Chemical characteristics of a Martian meteorite, Yamato 980459

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Abstract: As a part of consortium study, we analyzed a Martian meteorite, Yamato (Y) 980459 by prompt gamma-ray analysis (PGA), instrumental neutron activation analysis (INAA) and inductively coupled plasma mass spectrometry (ICP-MS). Our data confirmed that Y980459 belongs to olivine-phyric shergottites in chemical composition. Based on mg numbers (molar $Mg/(Mg+Fe)$ ratio), olivine-phyric shergottites are divided into two subgroups with high mg number and low mg number. Y980459 is grouped into members with high mg number along with DaG 476 and SaU 005. Abundances of rare earth elements (REEs) in Y980459 are depleted in light REEs (LREEs) and are similar to those of DaG 476 and SaU 005, being different from those for EETA 79001A, Dho 019 and NWA 1068, which are less depleted in LREEs. Based on the REE abundance in Y980459, a value of 0.19–0.25 was derived for the fraction of Martian crust in the Shergotty meteorite.

key words: Y980459, olivine-phyric shergottite, chemical composition, prompt gamma-ray analysis (PGA), instrumental neutron activation analysis (INAA), inductively coupled plasma mass spectrometry (ICP-MS)

1. Introduction

Yamato (Y) 980459 was collected on the bare ice field near the Minami-Yamato Nunataks on Antarctica by the Japanese Antarctic Research Expedition during the 1997–1999 collecting season. Martian meteorites consist of three major groups (shergottites, nakhlites and chassignite) and ALH 84001. Shergottites are further classified into two subgroups, basaltic shergottites and lherzolitic shergottites. Following the recent finding of a lot of meteorites in hot deserts of Oman, Libya and north west Africa, the third subgroup of shergottites, namely olivine-phyric shergottites, has been recognized (*e.g.*, Goodrich, 2002). Olivine-phyric shergottites are porphyritic rocks and display large olivine crystals in fine-grained groundmass. According to petrographic, oxygen isotopic and noble gas studies, Y980459 was grouped into olivine-phyric shergottites, to which Elephant Moraine A 79001 lithology A (hereafter, EETA 79001A), Dar al Gani (DaG) 476, Sahy al Uhaymir (SaU) 005, Dhofar (Dho) 019, North West Africa (NWA) 1068 and NWA 1195 also belong (Kojima and Imae, 2003). Unlike any known olivine-phyric shergottite found so far, Y980459 doesn't contain plagioclase (McKay and Mikouchi, 2003).

Olivine-phyric shergottites have been collected either in hot deserts or in cold deserts (Antarctica). Among 7 olivine-phyric shergottites so far recovered, Y980459 and EETA 79001A were collected on Antarctica, a cold environment less prone to terrestrial weathering than hot deserts after falling to the earth. Thus, elemental and isotopic characteristics of olivine-phyric shergottites are probably well preserved in these Antarctic meteorites rather than in hot desert meteorites, considering that contamination level and weathering effect are generally so high in hot desert meteorites that their chemical compositions and isotopic systematics were severely altered (*e.g.*, Barrat *et al.*, 2001).

It is well known that SNC meteorites have a large variation of rare earth element (REE) abundances, especially of those of light REEs (LREEs). Jones (1989), Wadhwa *et al.* (1994) and Wadhwa *et al.* (2001) suggest that LREEs-enriched shergottites either derived from the LREEs-enriched mantle sources or resulted from assimilation of LREEs-enriched components to their parental magma. According to them, LREEs-depleted shergottites represent LREEs-depleted mantle sources and have been less affected by assimilation of a LREEs-enriched components. Norman (1999) determined the REE composition of the crust component in Shergotty by assuming that it represents a mixture of a mantle-derived magma similar in composition to EETA 79001A and the LREEs-enriched crust component. Actually, REE abundances, especially LREE abundances in EETA 79001A are largely depleted in EETA 79001A compared with those for Shergotty.

As a member of the consortium study on Y980459 organized by Dr. Misawa of the NIPR (Misawa, 2003), we determined concentrations of a variety of major, minor and trace elements for its bulk composition by using two nuclear analytical techniques, prompt-gamma ray analysis (PGA) and instrumental nuclear activation analysis (INAA), and inductively coupled mass spectrometry (ICP-MS). Based on analytical data, we aim to characterize Y980459 in chemical composition and discuss the REE abundance in the Martian crust.

