REE, Rb, Sr and Ba Abundances in Yamato (j), (k) and (m) Meteorites

Akimasa MASUDA*, Tsuyoshi TANAKA**, Junko ASAKURA* and Hiroshi SHIMIZU*

やまと (j), (k) および (m) 隕石の中の REE, Rb, Sr, Ba

増田彰正*・田中　剛**・朝倉純子*・清水　洋*

要旨： やまと隕石 (j), (k) および (m) の中の希土類元素 (REE), Ba, Rb, Sr を安定同位体希釈法によって定量した. (j) については, 任意に二つの部分をとって分析した (提供された試料は, やや粗い粉末試料だった).

最も代表的な希土類元素相互存在度を示すと考えられる Leedey コンドライトの値で規格化すると, (k) は最も小さい分化を示すが, Eu によく見られる異常は別として, Gd と Dy との間に不連続性が見られるのが特徴である. (m) と (k) は, 成因的な関連が深いと判断された. (j) の二回の定量値の間には, 興味深い, 系統的な差がある.

(m) と (k) との関連, および (j) の内部的分化は, 共に, もとの母体小惑星内での溶融と結晶分化の効果を強く示唆すると解釈できる.

Abstract: Yamato (j), (k) and (m) meteorites were analyzed for rare-earth elements (REE), Rb, Sr and Ba. The Leedey-normalized REE pattern of (k) shows a small discontinuity between Gd and Dy. However, the REE pattern of (m) normalized by (k) exhibits a smooth fractionation with no Gd-Dy gap, except for Eu which is to be dealt with separately on account of its possible divalent state. The smooth fractionation between (m) and (k) suggests a genetically close association in origin.

Yamato (j) was investigated for two fractions, j_1 and j_2. The REE abundances in the former are not so smooth as that of the Leedey chondrite, and are lower than in j_2. Meanwhile, the internal abundance ratio pattern of j_2 against j_1 shows a quite smooth one, which can be explained in terms of the melting and subsequent solidification process, the mixing of the products mainly representing the residual melts, and the generally common partitioning function pertaining to the process.

* 神戸大学理学部地球科学教室. Department of Earth Sciences, Faculty of Science, Kobe University, Rokkodai, Nada-ku, Kobe 657.

** 地質調査所地球化学課. Geological Survey of Japan, Hisamoto, Takatsu-ku, Kawasaki 213.

In December 1969, the field party of the Japanese Antarctic Research Expedition found by chance nine pieces of meteorite at the southeastern foot of the Yamato Mountains. Of them, four larger pieces heavier than 60 g in weight were designated Yamato (a), (b), (c) and (d); other smaller ones are (e), (f), (g), (h) and (i) (YOSHIDA *et al.*, 1971; NAGATA, 1975; KUSUNOKI, 1975). The field party dispatched in 1973 succeeded in collecting twelve new pieces of meteorite-like rock in the same area (NARUSE, 1975; SIRAISHI *et al.*, 1976). Moreover, the 1974 field party has collected more than 600 pieces of meteorite-like rocks in the same locality (YANAI, 1976).

The stone meteorites Yamato (j), (k) and (m) studied here are the ones collected in 1973 (SHIRAISHI *et al.*, 1976). For the specimens (j), (k), (l) and (m), some studies have been reported about mineralogical (YAGI *et al.*, 1975), chemical (SHIMA, 1975) and magnetic (NAGATA *et al.*, 1975) properties.

This report presents the data on REE, Rb, Sr and Ba abundances in Yamato (j), (k) and (m).

1. Experimental

Rather coarsely pulverized sample of each specimen was decomposed with $HClO_4$-HF. The trace elements were separated through the cation exchange resin, and were determined by stable isotope dilution (MASUDA, 1968, for REE). The enriched nuclides employed as spikes are Sr^{84}, Rb^{87}, Ba^{136}, La^{138}, Ce^{142}, Nd^{145}, Sm^{149}, Eu^{151}, Gd^{157}, Dy^{163}, Er^{167}, Yb^{171} and Lu^{176}. For the specimen (j) only, two series of determination have been carried out for the samples independently and arbitrarily taken.

2. Results and Discussion

Contents of elements determined are presented in Table 1. Figs. 1(a)–(d) show the chondrite-normalized patterns. For REE, the abundances in the Leedey chondrite (MASUDA *et al.*, 1973) have been employed. Also for Ba, the value (4.21 ppm) in the same chondrite (NAKAMURA and MASUDA, 1973) has been employed. For Rb and Sr, the values 2.80 ppm and 11.1 ppm were adopted, respectively, based on the data compiled by MASON (1971). It should be noted that the plotting is done on an expanded logarithmic scale.

