A Sr AND Nd ISOTOPIC STUDY OF FIVE YAMATO POLYMICT EUCRITES AND A COMPARISON TO OTHER ANTARCTIC AND ORDINARY EUCRITES

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Abstract: Sr and Nd isotopic analysis of five Yamato polymict eucrites indicate that these samples formed at about 4.6 Ga ago with initial Sr and Nd ratios essentially the same as the analyzed non-Antarctic eucrites. The Yamato eucrites have Sr, Sm, and Nd concentrations that consistently lie among the highest found in eucritic samples. This characteristic identifies these Yamato samples as a closely related group. Comparisons between these Yamato samples and other Antarctic polymict eucrites clearly establishes that they all share some characteristic trace element features. Comparisons of Antarctic polymict eucrites with non-Antarctic ordinary eucrites reveal consistent differences. The most obvious is an enrichment of Rb in the polymict eucrites. These comparisons suggest that the Antarctic polymict eucrites belong to a single large family of material that is itself fairly diverse and distinct from the non-Antarctic eucrites.

1. Introduction

Five Yamato polymict eucrites (Y-74159, Y-74450, Y-75011, Y-75015, Y-790266) have been analyzed for Rb, Sr, Sm, and Nd concentrations and Sr and Nd isotopic compositions. This work is part of a cooperative effort by Japanese and American scientists to characterize these unusual objects that dominate the eucritic meteorites found in Antarctica. The Yamato samples will be compared to similar polymict eucrites from the Allan Hills (ALHA) and Elephant Moriane (EETA) areas of Antarctica. The ALHA and EETA samples were analyzed as part of other consortium efforts and that data will be reported elsewhere.

The mineralogy and petrology of the Yamato polymict eucrites have been described in detail in a series of papers by TAKEDA and others and MIYAMOTO and others. References to these papers can be found in TAKEDA and YANAI (1982). These authors have found that unlike most eucritic meteorites found outside of Antarctica, the polymict eucrites are breccias dominated by fragments of rocks and minerals that originated in a variety of mineralogically and compositionally different eucritic samples. A diogenitic component may be present, but its very low abundance (usually less than 10%) distinguishes the polymict eucrites from the other common achondritic breccias, the howardites. One characteristic feature of the polymict eucrites is the presence of mineral and rock fragments with mineral compositions like those found only in cumulate eucrites. As an example of the variability of these breccias, it is not unusual for these cumulate eucrite fragments to be found in the same thin section as fragments of rapidly cooled or even glassy material.

2. Analytical Techniques

All isotopic and concentration determinations were done in the solid-source isotopic analysis laboratory at Johnson Space Center. Analyses were made on 20–50 mg aliquots of homogenized samples. All samples were homogenized by repeatedly grinding in a boron carbide mortar and seiving until the entire sample passed through a 100 mesh screen. The matrix samples represent approximately one gram of material. The clast samples are smaller ranging from 700 to 200 mg in weight. A mixed Sm-Nd spike and HF acid were added to the powdered samples which were then heated in sealed teflon containers for at least one week to promote spike-sample equilibration. A mixed Rb-Sr spike was added later and the mixture heated for a shorter length of time. Rb, Sr, Sm, and Nd fractions were separated by standard ion exchange techniques (NYQUIST *et al.* (1979) has detailed descriptions and additional references). All Sr isotopic ratios are normalized to $^{88}Sr/^{86}Sr=8.3752$. NBS-987 gave an average $^{87}Sr/^{86}Sr$ ratio of 0.71019 ± 2 during these analyses. All Nd isotopic ratios are normalized to $^{148}Nd/^{144}Nd=0.24308$. BCR-1 gave an average $^{143}Nd/^{144}Nd$ ratio of 0.51194 ± 3 during these analyses. Total procedural blanks are about 0.05 ng for Rb, 0.5 ng for Sr, 0.03 ng for Sm, and 0.2 ng for Nd. Uncertainties for the $^{87}Rb/^{86}Sr$ and the $^{147}Sm/^{144}Nd$ ratios are respectively less than 1 and 0.3%.

3. Results

The Rb, Sr, Sm, and Nd concentration and isotopic composition data for the ten samples analyzed are given in Table 1. No Sr or Nd isotopic data are given for Y-75011,84 WR or Y-790266,60, 96–98 WR respectively. Further work will attempt to produce internal isochrons for several of the clast and matrix samples. These internal isochrons will give more information about the times of crystallization and brecciation-recrystallization than the whole-rock analyses by themselves do.

