REE CHARACTERISTICS OF ANTARCTIC EUCRITES

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***Abstract*:** Rare-earth elements (REE), Ba, Sr and Rb abundances were precisely determined for three Antarctic eucrites (ALH-78132, Y-790260 and Y-790266), Y-7308 howardite, Y-790143 LL chondrite, Pasamonte eucrite, and plagioclase and clinopyroxene fractions of the Y-790266 eucrite. A positive Ce anomaly and Yb-Lu deviation from smoothness characterize REE patterns of Antarctic eucrites. These REE features are commonly observed for Antarctic eucrites which have been analyzed thus far by us and our colleagues, employing mass-spectrometric isotope dilution method. The degrees of Ce and Yb-Lu deviations are small or substantially absent for almost all of non-Antarctic eucrites and Antarctic meteorites other than eucrites. Some discussions are given to the possible implications of the Ce anomaly and Yb-Lu deviation observed in Antarctic eucrites.

1. Introduction

About one hundred and fifty achondrites have been collected from Antarctica up to January 1980 (YANAI, 1981). Many researches on these Antarctic achondrites have been carried out and these studies have contributed to further the understanding of the genesis of achondrites. MASUDA *et al.* (1979, 1981) made a geochimical study on rare-earth elements (REE) in Antarctic diogenites and discussed REE features in them. Further, MASUDA *et al.* (1981) have suggested that intense melting took place for a parent body of the Yamato diogenites. Additional REE data on Antarctic eucrites were reported by NAKAMURA and MASUDA (1980) for Allan Hills-765, by GROSSMAN *et al.* (1981) for the same meteorite ALHA76005, by FUKUOKA and NAKAMURA (1981) for Allan Hills-77302 and by SHIMIZU and MASUDA (1981) for Yamato-74450. NAKAMURA and MASUDA (1980) and SHIMIZU and MASUDA (1981) pointed out a positive Ce anomaly for whole rock samples of ALH-765 and Y-74450. However, GROSSMAN *et al.* (1981) did not recognize this Ce deviation in ALHA76005. In this paper, we will report precisely determined abundances of REE, Ba, Sr and Rb for three Antarctic eucrites and two mineral separates from the Antarctic eucrite and will reveal REE features (including the Ce irregularity mentioned above) of Antarctic eucrites. Additionally, REE, Ba, Sr and Rb abundances will be reported for the Pasamonte eucrite, a Yamato howardite and a Yamato LL chondrite; these data will be useful for characterizing REE features of Antarctic eucrites.

2. Samples and Analytical Procedures

Antarctic eucrites analyzed in this study are Allan Hills-78132,71, Yamato-790260,74 and Yamato-790266,95. Plagioclase and clinopyroxene fractions from Y-790266,95 were separated by bromoform (d=2.85) and methylene iodide (d=3.33). According to MASON (1981) and NATL INST. POLAR RES. (1982), ALH-78132, Y-790260 and Y-790266 are polymict eucrites. About half of the Y-790266 eucrite consists of medium grained crystalline eucrite clasts, one of which has been donated to us. REE, Ba, Sr and Rb abundances are also determined for the Pasamonte eucrite, Yamato-7308 howardite and Yamato-790143,94 LL chondrite. TAKEDA (1979) suggested that Pasamonte represents a surface eucrite layer. Y-7308 howardite is rich in diogenitic component but eucritic clasts are also present in this meteorite (MIYAMOTO *et al.,* 1978). Y-790143 is described as an impact-melted, fine crystalline LL chondrite (SATO *et al.,* 1982).

REE, Ba, Sr and Rb abundances were determined by the mass-spectrometric stable isotope dilution method. The precisions of analyses are believed to be below 1% in most cases.