2. Experimental

2.1. Sample

Several lump specimens of Y980459 (Y980459,80) weighing 2.585 g were carefully ground in clean agate mortars. An aliquant of 248 mg of this powdered specimen was allocated to us for the consortium study of Y980459.

2.2. PGA procedure

A portion of the sample (0.0996 g) was sealed into a thin fluorinated ethylene polyethylene (FEP) film bag and was irradiated for two hours with cold neutrons (neutron flux: $1.4 \times 10^8 \text{cm}^{-2}\text{s}^{-1}$) guided out of the JRR-3M research reactor at the Japan Atomic Energy Research Institute (JAERI). Elemental contents of the sample were determined by comparison method with using JB-1 (a geological standard rock sample issued by the Geological Survey of Japan) for Na, Al, Si, K, Ca, Ti, Mn, Fe, Sm and Gd. In addition to JB-1, chemical reagent samples were prepared for the determination of H, B, Mg, Cl, S, Cr, Ni and Co. The analytical procedure of PGA is

essentially the same as that described by Oura *et al*. (2003).

2.3. INAA

In our INAA, samples are irradiated several times with different irradiation periods which are adjusted for half lives of nuclides usable for determining elements.   A sample weighing 0.03338 g was irradiated for 10 s at a thermal neutron flux of $1.5 \times 10^{13}\,cm^{-2}s^{-1}$ in the JRR-3 research reactor of JAERI and was immediately measured for their emitting gamma rays.   The samples were reirradiated for 20 min at a neutron flux of $4.3 \times 10^{13}\,cm^{-2}s^{-1}$ in the JRR-4 reactor of JAERI.   Together with a meteorite sample, a chemical reagent sample for correcting the production of ^{24}Na from ^{24}Mg was irradiated. After irradiation, samples were measured for gamma rays several times with different cooling intervals at the RI Research Center of Tokyo Metropolitan University.   Both JB-1 and the Smithsonian Allende powder samples were used as reference standards for the determination of Na, Mg, Al, K, Ca, Sc, Ti, V, Cr, Mn, Fe, Co, Ni, Zn, La, Sm, Eu, Yb and Lu.

2.4. ICP-MS

We determined Ba, REEs, Th and U in Y980459 by ICP-MS using a VG Plasma Quad-3 instrument.   Samarium was determined both by isotope dilution method using an enriched isotope of ^{149}Sm and by calibration method.   As for the other elements (Ba, the other REEs, Th and U), we applied an external calibration method using their standard solutions.   Chemical recoveries of these elements were corrected by using a recovery value for Sm.   A sample weighing 0.0291 g was placed in a Teflon container and digested with HF, HNO_3 and $HClO_4$ by using a microwave oven.   In measuring REEs, oxide ions of LREEs could interfere with metallic ions of heavy REEs (HREEs). The analytical procedure used in this study is basically similar to that described by Shinotsuka *et al*. (1996) with some modification.   Shinotsuka *et al*. (1996) used two kinds of monitor solutions of Ba-Pr mixture and Ce, while we used three, Ba-Pr mixture, Ce-Nd mixture and Sm-Gd-Tb mixture solutions.   The Smithsonian Allende reference powder was analyzed for a control.   The detailed analytical procedure will be reported elsewhere.

3.   Result and discussion

3.1.   Chemical characteristics of Y980459 and its classification

Major element abundances for Y980459 are shown in Table 1, where our data are compared with literature values of Y980459 and ranges for three shergottite subgroups. Our data are in good agreement with literature values of Y980459.   It is clear in Table 1 that basaltic shergottites, lherzolitic shergottites and olivine-phyric shergottites are separable in TiO_2, Al_2O_3, Cr_2O_3, MgO, CaO and Na_2O abundances.   Major element contents of Y980459 apparently fall in the range of olivine-phyric shergottites.   Trace element abundances are shown in Table 2.   Trace element abundances of other individual olivine-phyric shergottites also are shown for comparison.   For trace element contents of Y980459, our data are in good agreements with those of Dreibus *et al*. (2003a) except for La; our La value is 38% higher than that of Dreibus *et al*. (2003a), leading

Table 1. Major and minor element abundances of Y980459 in comparison with literature values for three shergottites goups (wt%).

