

**Sm-Nd AGE AND INITIAL  $^{87}\text{Sr}/^{86}\text{Sr}$  FOR YAMATO 980318: AN OLD CUMULATE EUCRITE.**  
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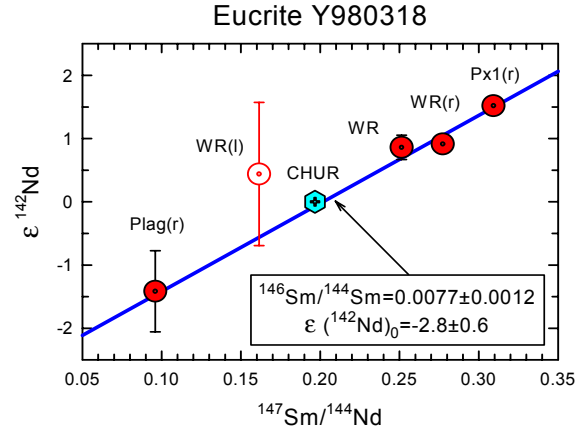
**Introduction:** The complex pyroxene exsolution texture of the Moore County cumulate eucrite was interpreted by Miyamoto and Takeda [1] as indicating initial cooling at 160°C/Ma followed by a sudden temperature rise and final cooling at 0.35°C/yr. They suggested initial cooling at a depth of ~8 km near the base of Vesta's crust, followed by impact excavation to its surface. Young Sm-Nd ages of ~4456, 4460, and 4410 Ma, respectively, for the Moore County, Moama, and Serra de Magé cumulate eucrites [2] are puzzling because closure to Nd isotopic exchange would occur in only a few Ma at the above initial cooling rate. The exception to young ages among the cumulate eucrites is EET87520, with a  $^{147}\text{Sm}$ - $^{143}\text{Nd}$  age of 4547-4598 Ma [2,3]. We report here initial results of a combined mineralogical/chronological study of the Yamato 980318 feldspar-cumulate eucrite.

**Mineralogy:** PTS Y980318,50-2 is of a coarse-grained crystalline rock with sub-rounded or lath-shaped plagioclase ( $\text{An}_{90}$ ) up to 4.5×1.5 mm in size enclosed in continuous networks of pyroxene grains up to 4.4×2.9 mm in dimension. Exsolution and inversion textures to orthopyroxene of the inverted pigeonites are similar to those of Serra de Magé [4]. A chain of small inclusions of chromite and ilmenite are distributed along the exsolved augite lamellae and in some pyroxene grains.

The bulk composition of the primary pigeonite is  $\text{Ca}_{12}\text{Mg}_{47}\text{Fe}_{41}$ . The thickness of augite lamellae ( $\text{Ca}_{45}\text{Mg}_{37}\text{Fe}_{18}$ ) on (001) of the original pigeonite is ~30  $\mu\text{m}$ . The host low-Ca pyroxene between the thick lamellae has decomposed into blebby augite inclusions in orthopyroxene ( $\text{Ca}_2\text{Mg}_{50}\text{Fe}_{48}$ ), and the orthopyroxene grew into adjacent pigeonites. Inversion texture similar to that of Y980318 has been proposed as developing in a cumulate pile in a very slowly cooling magma as in terrestrial layered intrusions.

**$^{146}\text{Sm}$  -  $^{142}\text{Nd}$  and  $^{147}\text{Sm}$  -  $^{143}\text{Nd}$  Ages:** The Sm-Nd study is ongoing, but initial results indicate an old, ~4560 Ma, age for Y980318, shown most robustly by the  $^{146}\text{Sm}$  -  $^{142}\text{Nd}$  data (Figure 1).

