

FORMATION OF A LUNAR GRANITE 4.1 AE AGO. L. Nyquist¹, C. -Y. Shih², B. Bansal², H. Wiesmann², and J. Wooden^{2,3}, ¹NASA Johnson Space Center, Houston, TX 77058; ²Lockheed, 1830 NASA Rd. 1, Houston, TX 77058; ³Lunar and Planetary Institute, 3303 NASA Rd. 1, Houston, TX 77058

A "large" 1.9 g pristine granitic clast was identified recently in breccia 14321 (1). Several small chips weighing a total of 150 mg were allocated to us for radiometric dating by the Rb-Sr, Sm-Nd, and 40-Ar-39-Ar methods. The sample was crushed and passed through a 149 μm sieve. A 30 mg aliquant was taken for whole rock (WR) analyses. The remaining sample was sieved to remove the <44 μm fraction and then separated into magnetic and non-magnetic fractions. "White feldspar" (WF1, 2) and "gray feldspar" (GF1,2) fractions were handpicked from the non-magnetic fraction. A clear phase (quartz?) was present in the non-magnetic fraction but was not analyzed. The magnetic fraction was further magnetically separated into less magnetic (LMF) and more magnetic (MMF) fractions. The magnetic fractions comprised ~13% of the sample by weight. The <44 μm fraction was analyzed for Sm isotopic composition. All other samples were spiked and analyzed for Rb, Sr, Sm, and Nd concentrations and Sr and Nd isotopic compositions. The whole rock sample was also spiked and analyzed for K concentration.

Results: Analytical results are given in Table 1. The whole rock 87-Rb/86-Sr and 87-Sr/86-Sr are the highest observed for a lunar rock. The whole rock Rb-Sr model age relative to LUN1 = 0.69503 is 4.11 ± 0.03 AE ($\lambda^{87\text{Rb}} = 0.0139$ AE⁻¹). The whole rock model age relative to a chondritic initial 143-Nd/144-Nd = 0.50598 at 4.56 AE ago (from (2) adjusted for interlaboratory bias) is 4.56 ± 0.02 AE.

Sr and Nd isotopic data are shown in isochron diagrams in Figures 1 and 2. The Rb-Sr and Sm-Nd mineral isochron ages are concordant at 4.09 ± 0.11 AE and 4.11 ± 0.20 AE, respectively, and both are concordant with the Rb-Sr model age. Some of the isotopic data deviate from the isochrons by slightly more than the expected analytical precision. This result is perhaps expected since the granite clast contains shock melted glass (~30% in the thin sections studied by (1)). Rb-Sr analyses of WF1 and MMF appear to be most aberrant (Fig. 1). If these analyses are excluded the isochron age becomes 4.13 ± 0.03 AE. Sample MMF also deviates from the Sm-Nd isochron to a greater than normal degree reinforcing the suspicion that its isotopic systematics are truly disturbed. Unfortunately, we failed to obtain Nd isotopic data for WF1 and Rb data for GF1 so that MMF is the only sample which can be used to check for mutual disturbance of the Rb-Sr and Sm-Nd isotopic systems. The age of the granite probably can be considered as determined to within the precision of the Rb-Sr isochron exclusive of WF1 and MMF. We interpret the age as giving the time of igneous formation of the granite clast and not the time of breccia formation. In this regard, we consider the concordance of the Rb-Sr mineral isochron and whole rock model age as significant. This concordance would not be expected if the mineral isochron had been rotated to a secondary age by local isotopic equilibration among mineral phases during breccia formation. Although terrestrial granites often appear to have been open to complete loss of radiogenic 87-Sr, such loss seems unlikely for the granite clast because Mark et al. (3) have demonstrated that Sr-isotopic equilibration did not occur in 14321 on a 1 mm scale.

The range of initial 87-Sr/86-Sr for the granite is shown in Figure 3 for isochron fits including all data (larger error parallelogram) or excluding WF1 and MMF (smaller error parallelogram). Either choice of data leads to a range of initial 87-Sr/86-Sr which overlaps the lunar initial ratio (LUN1). The restricted data set would limit the time averaged 87-Rb/86-Sr in precursors to ≤ 0.44 , whereas values as high as 1.29 are permitted when the entire data set is considered. A fractionation of the Rb/Sr ratio by at least sixfold and probably by more than a factor of seventeen is implied to have occurred during formation of the granite. In contrast, there was little or no fractionation in the Sm/Nd ratio as evidenced by the 4.56 AE Sm/Nd model age and $\epsilon(\text{Nd}, 4.11 \text{ AE}) = -0.6 \pm 0.4$.

Petrogenetic Implications: Several authors (e.g., (4,5,6)) have suggested that silicate-liquid immiscibility (SLI) was involved in formation of lunar granites. The evidence cited for this suggestion includes the large deviation of certain inter-element ratios (primarily alkali/REE) from average lunar values. The isotopic systematics of 14321, 1062 are consistent with SLI because liquid-liquid partition coefficients (7) indicate that large fractionation in alkalis/Sr should accompany large alkali/REE fractionation whereas little or no fractionation is expected among different REE. A mass balance calculation utilizing the liquid-liquid partition coefficients of (7) yields a four- to five-fold fractionation of Rb/Sr and a ten- to thirteen-fold fractionation of K/La if the acidic liquid is $\leq 10\%$ of the two-liquid system. This calculation assumes that K and Rb partition similarly to Cs. For these conditions elemental concentrations in the magma parental to 14321 granite are calculated to be: K = 1.9-2.4 %, Rb = 50-60 ppm, Sr = 95-99 ppm, and La = 160-170 ppm. These concentrations are similar to those in the 15405 quartz-monzodiorite (QMD) and indicate a highly evolved parental magma. A model calculation suggests that the REE pattern of the granite could be produced by fractionation prior to the onset of SLI of ~3% of a phase with partition coefficients similar to those of phosphate minerals (8,9) from a parental magma with REE abundances about twice those of the QMD. This calculation assumes a 9:1 ratio between basic and acidic liquids during SLI. These results support the suggestions (4,10) that lunar granites and quartz-monzodiorites formed by differentiation of KREEP basalt magmas in a plutonic environment.