The Rb-Sr data for the Yamato samples are shown on a Rb-Sr isochron diagram (Fig. 1) which includes the Allan Hills and Elephant Moraine samples. The Yamato samples alone do not have enough spread in Rb/Sr ratio to define an isochron. The composite isochron has an age of 4.63 ± 0.19 Ga and an initial Sr ratio of 0.69897 ±3 (^{87}Rb decay constant$=1.39\times10^{-11}$/yr. This decay constant is preferred by the JSC laboratory for self-consistency with previous results. The 1.42 decay constant gives an age of 4.53 Ga). This result is in good agreement with previous studies on

Table 1. Sr and Nd isotopic data for the Yamato polymict eucrites.

Sample	ppm Rb	ppm Sr	$^{87}Rb/^{86}Sr$	$^{87}Sr/^{86}Sr$	ppm Sm	ppm Nd	$^{147}Sm/^{144}Nd$	$^{143}Nd/^{144}Nd$
Y-74159,97 WR Matrix	0.467	78.3	0.0173	0.70010±4	2.39	7.57	0.1907	0.511833±20
Y-74450,63A WR Crystal-rich matrix	0.281	77.3	0.0105	0.69970±2	2.60	8.31	0.1892	0.511720±27
Y-74450,63 D+G WR Matrix	0.337	77.5	0.0126	0.69986±4	2.50	7.88	0.1918	0.511776±28
Y-75011,73 WR Matrix	0.358	84.2	0.0123	0.69973±4	2.74	8.70	0.1906	0.511738±30
Y-75011,84B WR Clast	0.246	81.3	0.0087	—	3.073	9.652	0.1925	0.511792±23
Y-75015,20B' WR Clast-rich matrix	0.297	84.3	0.0102	0.69964±2	3.13	9.90	0.1911	0.511782±22
Y-75015,20 E+F WR Matrix	0.425	83.6	0.0147	0.69995±3	2.65	8.45	0.1898	0.511781±27
Y-790266,94,99 WR Matrix	0.341	80.6	0.0122	0.69988±3	2.550	8.117	0.1900	0.511791±24
Y-790266,60,96-98 WR Clast	0.310	85.6	0.0105	0.69973±3	0.884	2.469	0.2165	—
Y-790266,94,99 WR Fine-grained clast #1	0.497	78.5	0.0183	0.70037±3	2.671	8.582	0.1882	0.511728±27

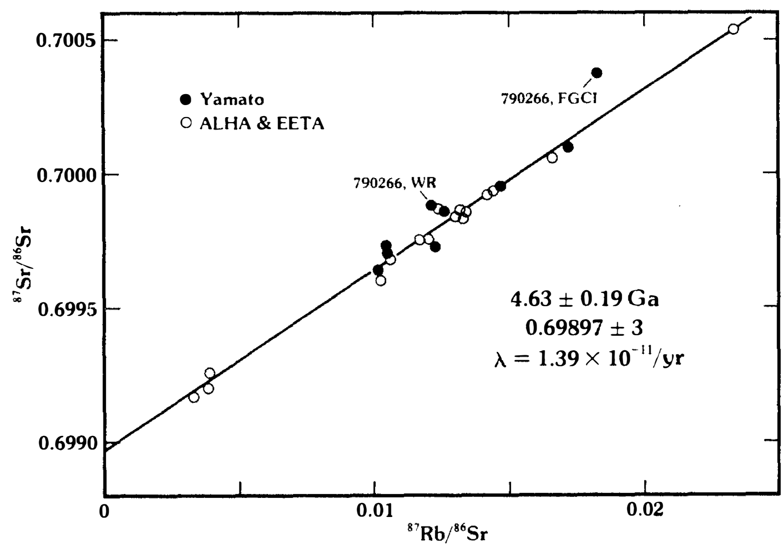

Fig. 1. Rb-Sr isochron diagram for the Antarctic polymict eucrites. The regression does not include the two labeled Y-790266 points. ALHA and EETA samples represent unpublished data from the JSC laboratory.

non-Antarctic eucrites conducted by PAPANASTASSIOU and WASSERBURG (1969) and BIRCK and ALLÈGRE (1978). Two samples from Y-790266, the matrix sample and fine-grained clast #1, do not lie within error of the composite isochron. There is no obvious explanation for these discrepant results as these samples do not show any obvious signs of weathering while in or on the Antarctic ice sheet. The 4.63 Ga age indicates that all eucritic material analyzed so far formed very early in solar system history. The results also indicate that the processes responsible for the brecciation and mixing of the parental basaltic rocks of the polymict eucrites did not greatly disturb the Rb-Sr systematics of these eucrites. However, if the brecciation and mixing occurred very close (100 Ma) to the time of crystallization, then any resetting of the Rb-Sr system would be difficult to distinguish.