3. Results and Discussion

Results of REE, Ba, Sr and Rb abundances obtained in this study are shown in Table 1 and Figs. 1, 2, 3 and 4, where the results for the following eucrites are also presented: ALH-765 and Juvinas (NAKAMURA and MASUDA, 1980), Y-74450 (SHIMIZU and MASUDA, 1981) and ALH-77302 (FUKUOKA and NAKAMURA, 1981).

The REE pattern of Y-790143 LL chondrite shows a small fractionation in light REE, might be brought about as a result of impact melt process.

A positive Ce anomaly and the apparent deviation of Yb and Lu from smoothness are observed for all patterns of Antarctic eucrites, whether from Yamato or Allan Hills. The degree of Ce deviation is presented numerically in Table 2. In this table the value of the factor indicating Ce deviation is the ratio between the observed Ce value and the calculated Ce value from Nd and Sm in the chondrite-normalized pattern. The Ce deviation factors for Antarctic eucrites are 1.06–2.14, whereas the corresponding values are 0.98–1.05 for other meteorites in Table 2, *i.e.,* Pasamonte and Juvinas eucrites, Y-7308 howardite, Y-790143 (LL), Y-74362 (L6), ALH-769 (L6), Barwise (H5), Kirin (H5) and Peace River (L6) chondrites. Of the Antarctic eucrites studied by us, Y-790266 has the highest factor indicative of positive Ce deviation. The clinopyroxene fraction of the Y-790266 meteorite has a higher Ce deviation factor than the whole rock sample of the same meteorite, whereas the Ce deviation factor of the plagioclase fraction of this meteorite is smaller than that of the whole rock. Until now, REE abundances have been determined by us and our colleagues for 27 Antarctic meteorites by the mass-spectrometric isotope dilution method (MASUDA *et al.,* 1977, 1979; MASUDA and TANAKA, 1978; SHIMIZU *et al.,* 1979; NAKAMURA and MASUDA, 1980; SHIMIZU and MASUDA,1981; FUKUOKA and NAKAMURA, 1981; this study). They include 8 chondrites, 7 diogenites, 6 eucrites, one howardite, two ureilites, one aubrite, one mesosiderite and one unique achondrite. Among them, a recog-

Table 1. REE, Ba, Sr and Rb abundances (ppm).

	ALH-78132	Y-790260	Y-790266	Y-790266	Y-790266	Y-74450[1]	ALH-765[2]	ALH-77302[3]	Pasamonte	Y-7308	Y-790143	normalizing value[4]
	eucrite	eucrite	eucrite	$d<2.85$	$d>3.33$	eucrite	eucrite	eucrite	eucrite	howardite	LL chondrite	
La	1.225	2.48	1.667	1.24	1.256	3.59	2.21	2.00	2.80	0.563	0.409	0.378
Ce	6.23	7.03	10.11	4.45	9.25	11.25	9.39	5.87	7.57	1.487	1.016	0.976
Nd	2.65	4.27	3.74	2.32	3.14	7.43	4.97	4.21	5.72	1.118	0.696	0.716
Sm	0.978	1.418	1.297	0.705	1.196	2.40	1.65	1.40	1.844	0.362	0.208	0.230
Eu	0.543	0.587	0.715	1.773	0.1260	0.708	0.671	0.532	0.617	0.1412	0.0834	0.0866
Gd	1.446	1.963	1.762	0.883	1.789	3.26	2.20	1.89	2.54	0.515	0.277	0.311
Dy	2.02	2.49	2.28	1.029	2.55	3.82	2.63	2.41	3.06	0.632	0.343	0.390
Er	1.365	1.598	1.485	0.612	1.754	2.37	1.73	1.50	1.929	0.413	0.219	0.255
Yb	1.509	1.667	1.636	0.546	2.09	2.30	1.80	1.56	1.877	0.424	0.229	0.249
Lu	0.236	0.251	0.249	0.0784	0.316	0.341	0.271	0.238	0.287	0.0672	0.0354	0.0387
Ba	36.6	40.8	52.9	143.3	9.42	44.6	—	37.0	—	6.21	5.28	4.21
Sr	68.2	70.4	79.3	215	12.71	78.5	—	78.0	—	18.39	10.03	11.1
Rb	0.408	0.314	0.350	0.852	0.284	0.362	—	0.704	—	0.463	3.93	—
amount taken (mg)	259.9	120.4	39.22	1.04	4.92	52.35	468	6.3	155.7	246.7	107.6	—

