CHARACTERIZING THE EFFECT OF SHOCK ON ISOTOPIC AGES II: Mg-SUITE TROCTOLITE MAJOR ELEMENTS.

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Introduction: Two troctolites from the lunar magnesium suite (Mg-suite), 76335 and 76535, have ¹⁴⁷Sm-¹⁴³Nd and ⁸⁷Rb-⁸⁷Sr ages that do not indicate the same age for their respective sample. In the case of 76335, the ¹⁴⁷Sm-¹⁴³Nd age is 4278 ± 60 Ma [1], but the ⁸⁷Rb-⁸⁷Sr data does not reveal an isochron [2]. For 76535, the ¹⁴⁷Sm-¹⁴³Nd age is significantly younger (4260 ± 60 Ma [3]) than the ⁸⁷Rb-⁸⁷Sr age (4570 ± 70 Ma, λ = 1.402x10⁻¹¹ [4]). This study was designed to discover why the ¹⁴⁷Sm-¹⁴³Nd and ⁸⁷Rb-⁸⁷Sr ages did not match for each individual sample.

Observations: Sample 76335 is composed of anorthite (An₉₈Ab₂) and olivine (Fo₈₈), with minor orthopyroxene (En₈₇Fs₁₂Wo₁) and various trace phases (including chromite, baddeleyite, zirkelite, metal, and merrillite). Microprobe analysis indicates that 76335 Fe-Ni-Co metal has Ni and Co abundances indicative of pristine rocks, supporting the conclusions of [5] and the status of 76335 as a monomict breccia.

Troctolite 76535 is unlike 76335 in most physical features, but is very much like 76335 in geochemistry. Sample 76535 is a coarse-grained annealed rock complete with 120° triple grain junctions [6], while 76335 is a cataclastite. Investigations are ongoing to determine if 76335 is part of the 76535 parent pluton, but with at least one subsequent cataclastic event that 76335 did not experience. There are a few points of evidence that would imply a shared origin. First, their geochemical pairing [7]. Second, their almost identical bulk trace element pattern [8, 9]. Third, the overlap of 76335 and 76535 in ¹⁴⁷Sm-¹⁴³Nd age versus εNd space [1]. Lastly, remnant 120° triple grain junctions and small linear inclusions of pyroxene [10] in the anorthite of cataclastized 76335 match those observed 76535. These shared features may indicate that the samples originated from the same parent pluton. Thus, the near identical ¹⁴⁷Sm-¹⁴³Nd ages may indicate the true age of both troctolites, while the subsequent cataclastic event experienced only by 76335 may have disturbed the ⁸⁷Rb-⁸⁷Sr isotopic systematics sufficiently to prevent an isochron.

Acknowledgements: The authors would like to thank Paul Carpenter for assistance with microprobe analyses. This research was supported by an appointment to the NASA Postdoctoral Program at the Marshall Space Flight Center, administered by Oak Ridge Associated Universities through a contract with NASA.

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Mg-suite Troctolite Major Elements
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76335

Photomicrograph of troctolite 76335.61. Note extreme cataclasis.

76335 Yttrium Silicate

A yttrium silicate with the approximate composition Y₂Si₂O₇ was observed in 76335. This silicate contains high concentrations (weight percent) of REEs (see figure at right) and other radioactive elements. The composition Y₂Si₂O₇ is the formula for the mineral yttrialite. The yttrium silicate in 76335 was not verified as a structural match for yttrialite because an electron backscatter diffraction (EBSD) pattern was not obtainable. Multiple efforts by Chi Ma to obtain an EBSD patterns from the mineral only proved that the structure was amorphous, likely due to the significant radiation damage the mineral experienced during its long life on the Moon (Chi Ma, personal comm. May 21, 2009).

A REE pattern was produced using detailed analysis using the microprobe at Washington University by Paul Carpenter and Ryan Zeigler. The yttrium silicate in 76335 has a strikingly similar REE pattern to yttrialite thought to be a result of breakdown of zircon [10] (see figure at right). Accessory phases baddeleyite and zirkelite are also present in 76335 and 76535.

76535

Photomicrograph of 76535.152.

Both yttrialite [10] and the yttrium silicate found in 76335 may be enriched in LREEs due to the preferential expulsion of LREEs from zircon during breakdown [11]. Thermally activated anhdyous recrystallization via particle and defect volume diffusion [11] may have ultimately produced the yttrium silicate in 76335.

Implications to Geochronology

The breakdown of zircon via particle and defect volume diffusion implies that 76335 experienced temperatures of approximately 750°C [11] long enough to create an entirely new mineral. This temperature is higher than the 147Sm-144Nd closure temperature [12] and the temperature for cation ordering [13], and thus likely occurred during a long-term cooling history in which the textures noted in the above figures were imparted to both 76335 and 76535. Therefore, the parent pluton of 76335 and 76535 existed prior to the age recorded by the 147Sm-144Nd isotopic system, and a yttrium silicate phase should be found in 76535.

Comments can also be made on the 87Rb-86Sr isotopic systematics of these two samples based on the comparisons above. Rubidium loss was measured in a sample experimentally heated to 800°C [14] and long-term heating of the parent pluton may be responsible for producing an older 87Rb-86Sr "pseudo-isochron" for 76335 [15]. In fact, Rb loss can be easily seen in two of the olivine mineral fractions from 76335 (ol and ol ox). Given the observed severity of Rb loss, and the resulting relatively low 87Sr/86Sr ratios, it is likely that the Rb loss event occurred very early in the history of the sample. Volatility of Rb during cataclasis/meteoritic bombardment likely promoted Rb loss in 76335 over 76535 (e.g., [16]).