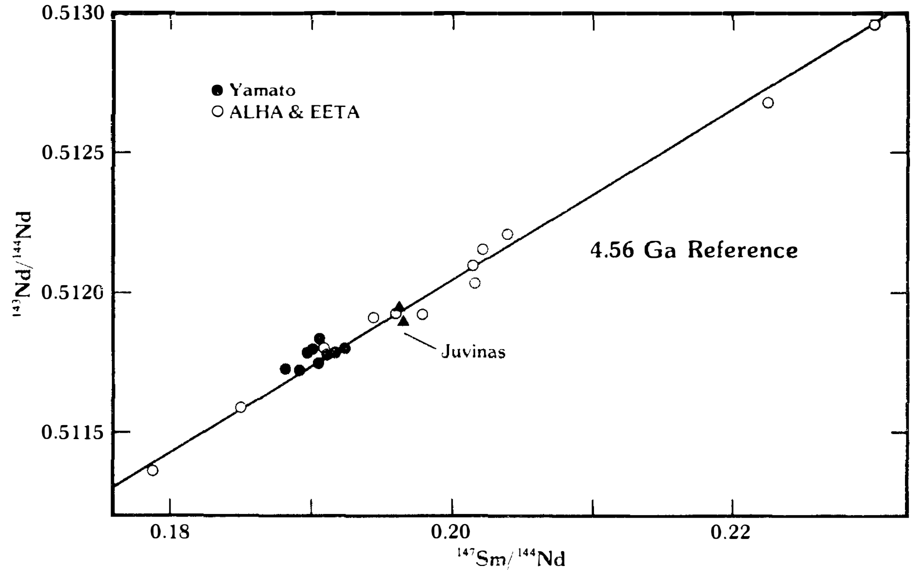

Fig. 2. Sm-Nd isochron diagram for the Antarctic polymict eucrites. All the data, including two Juvinas whole-rock points, lie along a 4.56 Ga reference isochron. All data are from the JSC laboratory.

The Sm-Nd isotopic data for the Yamato samples is shown in Fig. 2 along with the ALHA and EETA data. The very minor spread in Sm/Nd ratio for the Yamato samples is notable and prevents the Nd data from giving any direct age information. However, all the polymict eucrite data lie very close to a 4.56 Ga reference isochron which strongly suggests that all these samples were formed at that time. Therefore, the Sr and Nd data both indicate that the polymict eucrites have a formation age similar to non-Antarctic eucrites. In addition, the Nd data produced in the JSC laboratory for Juvinas lies on the same reference isochron as the polymict eucrite data. This indicates that the initial Nd ratio of all these eucrites is the same within analytical error.

The Rb and Sr concentration data for the Yamato samples are shown in Fig. 3 along with data for other Antarctic polymict eucrites and for non-Antarctic eucrites. Several interesting features of the Rb and Sr data are evident on this diagram. The Sr concentrations of the Yamato samples are among the highest observed. Only Ibitira and Stannern have higher Sr contents. Matrix samples for all the Antarctic polymict eucrites have consistently higher Rb contents than the ordinary non-Antarctic eucrites (Jonzac and Stannern are exceptions). The Rb and Sr data for the vast majority of the polymict matrix samples and the ordinary eucrites form good, but separate, linear arrays. The Rb concentrations of the clast samples are more variable than those

