

**Rb-Sr AND Sm-Nd AGES FOR LUNAR NORITE 78235/78236: IMPLICATIONS ON THE U-Pb ISOTOPIC SYSTEMATICS OF THIS HIGH-Mg ROCK;** Premo, W.R., U.S. Geological Survey, MS 963, Box 25046, Denver Federal Center, Denver, CO 80225

Rb-Sr and Sm-Nd isotopes were measured on several separates of lunar norite 78235 [1] and combined with previous results from norite 78236 [2,3] (from the same boulder) in an attempt to clarify the age and origin of this highly shocked and partially melted ancient lunar cumulate [4,5]. Previous to this work, there were two "accepted" ages for 78236 [6,7], 4.34 and 4.43 Ga, both results from Sm-Nd mineral isochrons. A key problem with using the U-Th-Pb system for age determinations on lunar samples has been the absence of precise measurements of initial Pb compositions essential for calculation of accurate lunar ages. This problem has reached the point where determinations of precise initial Pb compositions must be the primary goal. Continuing to present U-Pb ages using assumed initial Pb values given by CDT [8] is no longer acceptable. Initial Pb values for ancient highland rocks can also provide vital information regarding the extent of volatile element depletion in the early Moon. However, in order to calculate initial Pb values for our samples, we must have accurate and precise ages using other radiometric systems. Therefore, it's imperative that we clarify the age of norite 78235/78236 in order to better understand its U-Th-Pb isotopic systematics [1].

Although the cumulate layering of 78235/78236 was disrupted and crosscut by numerous veinlets of dark vesicular glass, the original mineralogy is reported to contain ~ 50% plagioclase and ~ 50% low-Ca pyroxene (bronzite) with minor high-Ca pyroxene, troilite, chromite, and whitlockite [3,4]. After a whole-rock (WR) split was taken, four separates were hand-picked for this study including deformed plagioclase + pyroxene (D-Pl-Px), maskelynite (Mask), dark vesicular glass (Glass), and Fe-Ni-Co metal (Metal). These separates were first treated with alcohol, then very dilute acids, in order to remove any terrestrial contamination and strip the grain surfaces of any adsorbed Pb component [1,9].

The Rb-Sr and Sm-Nd results for these separates, excluding Metal, are given in the tables below. Although the Rb-Sr results are quite scattered on an evolution diagram (not shown), several interesting points can be made: 1) The maskelynite and plagioclase separates appear to be best behaved with similar Rb-Sr concentrations of ~1.0 and ~200, respectively, and plot very nearly on top of one another, 2) The pyroxene separates are the worst behaved, with variable Rb and Sr concentrations, and scatter widely on the diagram, and 3) Our four separates yield poorly defined isochron ages between 4.4 and 4.7 Ga. Including the data of [4], an isochron age of  $4415 \pm 246$  Ma is calculated, and both sets of data define a disturbance at ~3.5 Ga.

Sample	Wgt. (g)	Rb (ppm)	Sr (ppm)	$^{87}\text{Rb}/^{86}\text{Sr}^\dagger$	$^{87}\text{Sr}/^{86}\text{Sr}^\dagger$	$^{87}\text{Sr}/^{86}\text{Sr}_i^\S$	$\epsilon_{\text{Sr}}^\S$
D-Pl-Px	.110	.33	3.86	$0.2491 \pm 13$	$0.716044 \pm 40$	$0.700212 \pm 329$	$13.6 \pm 2.5$
Mask	.053	.88	197	$0.0129 \pm 1$	$0.700285 \pm 38$	$0.699463 \pm 52$	$2.9 \pm 0.9$
Glass	.022	.86	90.8	$0.0275 \pm 7$	$0.701012 \pm 27$	$0.699267 \pm 48$	$0.7 \pm 0.9$
WR	.067	.84	75.7	$0.0320 \pm 4$	$0.701293 \pm 27$	$0.699257 \pm 48$	$-0.08 \pm 0.9$

† - Isotopic ratios corrected for blank and mass fractionation,  $^{87}\text{Sr}/^{86}\text{Sr}$  data are normalized to  $^{86}\text{Sr}/^{88}\text{Sr} = 0.1194$  and adjusted for instrumental bias to  $^{87}\text{Sr}/^{86}\text{Sr} = 0.710265$  for NBS SRM 987 standard. Uncertainties correspond to the last significant figure(s) at the 95% confidence level.