1) Shimizu and Masuda, 1981. 2) Nakamura and Masuda, 1980. 3) Fukuoka and Nakamura, 1981. 4) The normalizing values for REE and Ba are from abundances of these elements in Leedey chondrite (Masuda *et al.*, 1973; Nakamura and Masuda, 1973b). The normalizing value, 11.1 ppm, for Sr is from Gopalan and Wetherill, 1971.

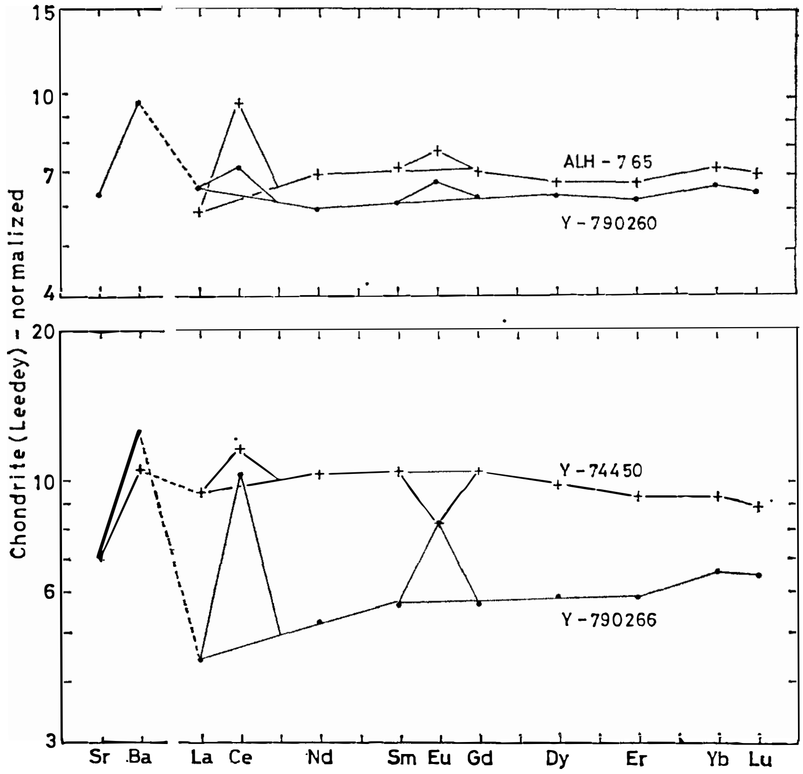

Fig. 1. *Chondrite-normalized REE-Ba-Sr patterns of Antarctic eucrites. Data for ALH-765 and Y-74450 are from* NAKAMURA *and* MASUDA *(1980) and* SHIMIZU *and* MASUDA *(1981), respectively.*