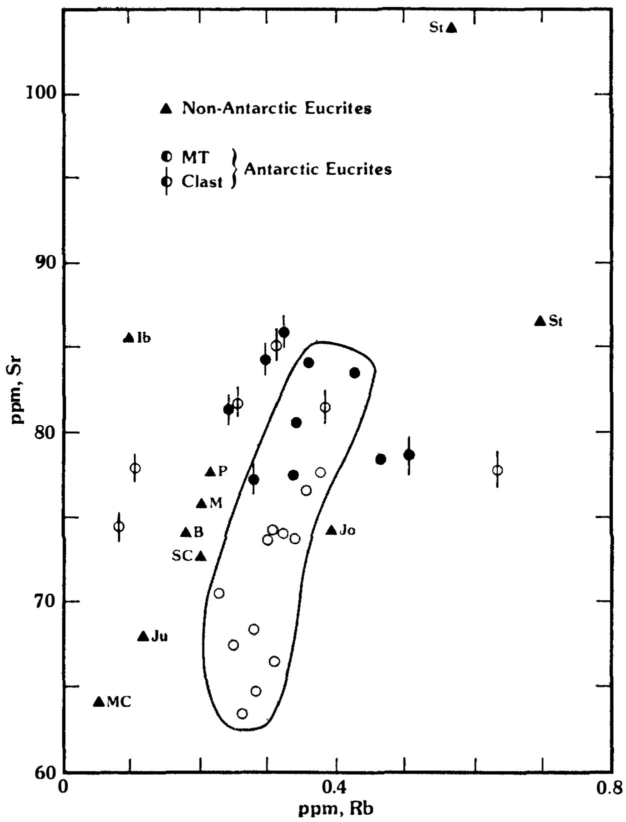

Fig. 3. Ppm Rb vs. ppm Sr for Antarctic and non-Antarctic eucrites. All Antarctic data are isotope dilution results from the JSC laboratory. Data for Stannern (St), Ibitira (Ib), Pasamonte (P), Macibini (M), Bereba (B), Jonzac (Jo), Sioux County (SC), Juvinas (Ju), and Moore County (MC) are averages of isotope dilution data from BIRCK and ALLÈGRE (1978), PAPANASTASSIOU and WASSERBURG (1969), and the JSC laboratory. Yamato samples are filled circles both with and without a slash.

of the matrix samples, and five of the clasts lie along the Rb-Sr array defined by the ordinary eucrites.

Some of the features of the Rb and Sr data are more easily explained than others. The clasts that have been analyzed are quite variable in weight and grain size. The smaller and coarser grained clasts are probably not representative of the bulk composition of a rock, but may be biased toward a mineral composition which would produce lower Rb contents or a mesotasis component which would increase the Rb content. The linear nature of the Rb and Sr data for each of the two groups (ordinary *vs.* polymict) is most likely the result of fractionation and crystal accumulation processes. The matrix samples are mixtures and as such tend to homogenize out end member compositions; therefore, the regolith sampled by the polymict eucrites must be enriched in Rb compared to most oridnary eucrites. The cause of this enrichment is problematic. The Rb enrichment must be a very ancient feature of these samples because Rb addition or Sr loss at any time well after 4.6 Ga would have greatly disturbed the Rb-Sr age of all these samples. One way of producing the apparent Rb enrichment in the Antarctic samples is the addition of a chondritic meteoritic component during the brecciation event that produced the polymict character of these samples. Chondrites have Rb contents about 10 times higher and Sr contents 6–8 times lower then the eucrites. However, about 5% chondritic contamination is needed to shift the polymict trend over from the ordinary eucrite trend. Five percent chondritic contamination would add approximately 500 ppm Ni to the polymict eucrites. The polymict eucrites generally have much less than 100 ppm Ni (SMITH and SCHMITT, 1981), so that even 1 or 2% chondritic contamination doesn't seem reasonable. The source of the Rb enrichment therefore seems indigenous to the parent body of the polymict eucrites. The most straightforward explanation is that the mantle source region for the basaltic magmas parental to these polymict breccias was enriched in Rb relative to the source for ordinary eucrites. Another possibility that must be considered is that the polymict breccias sampled a surface that contained a high percentage of basalts produced by a smaller percent of melting than that associated with the non-Antarctic eucrites. Fractional crystallization and crystal accumulation of these magmas with higher Rb and Sr concentrations would produce a separate but parallel trend to that of the non-Antarctic eucrites.

The Sm and Nd concentration data for the polymict eucrites also have some interesting features. The concentration range of the matrix samples is large—4 to 19 times chondritic values. Except for one clast sample, the Yamato samples lie entirely at