§ - Initial  $^{87}\text{Sr}/^{86}\text{Sr}$  ratios and  $\epsilon_{\text{Sr}}$  are calculated using an age of 4.34 Ga;  $\lambda = 1.42 \times 10^{-11}/\text{yr}$ ; present day  $(^{87}\text{Sr}/^{86}\text{Sr})_{\text{UR}} = 0.7045$ , and  $(^{87}\text{Rb}/^{86}\text{Sr})_{\text{UR}} = 0.0824$ , where UR = uniform reservoir.

Sample	Wgt. (g)	Sm (ppm)	Nd (ppm)	$^{147}\text{Sm}/^{144}\text{Nd}^\dagger$	$^{143}\text{Nd}/^{144}\text{Nd}^\dagger$	$^{143}\text{Nd}/^{144}\text{Nd}_i^\S$	$\epsilon_{\text{Nd}}^\S$
D-Pl-Px	.110	0.62	0.93	$0.4070 \pm 3$	$0.518660 \pm 18$	$0.506942 \pm 51$	$-0.64 \pm 0.5$
Mask	.053	1.00	4.63	$0.1297 \pm 1$	$0.510805 \pm 15$	$0.507070 \pm 22$	$1.9 \pm 0.4$
Glass	.022	1.51	5.20	$0.1756 \pm 2$	$0.511782 \pm 15$	$0.506728 \pm 25$	$-4.9 \pm 0.4$

† - Isotopic ratios corrected for blank and mass fractionation,  $^{143}\text{Nd}/^{144}\text{Nd}$  data are normalized to  $^{146}\text{Nd}/^{144}\text{Nd} = 0.7219$  and adjusted for instrumental bias to  $^{143}\text{Nd}/^{144}\text{Nd} = 0.511860$  for the La Jolla Nd standard. Uncertainties correspond to the last significant figure(s) at the 95% confidence level.

§ - Initial  $^{143}\text{Nd}/^{144}\text{Nd}$  ratios and  $\epsilon_{\text{Nd}}$  are calculated using an age of 4.34 Ga;  $\lambda = 6.54 \times 10^{-12}/\text{yr}$ ; present day  $(^{143}\text{Nd}/^{144}\text{Nd})_{\text{CHUR}} = 0.512638$ , and  $(^{147}\text{Sm}/^{144}\text{Nd})_{\text{CHUR}} = 0.1967$ , where CHUR = chondritic uniform reservoir.

## Rb-Sr and Sm-Nd Ages for Norite 78235/78236; Premo W.R.

The Sm-Nd data (renormalized) for all workers [3,4,this study] are illustrated on a Sm-Nd evolution diagram in the figure below. Our three separates yield an isochron age of  $4.34 \text{ Ga}$  with a very large error; whereas the Mask and D-Pl-Px tie line defines an isochron age of  $4272 \pm 13 \text{ Ma}$ . The analysis on the dark-brown glass was also excluded by [4] in their age determination and not analyzed by [3]. The age given by all the data is  $4306 \pm 82 \text{ Ma}$ , corresponding to an  $\epsilon_{\text{Nd}}(\text{CHUR})$  value of  $+1.3$  at that age. Whereas this determination is not very precise, eliminating some of the analyses due to suspected resetting or partial resetting of the systematics during the shock event, yields an age of  $4338 \pm 35 \text{ Ma}$  with an  $\epsilon_{\text{Nd}}(\text{CHUR})$  value of  $+2.6$  using the treatment of [10]. We believe this is the best estimate for the primary crystallization age of the norite.

Using this Sm-Nd age,  $4338 \pm 35 \text{ Ma}$ , we can calculate the initial Pb composition required to reproduce the same age and error in the U-Pb system. That initial composition is  $^{206}\text{Pb}/^{204}\text{Pb} = 44.19 \pm 0.5$ ,  $^{207}\text{Pb}/^{204}\text{Pb} = 74.84 \pm 0.5$ ,  $^{208}\text{Pb}/^{204}\text{Pb} = 55.21 \pm 0.5$ ; these values correspond to a  $^{238}\text{U}/^{204}\text{Pb}$  ( $\mu$ ) of 508 and an assumed  $^{232}\text{Th}/^{238}\text{U}$  ( $\kappa$ ) = 3.7, assuming CDT Pb values at 4.56 Ga, the age of the Moon. The  $\mu$  values increase sharply if we assume younger ages for the Moon; for example, at 4.51 Ga [6], the initial  $\mu$  is  $\sim 640$ . These results suggest that at least some high-Mg suite rocks were derived from sources with high- $\mu$  values, supporting the idea that they postdate the ferroan anorthosites [6,11].