Elements	Y 980459			basaltic shergottites (III)		lherzolitic shergottites (IV)		olivine-phyric shergottites (V)	
	This Work*	(I)	(II)	Max	Min	Max	Min	Max	Min
SiO_2	49.9 ± 1.3	48.70		51.48 - 46.0		45.5 - 41.3		51.65 - 45.52	
TiO_2	0.532 ± 0.052	0.54		1.98 - 0.67		0.46 - 0.193		1.67 - 0.33	
Al_2O_3	5.17 ± 0.06	5.27		12 - 3.53		3.86 - 1.28		7.71 - 4.17	
Cr_2O_3	0.695 ± 0.008	0.71	0.79	0.5761 - 0.014		1.21 - 0.829		0.834 - 0.516	
FeO	17.3 ± 0.2	17.32	18.24	21.4 - 14.15		20.9 - 17.9		24.3 - 15.39	
MnO	0.481 ± 0.018	0.52	0.49	0.620 - 0.200		0.53 - 0.44		0.54 - 0.45	
MgO	18.7 ± 1.2	19.64		12.31 - 3.53		29.69 - 22.72		20.75 - 11.94	
CaO	6.83 ± 0.61	6.37	5.88	11.48 - 6.57		4.54 - 2.66		9.42 - 5.18	
Na_2O	0.651 ± 0.004	0.48	0.68	2.24 - 1.25		0.597 - 0.198		1.14 - 0.51	
K_2O	0.0156 ± 0.0037	<0.02	0.0211	0.36 - 0.038		0.06 - 0.013		0.16 - 0.022	

(I) Misawa (2003). (II) Dreibus *et al.* (2003a).

(III) The ranges are for Shergotty, Zagami, EETA 79001B, QUE 94201 Los Angels, NWA480, NWA 856 and Dho378 (Lodders, 1998; Rubin *et al.*, 2000; Barrat *et al.*, 2002a; Jambon *et al.*, 2002; Dreibus *et al.*, 2002).

(IV) The ranges are for ALH77005, LEW88516 and Y793605 (Lodders, 1998).

(V) The ranges are for EETA79001A, DaG476, DaG489, SaU005, Dho019 and NWA1068 (Lodders, 1998; Zipfel *et al.*, 2000; Folco *et al.*, 2000; Dreibus *et al.*, 2000; Taylor *et al.*, 2002; Neal *et al.*, 2001; Barrat *et al.*, 2002b).

* Errors quoted are due to counting statistics (1σ).

Table 2. Trace element abundances of Y980459 compared with literature values (I~V) for other olivine-phyric shergotties (in ppm).

	Y980459			EETA79001A	DaG476	SaU005	Dho019	NWA1068
	This Work*	(I)	(II)	(III)	(II)	(II)	(IV)	(V)
B	1.00 ± 0.13							
S	1650 ± 320		1700	2100 ± 700	2700	1600		
Cl	64.4 ± 11.3		57	26	82	143		
Sc	34.9 ± 0.2		36.4	36 ± 2	29.9	29.9	31.2	37
V	188 ± 6			210 ± 15			175.1	280
Co	51.6 ± 1.1	70	56.2	48 ± 4	51.1	55	44.5	56.2
Ni	203 ± 30	270	240	180 ± 70	300	310	65.3	232
Zn	81.1 ± 7.0		76	73 ± 8	66	61	62	49
Ba	1.54 ± 0.02		<30	<10	73	<20	19.4	127
La	0.166 ± 0.002		0.12	0.4 ± 0.045	0.12	0.11	0.24	2.25
Ce	0.426 ± 0.006		<0.7	1.27 ± 0.23	0.354	0.35	1.45	5.38
Pr	0.0841 ± 0.0012						0.11	0.783
Nd	0.567 ± 0.012			1.35 ± 0.07	0.486	0.47	0.69	3.82
Sm	0.466 ± 0.003		0.498	0.74 ± 0.05	0.4	0.43	0.48	1.49
Eu	0.254 ± 0.003		0.25	0.37 ± 0.02	0.199	0.18	0.2	0.552
Gd	1.13 ± 0.01				0.845	0.86	0.99	2.14
Tb	0.244 ± 0.003		0.25	0.28 ± 0.04	0.181	0.19	0.2	0.414
Dy	1.70 ± 0.01		1.6	1.9 ± 0.3	1.32	1.35	1.3	2.8
Ho	0.379 ± 0.004		0.44	0.5	0.304	0.3	0.27	0.59
Er	1.09 ± 0.01						0.81	1.63
Tm	0.155 ± 0.001		0.17	0.18 ± 0.06			0.12	
Yb	0.971 ± 0.011		1.05	1.12 ± 0.08	0.81	0.79	0.81	1.37
Lu	0.150 ± 0.002		0.164	0.17 ± 0.02	0.125	0.12	0.12	0.198
Th	0.0213 ± 0.0007		<0.1	0.08	0.012	0.012	0.04	0.409
U	0.00596 ± 0.00009		<0.02	0.019	0.09	0.05	0.11	0.1

(I) Misawa (2003); (II) Dreibus *et al.* (2003a); (III) Lodders (1998); (IV) Taylor *et al.* (2002); (V) Barrat *et al.* (2002b).