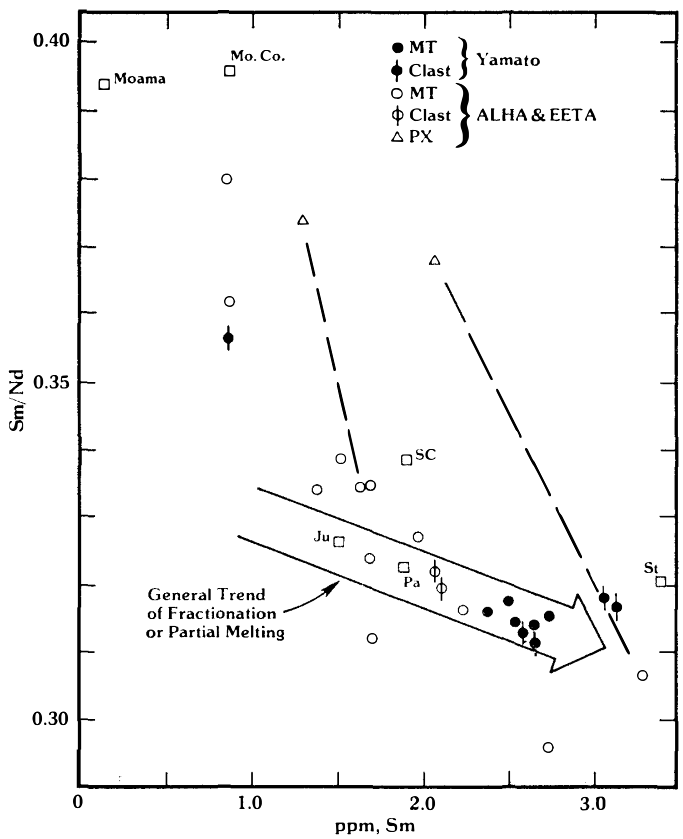

Fig. 4. Ppm Sm vs. the Sm/Nd ratio. All data are from the JSC laboratory except Moama (HAMET et al., 1978).

the top of this range (Fig. 4). High concentrations like these have been observed in non-Antarctic eucrites like Nuevo Laredo and Stannern whose compositions have been attributed to extreme fractional crystallization or a very small degree of partial melting respectively (CONSOLMAGNO and DRAKE, 1977; STOLPER, 1977). The Sm/Nd ratio of the Yamato samples is very restricted and slightly fractionated toward a Sm/Nd ratio lower than chondritic. The Yamato data contrasts strongly with the other Antarctic data which has a wide range of Sm/Nd ratios (Fig. 4). Trace element modeling of all the Antarctic eucrite data indicates that variable amounts of partial melting or fractional crystallization produce a shallow and restricted trend between Sm and the Sm/Nd ratio (see Fig. 4). Note that the Yamato samples do lie on this trend and in a position indicating extreme fractionation or small degrees of partial melting. Several of the Allan Hills and Elephant Moraine matrix samples lie above this trend at Sm/Nd ratios higher than those predicted by the trace element modeling. The steep trend shown by the Allan Hills and Elephant Moraine samples cannot result from partial melting or fractional crystallization. It is informative that the cumulate eucrites Moama and Moore County as well as two pyroxene separates from the polymict eucrites lie along the steep trend. The Allan Hills and Elephant Moraine Sm and Nd data, therefore, may result from mixing true melt compositions with pyroxenes or cumulate eucrite components. An examination of the Rb and Sr data for the Allan Hills and Elephant Moraine matrix samples suggests that those samples having the lowest Rb and Sr contents could also result from adding pyroxene to a melt composition. This model is consistent with the numerous petrologic-petrographic studies which have identified cumulate eucrite components in the polymict eucrites. Note that this model doesn't require diogenitic components but only a pyroxene component like those found in eucrites. Caution must be used in identifying a parental magma composition for the polymict eucrites. The most mafic samples probably result from the addition of a cumulate eucrite and/or a pyroxene component to less mafic liquid compositions. This problem doesn't seem as important for the Yamato samples which lie on a true magma trend.

4. Conclusions

Based on Sr and Nd isotopic characteristics and Rb, Sr, Sm, and Nd contents, the Yamato polymict eucrites resemble the other Antarctic polymict eucrites and non-Antarctic ordinary eucrites in some respects while differing from them in others. All these eucrites were apparently formed about 4.5 Ga ago. Most of the Antarctic polymict eucrites have an initial Sr ratio of about 0.69898, as do the non-Antarctic ordinary eucrites, but at least one Yamato sample (Y-790266) has a significantly higher ratio and at least one Allan Hills sample (ALHA76005) a significantly lower ratio. No significant differences have been found in the initial Nd ratio for any eucrites. All matrix samples of the Antarctic polymict eucrites show an enrichment in Rb with respect to Sr compared to the non-Antarctic ordinary eucrites. This enrichment must be a very early feature because these samples have 4.6 Ga Rb-Sr model ages. The enrichment is most easily explained as a difference in the source regions of ordinary and polymict eucrites. The Yamato eucrites have consistently high Sr, Sm, and Nd concentrations and a very limited Sm/Nd ratio. These features are consistent with these samples representing either fractionated magmas or magmas produced by a small percent of melting. The Yamato samples are not like several of the Allan Hills and Elephant Moraine samples which require a major cumulate eucrite or additional pyroxene component to explain their Sm and Nd variations. The data presented here clearly show that these five Yamato polymict eucrites are a closely related group.

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