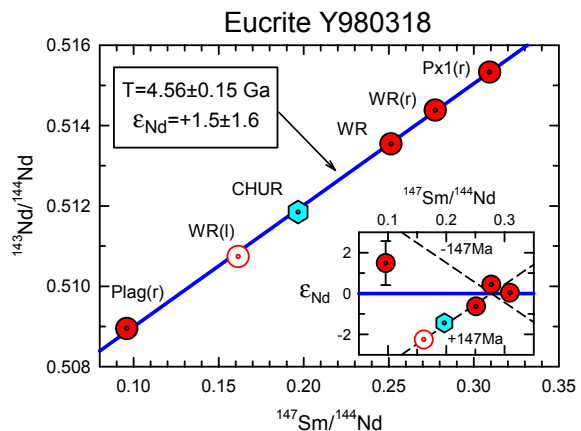
Initial  $^{146}\text{Sm}/^{144}\text{Sm} = 0.0077 \pm 0.0012$  is identical within error limits to  $^{146}\text{Sm}/^{144}\text{Sm} = 0.0076 \pm 0.0009$  [5] for the 4558 Ma old angrite LEW86010 [6] giving an absolute age of  $4561 \pm 24$  Ma for Y980318. This age is concordant with the absolute age of  $4560 \pm 150$  Ma calculated from the  $^{147}\text{Sm}$  -  $^{143}\text{Nd}$  data (Figure 2). The



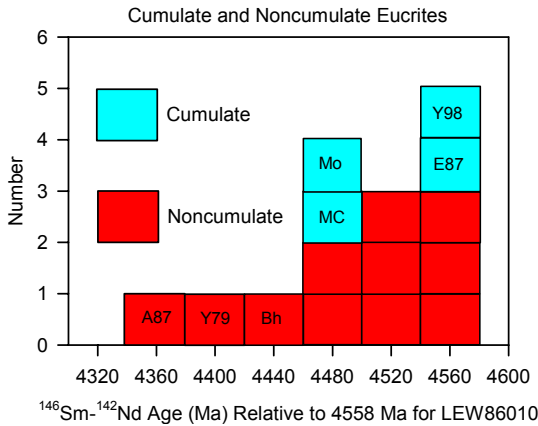
**Figure 1.**  $^{142}\text{Nd}/^{144}\text{Nd}$  shown as enrichments in parts in  $10^4$  from the chondritic value (CHUR) and plotted vs.  $^{147}\text{Sm}/^{144}\text{Nd}$ . The slope of the isochron is proportional to  $^{146}\text{Sm}/^{144}\text{Sm}$  at the time of closure to isotopic equilibration of Sm and Nd.

precision of the  $^{147}\text{Sm}$  -  $^{143}\text{Nd}$  age may be improved by additional analyses that are planned. The leachate data are not included in Sm-Nd isochrons because the analysis is of relatively low quality and is subject to terrestrial contamination.

**Summary of Eucrite  $^{146}\text{Sm}$  -  $^{142}\text{Nd}$  Ages:** Figure 3 summarizes  $^{146}\text{Sm}$  -  $^{142}\text{Nd}$  ages for cumulate and non-cumulate eucrites from  $^{146}\text{Sm}/^{144}\text{Sm}$  data from [2] and the JSC lab. There is an apparent bimodality in the age



**Figure 2.** Conventional  $^{147}\text{Sm}$  -  $^{143}\text{Nd}$  isochron plot for Y980318. Inset shows deviations from the isochron in  $\epsilon$ -units. Leachate data (WR(l)) not included in the regression. CHUR value shown for reference.

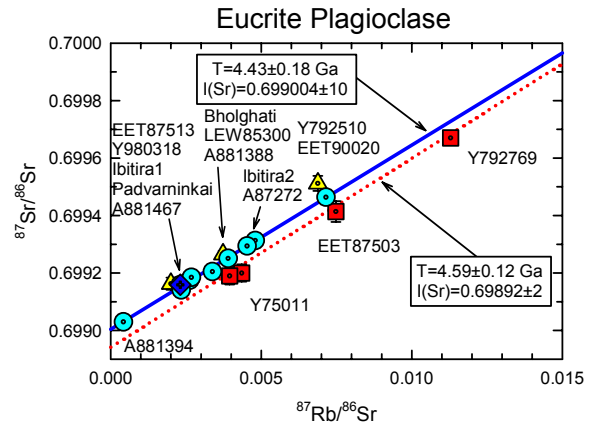


**Figure 3.** Histogram of  $^{146}\text{Sm}$ - $^{142}\text{Nd}$  ages for cumulate and noncumulate eucrites. Y98: Y980318, E87: EET87520, Mo: Moama, MC: Moore County, Bh: Bholghati clast, Y79: Y792510, A87: A87272.

distribution of cumulate eucrites that rests on a nearly continuous distribution of ages for noncumulate eucrites in the time interval from  $\sim 4460$  to  $\sim 4560$  Ma. The continuity of noncumulate eucrite ages suggests that the cumulate eucrite pattern might be filled in as more data become available.