* Errors are due to counting statistics (1σ) in γ-ray counting for elements except for Ba, REEs, Th and U, for which values of standard deviations ($n = 5$) in ICP-MS are quoted.

a discrepancy in K/La ratio between the two. K/La ratios are often used for discriminating planetary materials including basaltic achondrites (Wänke, 1991). This will be discussed later.

CI-normalized abundances of lithophile, chalcophile and siderophile elements in Y980459 are showed in Fig. 1. For comparison, an abundance range for each sub-group of shergottites also is shown. In illustrating Fig. 1, Ba and K abundances of those meteorites found in hot deserts are excluded. These elements, along with such elements as Sr, Rb and U, are known to be influenced for their abundances in hot desert meteorites compared with those in Antarctic meteorites (*e.g.*, Barrat *et al.*, 2001). Apparently, CI-normalized values of olivine-phyric shergottites for most elements makes a range between those of basaltic shergottites and lherzolitic shergottites. Y980459 values fall within the range of olivine-phyric shergottites except for K and Ba.

Our barium abundance of Y980459 (1.54 ppm) is lower than the reported value of EETA 79001A (5.28 ppm; an average of two) (Neal *et al.*, 2001). Our potassium abundance of Y980459 (156 ppm) also is lower than that of EETA 79001A, which ranges from 270 to 400 ppm. Most Martian fall meteorites take chondritic Th/U ratios of about 3.6, while a number of shergottites from hot deserts have much lower Th/U ratios (McLennan, 2003). A Th/U ratio of Y980459,80 is 3.57, which is in the range of Th/U ratios for non-hot desert shergottites. When compared with literature values
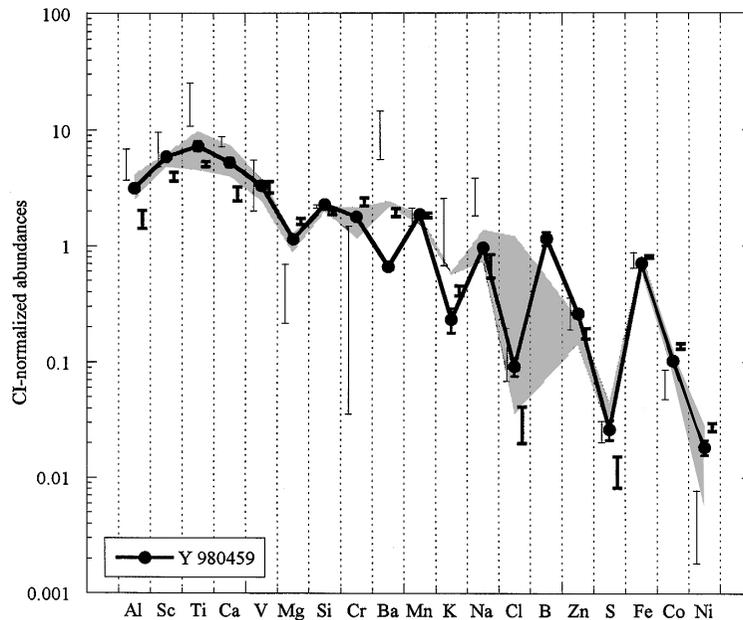

Fig. 1. *CI-normalized abundances of lithophile, chalcophile and siderophile elements in Y980459. Abundance ranges are compared for three shergottite subgroups (basaltic, lherzolitic and olivine-phyric shergottites). The shaded area covers literature values for olivine-phyric shergottites. Thin and thick bars indicate the range of abundances in basaltic and lherzolitic shergottites, respectively. Literature data used are taken from literatures cited in Table 1.*

for EETA 79001A, our Th and U abundances of Y980459 are 73% and 69% lower, respectively.   REEs, especially light REEs (LREEs) also are depleted in Y980459 compared with those in EETA 79001A, as discussed later.   Systematically lower abundaces of K and Ba in Y980459 seem to be consistent with its similarly lower values of Th, U and LREEs.   Thus, Y980459 is the most depleted in incompatible elements such as K, Ba, REEs, Th and U among olivine-phyric shergottites including EETA 79001A.   Among these elements, REEs and Th are less prone to weathering effects in hot deserts than the other.