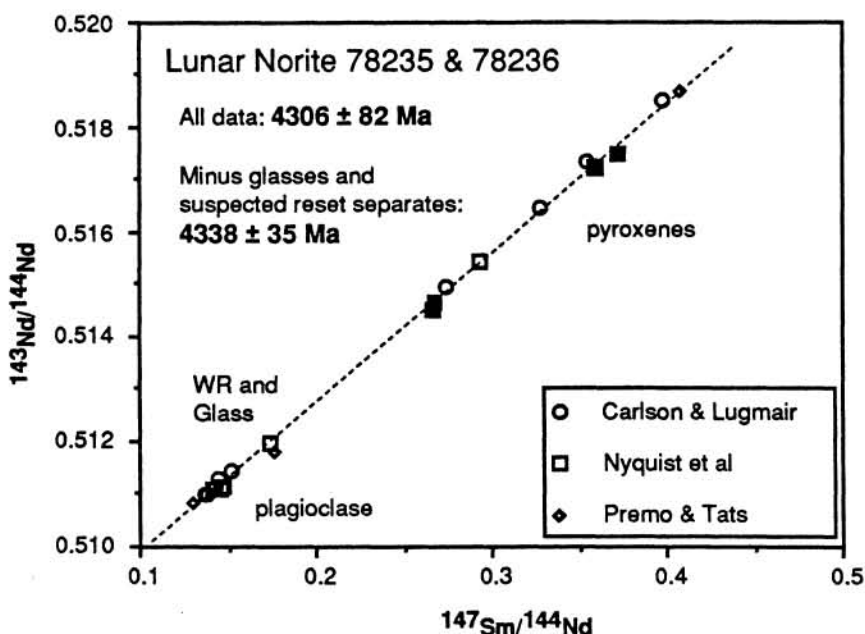


Fig. 1: Sm-Nd evolution diagram illustrating all the data (renormalized) for 78235 and 78236, which yield an age of  $4306 \pm 82 \text{ Ma}$ . Excluding some of the suspected deviant analyses (black glass and D-Pl-Px of this study; WR, solid squares, PL2, MS2 of [4]; and Pl-1 of [3]), the age is more precise at  $4338 \pm 35 \text{ Ma}$  using eleven out of twenty-one analyses.

**References:** [1] Premo, W.R. and Tatsumoto, M., (1991) Proc. Lunar Planet. Sci. Conf. 21st, in press. [2] Carlson, R.W., and Lugmair, G.W. (1981) EPSL 52, p. 227-238. [3] Nyquist, L.E., Reimold, W.U., Bogard, D.D., Wooden, J.L., Bansal, B.M., Wiesman, H., and Shih, C.-Y. (1981) Proc. Lunar Planet. Sci. Conf. 12B, p. 67-97. [4] Jackson, E.D., Sutton, R.L., and Wilshire, H.G. (1975) GSA Bull 86, p. 433-442. [5] McCallum, I.S., and Mathez, E.A. (1975) Proc. Lunar Sci. Conf. 6th, p. 395-414. [6] Carlson, R.W., and Lugmair, G.W. (1988) EPSL 90, p. 119-130. [7] Shih, C.-Y., Nyquist, L.E., Dasch, E.J., Bansal, B.M., and Wiesman, H., (1989) Lunar and Planetary Science XX, pp. 1004-1005. [8] Tatsumoto, M., Knight, R.J., and Allege, C.J. (1973) Science 180, p. 1279-1283. [9] Tatsumoto, M. (1970) Proc Lunar Conf 1st, 1695-1612. [10] Ludwig, K.R. (1985) U.S. Geol. Surv. Open-File Rep. 85-513, 102 p. [11] Warren, P.H. (1985) Ann. Rev. Earth Planet. Sci. 13, p. 201-240.