2.1. Yamato (k)

Fig. 1(c) shows that, of three chondrite specimens investigated, REE abundances in this meteorite are least fractionated relative to the Leedey chondrite. However, one can recognize the small but clear discontinuity between Gd and

Dy. INENAGA (1975) has found that a discontinuity in partitioning occurs sometimes between Gd and Dy in his studies employing a synthetic $MgCaSi_2O_6$ matrix under one atmosphere. JIBIKI and MASUDA (1974) also pointed out a discontinuity between Gd and Dy in their paper on basaltic rocks from the Puerto Rico Trench. Thus, the Gd-Dy discontinuity cannot be always considered as an unusual case

Table 1. Abundances (ppm) of REE, Rb, Sr and Ba in Yamato meteorites.

	(j_1)	(j_2)	(k)	(m)
La	0.403	0.530	0.3625	0.401
Ce	0.963	1.245	0.942	1.024
Nd	0.611	0.745	0.695	0.730
Sm	0.1848	0.211	0.2259	0.2280
Eu	0.0623	0.0666	0.0743	0.0831
Gd	0.255	0.266	0.310	0.310
Dy	0.308	0.316	0.374	0.369
Er	0.1984	0.2019	0.2433	0.2374
Yb	0.190		0.238	0.231
Lu	0.0316	0.0314	0.0371	0.0355
Ba		16.1	3.67	4.80
Sr			8.87	10.45
Rb			2.40	2.28
Amount taken (mg)	281.5	547.1	686.2	670.6

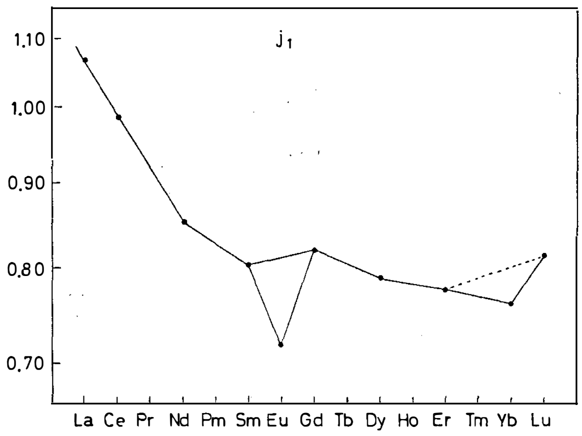

Fig. 1(a). Leedey-normalized REE pattern for j_1.

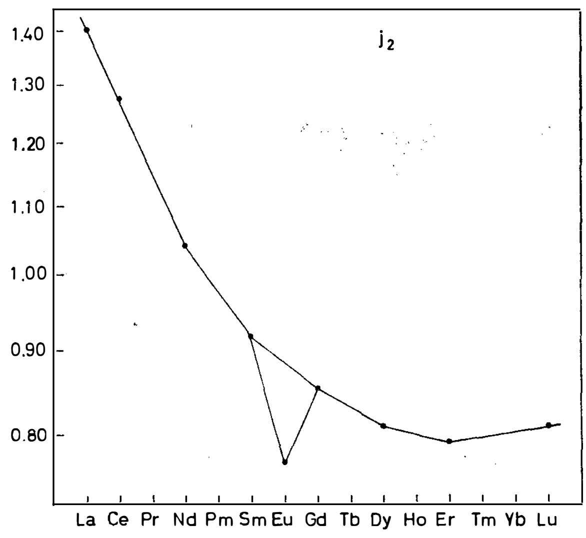

Fig. 1(b). Leedey-normalized REE pattern for j_2.

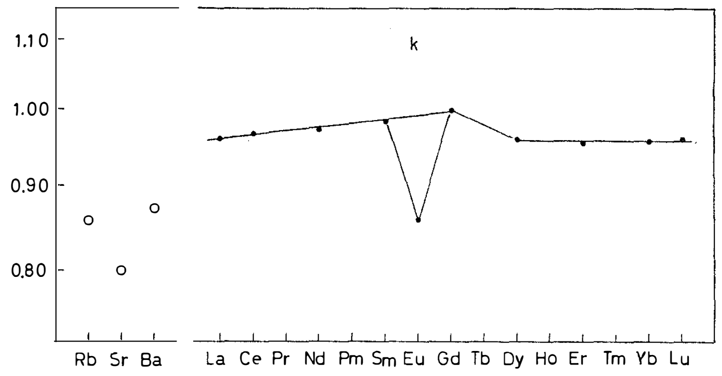

Fig. 1(c). Leedey-normalized REE pattern (solid circles) and the abundance ratios (open circles) relative to standard values (cf. text), for k.