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Table 1. Analytical Results for Lunar Granite 14321,1062

Sample	Wt. (mg)	K (%)	Rb (ppm)	Sr (ppm)	Sm (ppm)	Nd (ppm)	$^{87}\text{Rb}/^{86}\text{Sr}^a$	$^{87}\text{Sr}/^{86}\text{Sr}^{a,b}$	$^{147}\text{Sm}/^{144}\text{Nd}^a$	$^{143}\text{Nd}/^{144}\text{Nd}^{a,c}$
WR	28.1	6.29	166.9	64.0	18.62	60.58	7.54^{+5}	1.14213^{+4}	0.1858^{+3}	0.511607^{+22}
LMF	5.9	-	149.6	67.9	106.0	303.7	6.38^{+5}	1.07529^{+14}	0.2111^{+3}	0.512296^{+26}
MMF	3.4	-	147.3	99.6	27.6	97.1	4.28^{+4}	0.94797^{+7}	0.1720^{+3}	0.511256^{+24}
WF1	2.2	-	175.1	129.6	6.12	-	3.91^{+3}	0.93381^{+11}	-	-
WF2	3.0	-	189.0	114.4	-	-	4.78^{+4}	0.98008^{+8}	-	-
GF1	3.5	-	-	51.7	20.41	71.16	-	1.29007^{+7}	0.1735^{+3}	0.511240^{+26}
GF2	2.3	-	185.6	50.3	27.03	89.93	10.67^{+9}	1.32854^{+13}	0.1818^{+3}	0.511487^{+24}

^aUncertainties correspond to last figures.
^bNormalized to $^{88}\text{Sr}/^{86}\text{Sr} = 8.37521$
^cNormalized to $^{148}\text{Nd}/^{144}\text{Nd} = 0.24308$

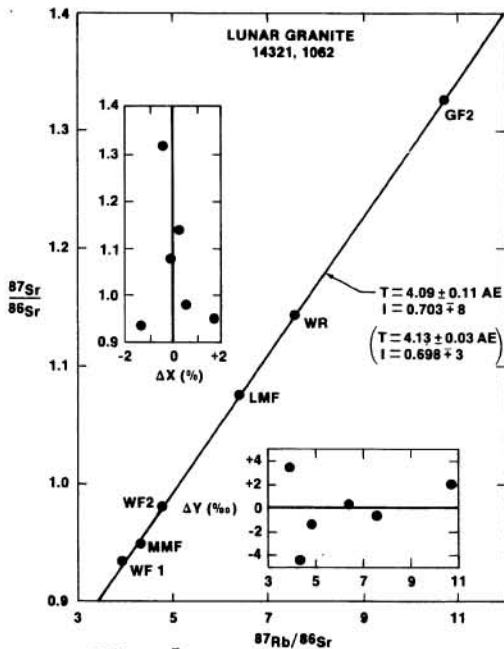


Fig. 1

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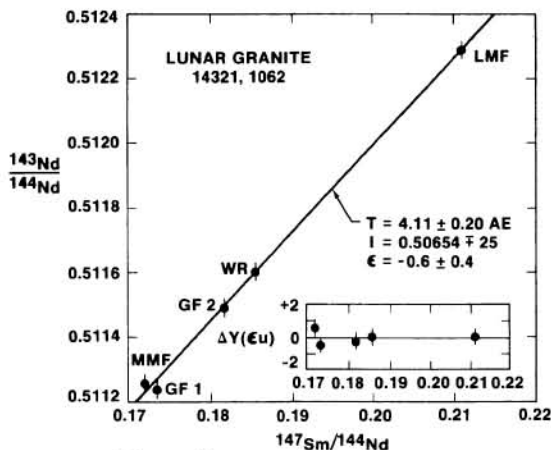


Fig. 2

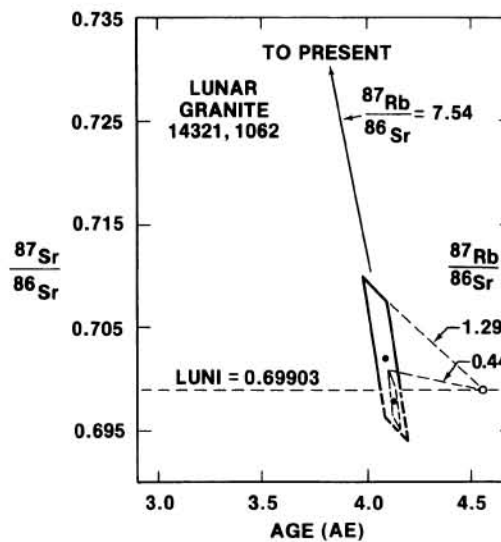


Fig. 3