Wänke and Dreibus (1988) derived a K/La ratio for the Martian primitive mantle and deduced a value of 635 from data for Martian meteorites.   K/La ratios for Antarctic Martian meteorites mostly converge to this value.   In contrast, values for some meteorites found in hot deserts are largely scattered.   These meteorites have generally high K/La ratios due to an enrichment of K caused by terrestrial weathering (*e.g.*, Zipfel *et al.*, 2000).   Our K/La value for Y980459 is 778, which is close to the Martian meteorite value (635).   Dreibus *et al.* (2003a), however, reported a value of as high as 1460, which is close to the SaU 005 value (1660) rather than the Martian meteorite average.

Oura *et al.* (2003) showed that a plot of Mg/Si versus Ca/Si is utilized for classifying Martian meteorites.   A plot of Mg/Si versus Ca/Si seems to be similarly usable even for the subclassification of shergottites as illustrated in Fig. 2.   On this plot, shergottites are spread on a line tying a point with high Ca/Si and low Mg/Si ratios and
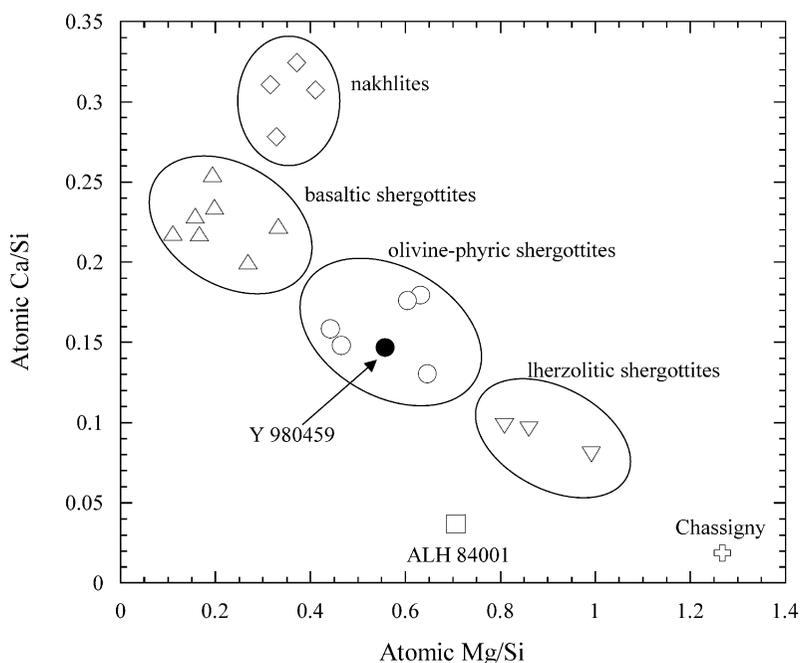

