Sm-Nd ISOTOPIC SYSTEMATICS OF TROCTOLITE 76335. J. Edmunson1, L. E. Nyquist2, and L. E. Borg3,  
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Introduction: A study of the Sm-Nd isotopic systematics of lunar Mg-suite troctolite 76335 was undertaken to further establish the early chronology of lunar magmatism. Because the Rb-Sr isotopic systematics of similar sample 76535 [1] yielded an age of 4570±70 Ma [2, λ = 1.402x10^{-11}], 76335 was expected to yield an old age. In contrast, the Sm-Nd and K-Ar ages of 7635 by [3-7] indicate that the sample is approximately 4260 Ma old, one of the youngest ages obtained for a Mg-suite rock. This study establishes the age of 76335 and discusses the constraints placed on its petrogenesis by its Sm-Nd isotope systematics.

Background: Samples 76335 and 76535 are both composed of plagioclase and olivine, but have different modal mineralogies and extents of shock. The 76335 aliquot received for this study was composed of ~85% plagioclase, ~-13% olivine, and ~2% oxides and impact melt. The sample is highly brecciated and often disintegrated into a fine powder during handling. Comparatively, 76535 has a modal mineralogy of 58% plagioclase, 37% olivine, 4% bronzite, and ~1% accessory minerals, and shows little evidence for shock metamorphism [8]. If shock disturbed the Sm-Nd isotopic systematics of 76335, it should be apparent when its petrogenesis by its Sm-Nd isotope systematics. The Sm-Nd isochron for 76335 indicates an age of 4278 ± 60 Ma with an initial ε_{Nd} value of 0.06 ± 0.39 relative to CHUR. Normalized to ^{146}Nd/^{144}Nd = 0.724134. Values calculated using Isoplot [11]. Inset shows the deviation of each point from the isochron in ε_{Nd} units. Plag = plagioclase, rej = material rejected during the hand-picking process, WR = whole rock, Ol = olivine, Ox = oxide and impact melt-rich separate.

Methods: Approximately 2g of 76335 was crushed with a sapphire mortar and pestle and sieved. The 100-200 mesh size fraction was selected for magnetic separation, from which three mineral fractions were obtained for hand-picking. The mineral fractions were hand-picked to the highest possible purity at ~95x magnification. Samples were spiked with a mixed ^{146}Sm-^{150}Nd tracer. Chemical separation procedures and thermal ionization mass spectrometry were completed at the Lyndon B. Johnson Space Center.

Results: The Sm-Nd isotopic systematics of 76335 yield an age of 4278 ± 60 Ma (Fig. 1). This age is concordant with the relatively young ages determined for similar troctolite 76535 by [3-7-]. The mineral isochron of 76335 indicates an ε_{Nd} value of 0.06 ± 0.39 relative to the chondritic uniform reservoir (CHUR) at the time of crystallization. The initial ε_{Nd} value of 76335 is -0.76 ± 0.39 if the HED parent body composition of [9] is used to describe the bulk Nd isotopic composition of the Moon, as suggested by [10].

Discussion: The relatively young age and chondritic initial ε_{Nd} value was not expected in the analysis of 76335. According to previous estimates [e.g., 12,13], KREEP-rich samples have source regions with a ^{147}Sm/^{144}Nd ratio of 0.178 ± 0.006. This KREEP component is thought to have formed 4492 ± 61 Ma ago (Fig. 2). However, the 76335 Mg-suite troctolite does not lie along the KREEP trend. There are a few reasons why this may occur.

(1) The Sm-Nd isotopic systematics of 76335 are disturbed. This scenario would seem likely, given the highly brecciated state of 76335. In fact, the Sm-Nd isotopic systematics of 76335 could be disturbed without sacrificing the linearity of the isotopic data [e.g., 14]. Experimental thermal disturbance of mare basalt 15555 showed that the Sm-Nd age of the sample decreased, and the initial ε_{Nd} value increased, with increasing temperature. However, sample 76355, which shows little evidence of shock metamorphism [8], has nearly the same age and initial ε_{Nd} value as 76335 (Fig. 2). Thus, it seems unlikely that the isotopic systematics of 76335 would be disturbed, unless the same disturbance occurred in the Sm-Nd isotopic systematics of 76355.
may then have risen as a diapir into the ferroan anorthosite (FAN) crust. The Sm-Nd isotopic systematics of similar sample 76535. Thus, it appears that a robust Sm-Nd age can be determined from a highly brecciated lunar sample. The Sm-Nd isotopic systematics of troctolites 76335 and 76535 appear to be different from those dominating the Mg-suite norites and troctolite 76535 [1], it cannot, with the isotopic data currently available, be ruled out. Further study of the Mg-suite is therefore required to establish an isotopic link between the norites and troctolites.

Conclusions: The Sm-Nd isotopic system of lunar Mg-suite troctolite 76335 indicates an age of 4278 ± 60 Ma with an initial \( \varepsilon_{\text{Nd}} \) value of 0.06 ± 0.39. These values are consistent with the Sm-Nd isotopic systematics of similar sample 76535. Thus, it appears that a robust Sm-Nd age can be determined from a highly brecciated lunar sample. The Sm-Nd isotopic systematics of troctolites 76335 and 76535 appear to be different from those dominating the Mg-suite norites and KREEP basalts. Further analysis of the Mg-suite must be completed to reveal the isotopic relationships of these early lunar rocks.


Figure 2: Time versus initial \( \varepsilon_{\text{Nd}} \) value of KREEP-rich samples [12,13]. Black polygon = troctolite 76335, white polygons = samples not used in the linear regression for \( ^{147}\text{Sm} / ^{144}\text{Nd} \) ratio estimate of KREEP-rich sources, dark gray polygons = Mg-suite samples, light gray polygons = KREEP basalts and KREEP-rich olivine cumulate NWA 773.

(2) Sample 76335 is a product of mixing between a KREEP and LREE-depleted (positive \( \varepsilon_{\text{Nd}} \) value) reservoir. It is possible that this sample originated as a melt in a KREEP and Mg-rich reservoir. The melt may then have risen as a diapir into the ferroan anorthosite (FAN) crust. The Sm-Nd isotopic systematics of FANs indicate that they have positive \( \varepsilon_{\text{Nd}} \) values [e.g., 15]. The melt could then have assimilated a portion of the crust as it crystallized, influencing the Nd isotopic signature of the 76335 source. The difficulties in this scenario lie in the conclusions that Mg-suite samples would not have such high Mg#s if they simply assimilated crustal material during crystallization [16], and that FANs should represent LREE-enriched source regions [17] with negative \( \varepsilon_{\text{Nd}} \) values relative to CHUR and therefore may not correctly represent the isotopic composition of the lunar crust.

An alternate mixing scenario could involve the mixing of reservoirs with Mg-rich, LREE-depleted cumulates and KREEP-rich, LREE-enriched material. From this single mixing scenario, there are two possible situations that can be described. The first situation involves a late differentiation age of the Moon [e.g., 4320 ± 56 Ma; 18,19]. In this case, a Mg-suite troctolite could have formed from reservoirs with different REE patterns, but the same \( ^{143}\text{Nd} / ^{144}\text{Nd} \) isotopic ratio (due to the lack of time required to grow observable positive or negative \( \varepsilon_{\text{Nd}} \) values). This seems unlikely given the ages and initial \( \varepsilon_{\text{Nd}} \) values of the Mg-suite norites in Fig. 2, as well as the relatively old Hf-W and Rb-Sr ages for lunar differentiation [19,20].