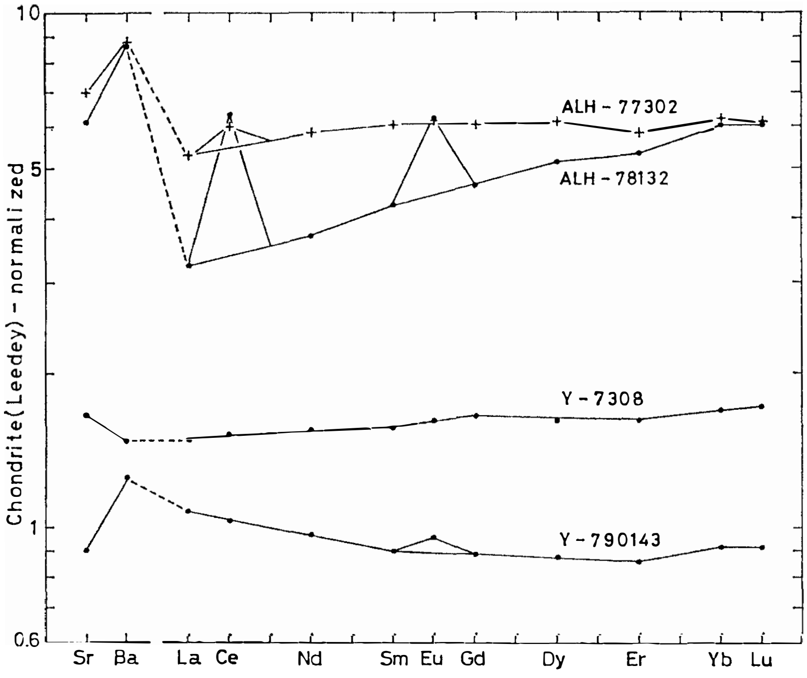

Fig. 2. *Chondrite-normalized REE-Ba-Sr patterns of Antarctic eucrites (ALH-77302 and ALH-78132), howardite (Y-7308) and LL chondrite (Y-790143). Data for ALH-77302 are from* FUKUOKA *and* NAKAMURA *(1981).*