Fig. 2.   *Mg/Si vs. Ca/Si diagram for Martian meteorites.   Atomic ratios are plotted.   Literature data are from Dreibus et al. (2003b), Sautter et al. (2002) and literatures cited in Table 1.*
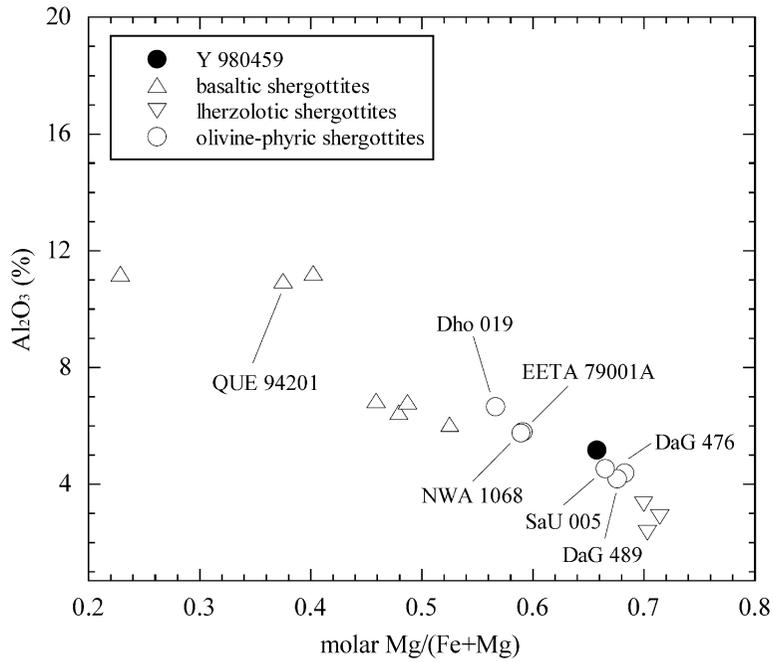
Fig. 3. An mg number vs. Al₂O₃ diagram for shergottites. Literature data used are taken from literatures cited in Table 1.
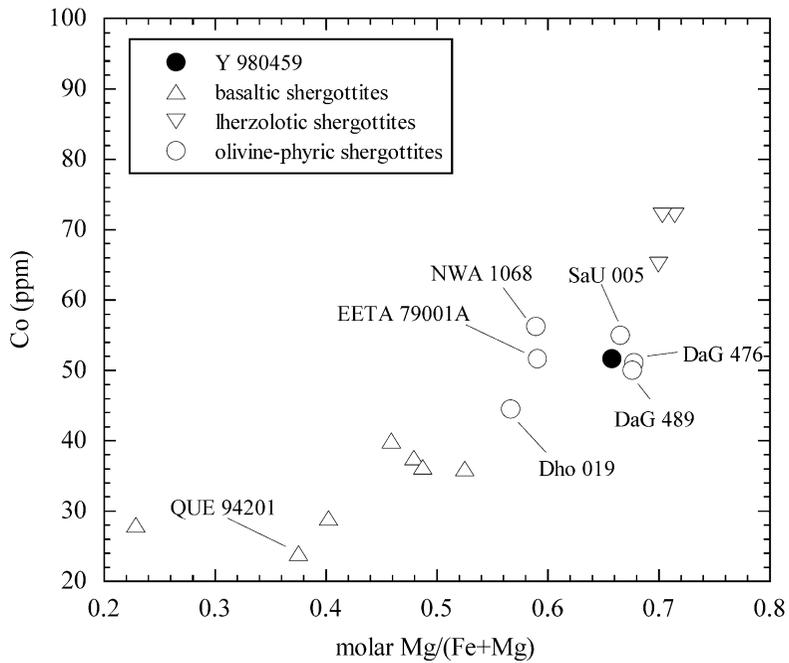

Fig. 4. An mg number vs. Co diagram for shergottites. Literature data used are taken from literatures cited in Table 1.

a point with low Ca/Si and high Mg/Si ratios.   Chassigny has an even lower Ca/Si ratio than those for shergottites but seems to be on the line represented by shergottites. Nakhlites and ALH84001 are off the shergottite line.   Olivine-phyric shergottites exist in the area between lherzolitic shergottites and basaltic shergottites.   A similar correlation can be confirmed in a plot of Sc versus Co.   This is quite reasonable in consideration that Co is mostly hosted by olivine (a Mg-favoring mineral) and Sc is favorably partitioned in pyroxene (a Ca-favoring mineral).   As clearly confirmed in Fig. 2, Y980459 belongs to olivine-phyric shergottites.

   To compare Y980459 with other olivine-phyric shergottites, mg numbers (molar $Mg/(Mg+Fe)$ ratios) are plotted against Al_2O_3 and Co values in Figs. 3 and 4, respectively.   Y980459 is plotted near DaG 476 and SaU 005, which are positioned close to lherzolitic shergottites rather than basaltic shergottites.   Figures 3 and 4 suggest that olivine-phyric shergottites be divided into two groups, high mg number and low mg number shergottites, which are close to lherzolitic shergottites and basaltic shergottites, respectively.   Apparent correlations noticed in Figs. 3 and 4 imply that lherzolitic shergottites evolved from more primitive magma than that for basaltic shergottites.   Considering that shergottites recovered so far could not be biased in launching locality, it must be significant to observe such a single trend for all of them.

