulk rock leachates approach the present seawater value of $^{87}\text{Sr}/^{86}\text{Sr} \sim 0.7090$, strongly suggesting that the hot-desert environment has a severe effect on the Rb-Sr isochron system of the meteorite. This effect has been observed previously in a number of Martian meteorites found in hot-deserts e.g. DaG 476, Dhofar 019 and Los Angeles [7-9]. However, meteorites found in the very cold Antarctic environment do not appear to have such an effect; e.g. concordant Rb-Sr and Sm-Nd mineral isochron ages were reported for lunar mare basalt meteorite A881757 [10]. The linear array of three mineral residues, Plag, Px1 and Opq, all subjected to aggressive leaching, yields an apparent old age of ~ 4.2 Ga, but this age is probably not the original crystallization age of the basalt because the desert alteration products were probably not completely eliminated from these minerals. A reference isochron for the Sm-Nd age of 3.46 Ga through the Plag point gives an estimate of the initial $^{87}\text{Sr}/^{86}\text{Sr}$ (~ 0.699472), since the plagioclase has the largest Sr budget of the basalt, making isotopic alteration less noticeable. The Apollo 15 green glasses [6] plot on the reference isochron near the Plag point, implying a close petrogenetic relationship between this basalt and green glass.

Isotopic constraints on source mineralogies of Dhofar 287A: In the context of mare basalt genesis by partial melting in the LMO cumulate model [e.g. 11-12], we assumed mare basalt sources are mixtures of the green glass source (early LMO cumulate of orthopyroxene and olivine) and late-stage LMO (Ti-rich) cumulates and residual liquids. We used Sr and Nd isotopic data for the Dhofar 287A basalt to constrain its source mineralogy. In Fig. 3, Rb/Sr and Sm/Nd ratios for sources of A15 green glasses and various types of

mare basalts are calculated for a single-stage model, i.e. the sources formed at 4.56 Ga. Most mare basalt sources are low in Rb/Sr and high in Sm/Nd, whereas the Dhofar 287A source is high in Rb/Sr and low in Sm/Nd, and plots near the datum for the green glass source. These heterogeneous sources are probably due to mixing of late-stage cumulate and residual liquid with the green glass source at depth [e.g. 11]. As in [6], we evaluate this mixing process and the constituents of the late-stage Ti-rich cumulate and residual liquid by assuming (i) the initial LMO has Rb abundance $\sim 7x$ less than that proposed by [12], (ii) Rb, Sr, Sm, and Nd abundance data for clinopyroxene, plagioclase and ilmenite that crystallized from the LMO at 95 PCS of [13] to approximate the late-stage cumulates, (iii) residual LMO liquid at 95 PCS for urKREEP, and (iv) a green glass source of $\sim 0.3x\text{CI}$ Nd and probably $\sim 0.3x\text{CI}$ for Sr, as suggested by [11]. The curves show the effects of addition of these minerals (dotted) and residual liquid (solid) to the green glass source. The Dhofar 287A source, plotted on the urKREEP addition curve, is probably a hybrid source composed of the green glass (orthopyroxene+olivine) source mixing with a small amount ($\sim 1-2\%$) of late-stage urKREEP component. The DF287A basalt could be a small degree melt of such a source ($1-2x\text{CI}$ REE), or a larger degree melt followed by near surface fractionation [2].

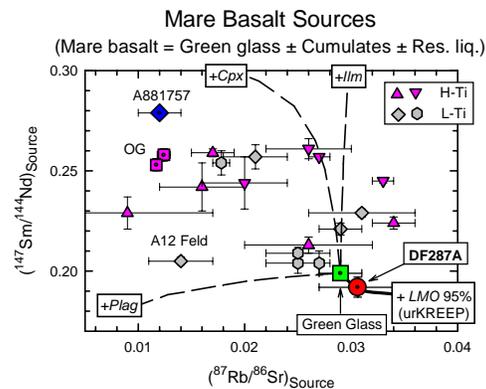


Figure 3. Calculated Rb/Sr and Sm/Nd for mare basalt sources.

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