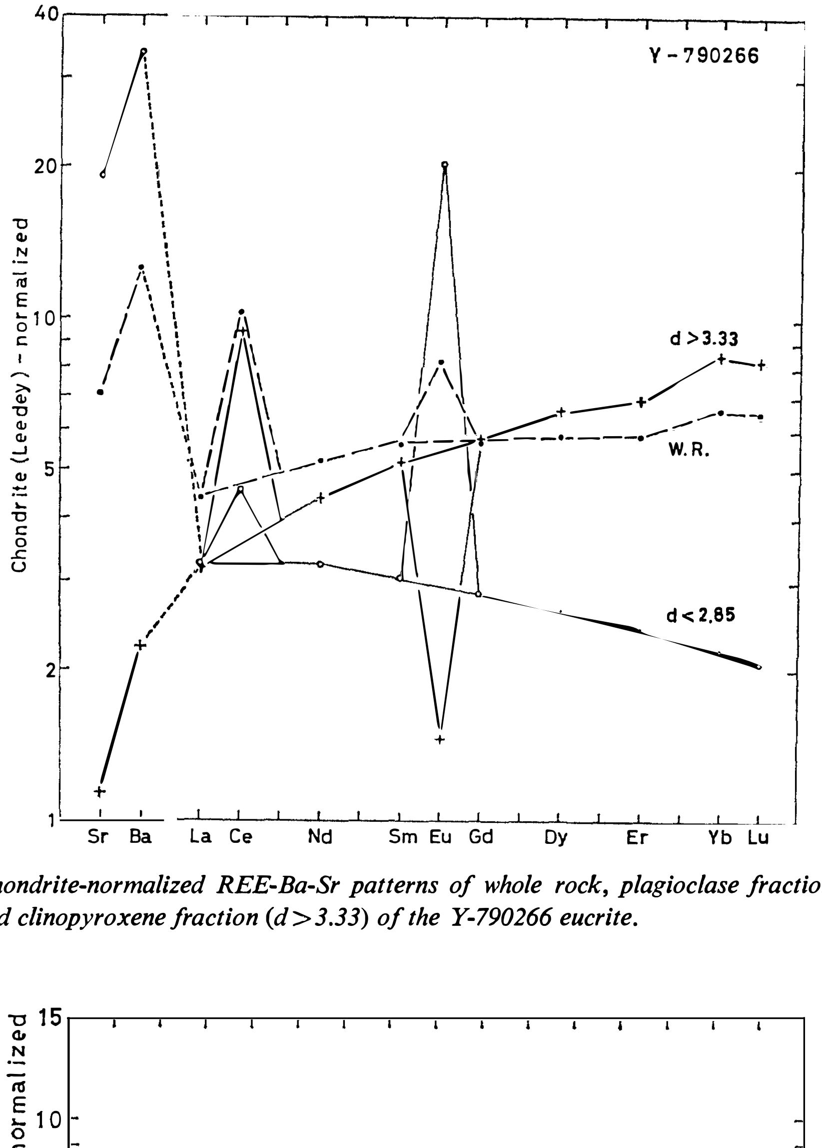

Fig. 3. Chondrite-normalized REE-Ba-Sr patterns of whole rock, plagioclase fraction (d<2.85) and clinopyroxene fraction (d>3.33) of the Y-790266 eucrite.

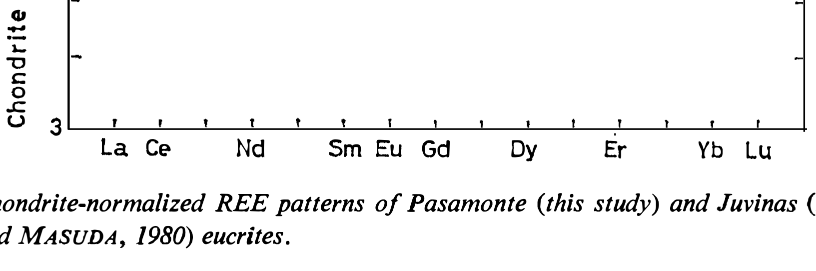

Fig. 4. Chondrite-normalized REE patterns of Pasamonte (this study) and Juvinas (NAKAMURA and MASUDA, 1980) eucrites.

nizable Ce anomaly or irregularity has been observed for two diogenites, one unique achondrite and all six of eucrites studied. On the other hand, according to the investigations published thus far and presented here, Ce anomaly is not observed for

Table 2. Ce and Yb deviation factors (see text).

		Ce deviation	Yb deviation
ALH-78132	eucrite	1.982	1.038
Y-790260	eucrite	1.249	1.043
Y-790266	eucrite	2.137	1.056
Y-790266	$d<2.85$	1.335	1.023
Y-790266	$d>3.33$	2.562	1.089
Y-74450[1]	eucrite	1.119	1.032
ALH-765[2]	eucrite	1.433	1.043
ALH-77302[3]	eucrite	1.062	1.035
Pasamonte	eucrite	0.976	1.010
Juvinas[2]	eucrite	1.007	0.987
Y-7308	howardite	0.985	1.004
Y-790143	LL	0.997	1.025
Y-74362[4]	L6	0.993	0.985
ALH-769[4]	L6	0.997	1.018
Barwise[5]	H5	0.988	1.012
Kirin[6]	H5	1.033	1.018
Peace River[6]	L6	1.053	1.019

1) SHIMIZU and MASUDA, 1981. 2) NAKAMURA and MASUDA, 1980. 3) FUKUOKA and NAKAMURA, 1981. 4) SHIMIZU *et al.*, 1979. 5) TAKAHASHI (unpublished data). 6) YONEDA (unpublished data).

non-Antarctic eucrites (*e.g.*, SCHNETZLER and PHILPOTTS, 1969; GAST and HUBBARD, 1970).