   Two groups with high and low mg numbers in olivine-phyric shergottites can be also recognized when abundances of incompatible elements such as REEs are taken into account.   CI chondrite-normalized REE abundance patterns of shergottites including Y980459 are illustrated in Fig. 5. It can be noticed that LREEs are strongly depleted in
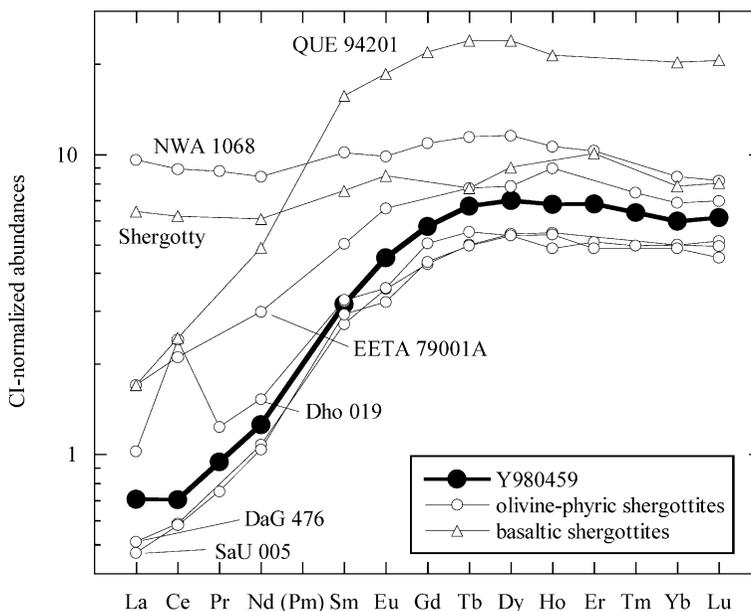

Fig. 5.   CI-normalized rare earth element abundance patterns for Y980459 and some other shergottites.   Literature data used are taken from literatures cited in Table 1.

Y980459.   Its REE abundances are steeply increased toward middle REEs, while they are flat in the HREE region.   REE contents and their abundance pattern of Y980459 are very similar to those for two other olivine-phyric shergottites, DaG 476 and SaU 005, suggesting a close genetic linkage among these three meteorites.   Other olivine-phyric shergottites have higher REE abundances (especially for LREEs) than those for Y980459 (and DaG 476 and SaU 005).   It may be noted that REE abundance patterns for Y980459, DaG 476 and SaU 005 are similar to that for a basaltic shergottite, Queen Alexandra Range (QUE) 94201.   As suggested by their mg numbers, QUE 94201 (mg#= 0.38) was derived from a more evolved magma than that for olivine-phyric shergottites (mg#=0.57–0.68).   Interestingly, both crystallization and ejection ages for Y980459 are comparable to those for QUE 94201 (Nagao and Okazaki, 2003; Shih *et al*., 2003). Thus, a possible linkage between Y980459 (and other two olivine-phyric shergottites) and QUE 94201 is hinted and will be studied in future.

3.2.   Geochemical evolution of shergottites inferred from the chemical composition of Y980459.

Jones (1989) and Wadhwa *et al*. (1994, 2001) suggested that LREEs-enriched shergottites were derived from either LREEs-enriched mantle sources or assimilation of a LREEs-enriched component to their parental magma.   Analogously, LREEs-depleted shergottites may have been directly derived from LREEs-depleted mantle sources and less affected by assimilation of a LREEs-enriched crust component.   Based on REE concentrations in pyroxene, it was inferred that REE abundance patterns of the parent magma of shergottites was similar to those of bulk meteorites (whole rock samples) (Wadhwa *et al*., 2001, 1994).   As shown in the previous section, REE abundances of Y980459, DaG 476 and SaU 005 are more LREEs-depleted than those of EETA 79001A.   This implies that these meteorites (Y980459, DaG 476 and SaU 005) were generated from more LREE-depleted sources in the Mars mantle than those for basaltic shergottites and less affected by assimilation of the LREEs-enriched component. Crozaz and Wadhwa (2001) argued that Antarctic meteorites are better candidates for geochemical studies of whole rocks than hot desert meteorites, judging from observations that Antarctic meteorites are less influenced by weathering effects compared with hot desert meteorites.   Considering that Y980459 is less altered by terrestrial weathering compared with DaG 476 and SaU 005 observed in hot deserts, Y980459 can be a better candidate than DaG 476 and SaU 005 for the discussion of geochemical processes on Mars.