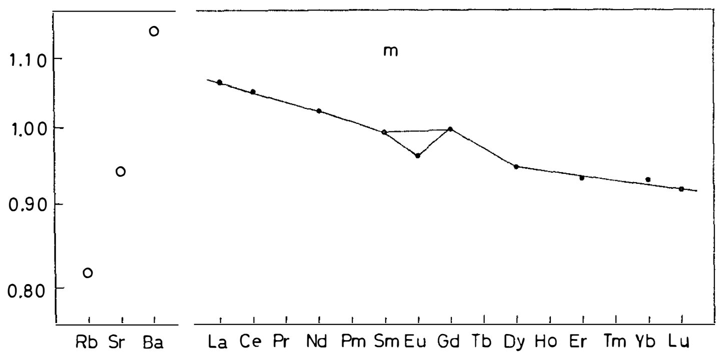

Fig. 1(d). Leedey-normalized REE pattern (solid circles) and the abundance ratios (open circles) relative to standard values (cf. text), for m.

in the behaviors of REE in solidification of silicate matrix melt, although the cause of this effect is not understood well.

2.2. Yamato (m)

Apart from Eu which exhibits anomaly due to divalent state, a small anomaly of Gd may draw our attention (see Fig. 1(d)). The only chondrite that shows a comparatively much larger Gd anomaly is the Khohar chondrite (NAKAMURA and MASUDA, 1973). In the case of Khohar, we cannot rule out the possibility that the Gd anomaly is associated with the anomaly in ionization energies for neutral and singly ionized state (cf. the data presented by SUGER and READER, 1973). For Gd anomaly of Yamato (m), however, we need not invoke the possible effect of ionization energies. Fig. 2 shows the REE pattern of (m) normalized against (k). It would be noticed that the small Gd anomaly in question disappears in this diagram. It follows that the apparent small anomaly of Gd of (m) is accounted for by the assumption that the original source material had the same Gd-Dy dis-

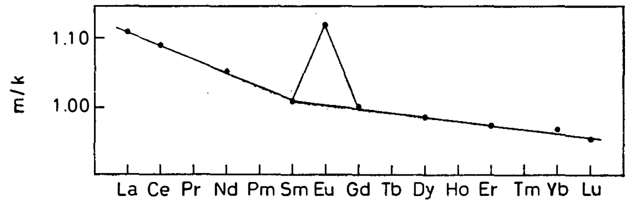

Fig. 2. The REE pattern of m normalized by k.

continuity as (k) and that the REE partitioning function responsible for the development of (m) had a sharp break at Sm. Namely, this reasoning posits that some extent of melting and solidification took place on the parental planetesimal and that Yamato (k) and (m) meteorites are probably closely associated in origin.

2.3. Yamato (j)

As mentioned in "Experimental", two fractions (j_1 and j_2) arbitrarily taken were examined. As seen in Figs. 1(a) and 1(b), the REE abundances in j_1 are lower than in j_2. Anyway, it is noticeable that the extent of REE fractionation relative to Leedey is comparatively large for ordinary chondrite. Also the not-very-smooth feature for j_1 (Fig. 1(a)) can be a characteristic of this meteorite.

Fig. 3 shows the abundance ratios between j_1 and j_2. The resultant highly smooth pattern can be of much significance. In particular, emphasis could be placed on that the zigzag features in Fig. 1(a) appear obliterated for the internally normalized REE pattern (Fig. 3) and that the bulk partition coefficient function

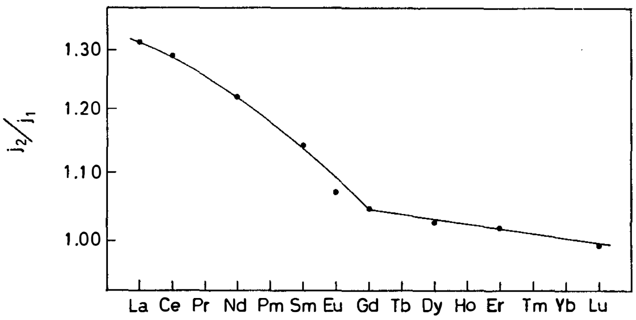

Fig. 3. The REE pattern of j_2 internally normalized by j_1.

accountable for this pattern is one of the commonest ones (MASUDA and JIBIKI, 1973). This strongly suggests that the higher contents in j_2 are not caused by the terrestrial contamination. In this connection, it would be worth mentioning that the Yamato meteorites were found (KUSUNOKI, 1975) on the surface of ice sheet free from snow (bare ice).