Yb and Lu deviations from smoothness defined by other REE for Antarctic eucrites are not remarkable but clearly recognizable. This effect is observed as a sort of step-up discontinuity between Er and Yb. The degree of Yb deviation is also presented in Table 2. The value of the Yb deviation factor in this table is the ratio between the observed Yb value and the Yb value calculated by drawing a straight line between Er and Lu in the chondrite-normalized pattern. Yb deviation factors for six Antarctic eucrites are 1.03–1.05, while the values are 0.98–1.02 for the other nine meteorites in Table 2; these include Antarctic chondrites and a howardite, and non-Antarctic chondrites and eucrites. The Y-790266 meteorite has the highest Yb deviation factor (1.056). Moreover, the corresponding value for the clinopyroxene fraction of this eucrite is larger than that of the whole rock and the corresponding value of plagioclase fraction is smaller than that of the whole rock of Y-790266. These results for the Yb deviation of Y-790266 whole rock, clinopyroxene fraction and plagioclase fraction appear to be parallel with those for the Ce deviation of the same eucrite. Thus, the Ce deviation and Yb deviation seem to be related. It is probable that the same processes have caused the Ce anomaly and Yb and Lu deviations of the Antarctic eucrites. As seen in Figs. 1 and 2, chondrite-normalized values of Ba are larger than those of Sr for Antarctic eucrites. The Juvinas eucrite has similar normalized values for these two elements (TAKAHASHI, unpublished).

Several researchers have discussed the problem of the Ce deviation in meteorites. BOYNTON (1978) noted that the Ce anomaly observed for Allende inclusions could be caused in the outer zones of supernova with oxiding gas composition. NAKAMURA and MASUDA (1973a) showed a negative Ce anomaly (6–20%) for three fragments with relatively high La abundances from the Barwise chondrite (H5). They suggested that the observed REE fractionations for Barwise were due to pre-terrestrial processes rather than terrestrial contamination. MASUDA and TANAKA (1980) reported a negative Ce anomaly (51%) for the Melrose-b howardite and stated that a specific Ce fractionation took place in less reducing parts or stages which occurred heterogeneously in the solar nebula. Generally, the following two possibilities will be considered to cause the Ce anomaly observed for the Antarctic eucrites: a pre-terrestrial fractionation and a terrestrial process. PATCHETT and TATSUMOTO (1980) carried out a Lu-Hf systematic study for the eucrites and showed that ALHA77302 eucrite deviated from the isochron for other non-Antarctic eucrites, that is, Stannern, Nuevo Laredo, Bereda, Pasamonte, Sioux County, Juvinas, Serra de Mage, Moore County and Moama. They suggested that ALHA77302 lost Lu in the recent past, perhaps while embedded for a long period in the Antarctic ice. According to a study of REE distribution in natural samples connected directly or indirectly to water, the behaviors of Yb and Lu appear to be irregular in some cases (MASUDA and IKEUCHI, unpublished). Moreover, a Ce anomaly is commonly observed for samples from the marine environment. Thus, chemical processes in the marine environment or hydrosphere may sometimes bring about a Ce anomaly and Yb and Lu irregularity. These considerations may lead us to an interpretation in terms of a terrestrial effect, that is, the reaction with the Antarctic ice. In this case, there can be two possibilities. As one possibility, it may be considered that Ce and Yb plus Lu have been added to the eucrites in question during their burial in ice. Alternatively, it is also conceivable that Ce, Yb and Lu were less leachable than other REE. However, if the Ce anomaly and Yb-Lu irregularity for Antarctic eucrites are due to a terrestrial effect, similar REE features should be observed for other Antarctic meteorites. However, such REE features are not observed for any Antarctic meteorite but eucrites. These results argue against the interpretation as a terrestrial effect and rather favor a pre-terrestrial fractionation. If the observed facts are to be explained as a terrestrial effect, they might imply either that the burial in Antarctic ice was longer for eucrites than for other meteorites, or that the REE other than Ce, Yb and Lu are more leachable for eucrites than for other meteorites. (If so, it is likely that Hf is less subject to loss than Lu is.) If fractionation occurred preterrestrially, it is considered that Antarctic eucrites were pieces of a single fall. Another possible explanation is that Antarctic eucrites happened to come from the same parts of the same parent body. But, for such interpretations favoring the pre-terrestrial effect, a question remains about how the variations in Ce anomaly and Yb-Lu irregularity are caused.

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