Based on REE abundances in shergottites, Norman (1999) determined the REE composition of the Martian crust component in Shergotty.   In his discussion, it is assumed that Shergotty represents a mixture of a mantle-derived magma similar in composition to EETA 79001A and the LREEs-enriched crust component.   Following his discussion, we tried to estimate the crust fraction in Shergotty using our own data. Here, we use the REE abundance of Y980459 for representing the LREEs-depleted magma and assume that Shergotty represents a mixture of a mantle-derived magma similar to Y980459 in composition and the LREEs-enriched crust component.   Then, REE concentrations of the crust component in Shergotty can be determined by subtracting the LREEs-depleted parental magma composition similar to that for

Table 3.   Rare earth elements concentration (ppm) in the Mars crust.

|			Fraction of the Mars crust					
	Y980459	Shergotty*	0.10	0.15	0.19	0.25	0.30	0.40
La	0.166	2.29	21.4	14.3	11.5	8.60	7.25	5.48
Ce	0.426	5.54	51.6	34.5	27.8	20.7	17.5	13.2
Pr	0.0841							
Nd	0.567	4.2	36.9	24.8	20	15	12.7	9.65
Sm	0.466	1.37	9.51	6.50	5.30	4.06	3.48	2.73
Eu	0.254	0.56	3.32	2.30	1.89	1.47	1.27	1.02
Gd	1.13	2.2	11.8	8.26	6.85	5.38	4.70	3.80
Tb	0.244	0.4	1.81	1.29	1.08	0.865	0.765	0.635
Dy	1.70	2.7	11.7	8.34	7.03	5.66	5.02	4.19
Ho	0.379							
Er	1.09							
Tm	0.155							
Yb	0.971	1.6	7.26	5.17	4.34	3.47	3.07	2.54
Lu	0.150	0.22	0.852	0.618	0.526	0.429	0.384	0.325

* Laul *et al.*, 1986
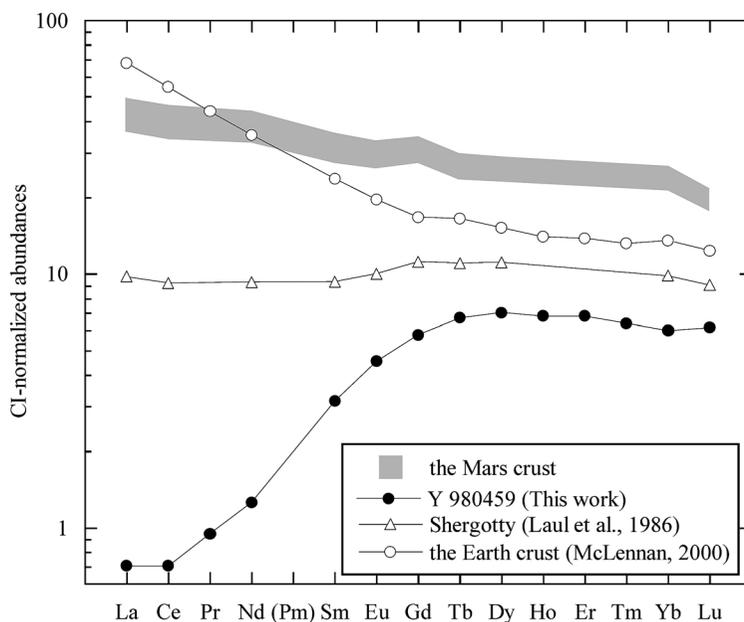
Fig. 6.   Estimated REE abundances for the Martian crust.   Abundance patterns for Y980459 (this study), Shergotty (Laul et al., 1986) and the Earth crust (McLennan, 2000) are shown for comparison.

Y980459 from the observed REE composition of Shergotty.   As we did not analyze Shergotty for REEs, we adopted its REE composition given by Laul *et al*. (1986). Derived value of REE concentrations are summarized in Table 3, where the fraction of the Martian crust in Shergotty are varied from 0.10 to 0.40.

Based on Nd concentrations and ε ^{143}Nd values for EETA 79001A and Shergotty,

Norman (1999) considered the mass balance of mantle and crust of Mars and estimated the thickness of Mars crust to be 20–30 km as an optimum value and further calculated its Nd concentration to be 15–20 ppm. With this value (15–20 ppm) for Nd concentration in the Martian crust, the crust fraction in Shergotty can be estimated to be 0.19–0.25 from Table 3. Corresponding REE abundance patterns for the Martian crust can be drawn as shown in Fig. 6, where abundance patterns are illustrated with a certain range, with upper and lower limits corresponding to 20 and 15 ppm of Nd contents, respectively. In Fig. 6, it is compared a REE abundance pattern for the earth crust (McLennan, 2000), which is characterized by a rather steep inclination in the LREE span and a flat plateau in the heavy REE span. It is noted that the REE abundances in the Martian crust (La/Yb=2.0–3.3) are less fractionated compared with those in the Earth crust (La/Yb=7.3). To deepen our discussion on the REE abundance in Martian crust, Nd isotopic data for Y980459 should be considered together with its REE abundances. The discussion in this line will be developed in future.

Acknowledgments

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