It turns out that the aforementioned observations suggest again the melting of the parental material followed by fractional crystallization or some extent of partial melting.

The Barwise chondrite studied by NAKAMURA and MASUDA (1973) displayed also the internal REE fractionation. However, since Barwise was a find from soil, there remained some suspicion of terrestrial contamination in spite of several facts strongly endorsing the pre-terrestrial fractional crystallization effect. Yamato (j) deserves further scrutiny, because the terrestrial contamination is almost inconceivable for REE in this specimen.

3. Conclusion

Yamato (m) and (k) are considered to have been derived from the originally closely associated body. The REE abundance ratio patterns between (m) and (k) and between (j_1) and (j_2) indicate that the melting and solidification processes took place on or within their parental bodies.

Acknowledgment

We wish to express our thanks to the National Institute of Polar Research, Japan, for providing the samples studied.

References

INENAGA, N. (1975): Keisan-en ganseki kessho-ka ni tomonau kido-rui genso no bunpai (Experimental determination of partitioning of rare-earth elements in the process of crystallization of silicate systems). Master Thesis, Science University of Tokyo, 38 p.

JIBIKI, H. and MASUDA, A. (1974): Basalts and serpentinite from the Puerto Rico Trench, 2. Rare-earth geochemistry. Mar. Geol., **16**, 205–211.

KUSUNOKI, K. (1975): A note on the Yamato meteorites collected in December 1969. Mem. Natl Inst. Polar Res., Spec. Issue, **5**, 1–8.

MASON, B. (1971): Handbook of Elemental Abundances in Meteorites. New York, Gordon and Breach, 555 p.

MASUDA, A. (1968): Lanthanides in the Norton County achondrite. Geochem. J., **2**, 111–135.

MASUDA, A. and JIBIKI, H. (1973): Rare-earth patterns of Mid-Atlantic Ridge gabbros: Continental nature? Geochem. J., **7**, 55–65.

MASUDA, A., NAKAMURA, N. and TANAKA, T. (1973): Fine structures of mutually normalized rare-earth patterns of chondrites. Geochim. Cosmochim. Acta, **37**, 239–248.

NAGATA, T. (1975): Yamato meteorites collected in Antarctica in 1969. Mem. Natl Inst. Polar Res., Spec. Issue, **5**, i.

NAGATA, T., SUGIURA, N. and SCHWERER, F. C. (1975): Magnetic properties of Yamato meteorites (j), (k), (l) and (m) from Antarctica. Paper presented at the First Symposium on Yamato Meteorites, Oct. 1975, Tokyo.

NAKAMURA, N. and MASUDA, A. (1973): Chondrites with peculiar rare-earth patterns. Earth Planet. Sci. Lett., **19**, 429–437.

NAKAMURA, N. and MASUDA, A. (1973): A detailed chemical study on the Barwise chondrite. Meteoritics, **8**, 149–167.

NARUSE, R. (1975): Dai-14-ji nankyoku chiiki kansokutai nairiku chôsa gaihô 1973–1974 (General reports on investigation of inland area of Antarctica by the 14th Japanese Research Expedition in 1973–1974). Nankyoku Shiryo (Antarct. Rec.), **53**, 127–140.

SHIMA, M. (1975): Chemical studies on the Yamato meteorites (j), (k), (l) and (m) from Antarctica. Paper presented at the First Symposium on Yamato Meteorites, Oct. 1975, Tokyo.

SHIRAISHI, K., NARUSE, R. and KUSUNOKI, K. (1976): Collection of Yamato meteorites, Antarctica, in December 1973. Nankyoku Shiryo (Antarct. Rec.), **55**, 49–60.

SUGAR, J. and READER, J. (1973): Ionization energies of doubly and triply ionized rare-earths. J. Chem. Phys., **59**, 2083.

YAGI, K., SHIMA, M. and OKADA, A. (1975): Mineralogical studies on the Yamato meteorites (j), (k), (l) and (m) from Antarctica. Paper presented at the First Symposium on Yamato Meteorites, Oct. 1975, Tokyo.

YANAI, K. (1976): 1974-nen no nankyoku-san Yamato inseki no tansa to saisyû (Search and collection of Yamato meteorites, Antarctica, in October and November 1974). Nankyoku Shiryo (Antarct. Rec.), **56**, 70–81.

YOSHIDA, M., ANDO, H., OMOTO, K., NARUSE, R. and AGETA, Y. (1971): Discovery of meteorites near Yamato Mountains, East Antarctica. Nankyoku Shiryo (Antarct. Rec.), **39**, 62–65.