**Evidence for an  $\sim 4430$  Ma Age in Eucrite Rb-Sr data:** Pb-Pb ages of cumulate eucrites provide support for an  $\sim 4.4$  Ga event. The average Pb-Pb age of four cumulate eucrites is  $4432 \pm 36$  Ma [2]. Included in this average are EET87520, which initially had  $^{146}\text{Sm}/^{144}\text{Sm} \sim 0.007$ ; i.e., has a  $^{146}\text{Sm}$ - $^{142}\text{Nd}$  age of  $\sim 4540$  Ma, and Serra de Magé, for which  $^{53}\text{Mn}$  (half-life 3.7 Ma) was live during crystallization [2]. Pb-Pb ages in this range are not restricted to cumulate eucrites, however. Also, some unbrecciated noncumulate as well as cumulate eucrites have Ar-Ar ages of  $\sim 4480$  Ma [7].

Figure 4 shows data from the JSC lab for plagioclase analyses of a number of eucrites and eucrite clasts. Most of the data are co-linear, defining an "isochron" of apparent age  $4430 \pm 180$  Ma and initial  $^{87}\text{Sr}/^{86}\text{Sr} = 0.699004 \pm 10$  (uncertainty refers to last digits). However, data for some eucrites, including pristine eucrite clast Y75011,84 [8] lie distinctly below the  $\sim 4430$  Ma isochron, along an  $\sim 4590$  Ma isochron. These two isochrons would intersect at  $^{87}\text{Rb}/^{86}\text{Sr} \sim 0.035$ , an estimate of  $^{87}\text{Rb}/^{86}\text{Sr}$  in a hypothetical common precursor. This value is higher than  $^{87}\text{Rb}/^{86}\text{Sr}$  for typical eucrites, but is imprecisely defined. For comparison, the intersection of the  $\sim 4.43$  Ga isochron with a reference 4.56 Ga isochron through initial  $^{87}\text{Sr}/^{86}\text{Sr} = 0.698972$ , as measured for LEW86010 [5], occurs for  $^{87}\text{Rb}/^{86}\text{Sr} \sim 0.016$  similar to that of eucrites. These observations suggest the possibility of a 4.56 Ga primary isochron for a few pristine eucrites coupled



**Figure 4.** Rb-Sr data for eucrite plagioclase. Isochron regressions are to data shown as light blue circles plus Y980318 (dark blue diamond) and to data shown as red squares, respectively.

with an  $\sim 4.4$  Ga secondary isochron for the majority, including cumulate eucrites.

**Conclusions:** We suggest (a) all eucrites, including cumulate eucrites, crystallized from parental magmas within a short interval following differentiation of their parent body, and (b) most eucrites participated in an event or events in the time interval  $\sim 4400$ - $4560$  Ma in which many isotopic systems were partially reset. The most susceptible isotopic systems were reset in most eucrites, but the most resistant ones were relatively undisturbed in some.

Some cumulate eucrites may have been excavated from depth during slow cooling, removing them from a heat source tending to keep the isotopic systems open. Some were then buried in hot ejecta deposits, causing additional isotopic equilibration and resetting of the isotopic ages. A few eucrites may have escaped reheating and age resetting. From comparing the isotopic data of Y980318 to that of the mineralogically similar Serra de Magé we conclude that final Nd isotopic closure probably is unrelated to the cooling recorded in pyroxene exsolution textures.

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**References:** [1] Miyamoto M. and Takeda H. (1994) *EPSL*, 122, 343-349. [2] Carlson R. W. and Lugmair G. W. (2000) *Origin of the Earth and Moon*, pp. 25-44. [3] Lugmair G. W. et al. (1991) *Meteoritics* 26, 368. [4] Takeda H. et al. (1983) *Proc. 8th Symp. On Antarctic Met.* pp. 181-205. [5] Nyquist L. E. et al. (1994) *Meteoritics* 29, 872-885. [6] Lugmair G. W. and Galer S. (1992) *GCA* 56, 1673-1694. [7] Bogard D. and Garrison D. H. (2003) *MAPS* 30, 669. [8] Nyquist L. E. et al. (1986) *JGR* 91, 8137-8150.