COSMO-CHEMICAL STUDIES ON THE YAMATO METEORITES ——A SUMMARY OF CHEMICAL STUDIES ON YAMATO (A), (B), (C) AND (D) METEORITES——

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Abstract: Analyses of the bulk chemical compositions, rare gases and trace elements of Yamato (a), (b), (c) and (d) meteorites have been carried out, along with their ^{57}Fe Mössbauer analysis. These data of chemical analyses, together with some petrological data, have indicated that Yamato (a), (b), (c) and (d) meteorites can be identified to enstatite chondrite, Ca-poor achondrite, carbonaceous chondrite Type III, and iron-rich bronzite chondrite, respectively.

1. Introduction

Results of cosmo-chemical studies on Yamato (a), (b), (c) and (d) meteorites have already been described in several separate reports (SHIMA *et al.*, 1973a, b; SHIMA, 1974; SHIMA *et al.*, 1974).

However, since the chemical data, particularly radio-chemical ones, are essential to identify and classify meteorites, those results will be summarized in this short note for the purpose of comparing them with mineralogical, petrographical and physical properities of the same meteoritic samples.

2. Bulk Chemical Compositions

The technical methods of analysis of the bulk chemical compositions of the meteorites have been reported elsewhere in detail (SHIMA *et al.*, 1973a; SHIMA, 1974). These techniques were specifically adopted in the present analysis in order to obtain as accurately as possible the quantitative chemical compositions of these samples which consist not only of silicates but also metals and metallic sulfides.

The bulk chemical compositions of the four meteorites thus obtained are summarized in Table 1.

It is observed in Table 1 that the abundance of total Fe and S is particularly high in Yamato (a) meteorite. This meteorite seems to be specifically rich in metallic iron, troilite (FeS) and oldhamite (CaS). In Yamato (b) meteorite, the abundance of Si and Mg is high, that of Ca is relatively low and that of Fe, Ni and S is extremely low. This result may suggest that Yamato (b) is a Ca-poor achondrite. The chemical composition of Yamato (c) suggests that this meteorite belongs to carbonaceous chondrite Type III, though the abundance of carbon itself has not yet been determined. On the other hand, Yamato (d) has the ordinary chemical composition of a high-iron chondrite.

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Table 1. Bulk chemical composition of Yamato meteorites (wt %).

		Yamato meteorite			
		(a)	(b)	(c)	(d)
Silicate phase	SiO_2	37.98	55.17	33.26	38.9
	MgO	19.28	26.22	24.42	24.08
	FeO	0.48	12.58	27.95	12.32
	Al_2O_3	1.55	0.70	2.44	1.93
	CaO	0.45	1.21	2.37	1.68
	Na_2O	0.864	0.0124	0.457	0.923
	K_2O	0.0847	0.0059	0.0393	0.104
	Cr_2O_3	0.418	1.375	0.564	0.498
	MnO	0.247	0.515	0.173	0.302
	TiO_2	0.075	0.072	0.133	0.082
	P_2O_5	0.464	$\leqq 0.009$	0.217	0.247
Metal phase	Fe	22.18	0.66	0.06	12.45
	Ni	1.86	$\leqq 0.004$	1.32	1.52
	Co	0.089	0.003	0.075	0.081
Sulphide phase	Fe	7.20	0.85	2.30	3.38
	Ca	0.72	—	—	—
	S	4.71	0.489	1.32	1.94
Total Fe	29.75	29.75	11.29	24.09	25.41
Total	98.65	99.88	97.10	100.44	99.64

3. Rare Gas Elements

The analyses of rare gas elements were carried out on three elements, He, Ne and Ar, by use of a special super-high vacuum mass spectrometer (HINTENBERGER *et al.*, 1968).

Results of the analyses are summarized in Table 2. As shown in the table, all the four meteorite samples contain ^{3}He, ^{21}Ne and ^{38}Ar, which are to be identified as the products of the cosmic-ray exposure of these samples in the interplanetary space.

From the observed abundances of ^{3}He and ^{21}Ne in comparison with their respective isotopes, the exposure ages of the four Yamato meteorites have been estimated separately for ^{3}He and ^{21}Ne, the results being given in Table 2. The agreement between the Ne- and He-exposure ages of each sample is reasonably good to distinguish the considerable differences among the exposure ages of the four meteorites.

Table 2. Rare gases in Yamato meteorites (Concentration in cm³ STP/g).

Element	Yamato meteorite			
	(a)	(b)	(c)	(d)
^{3}He	2.62×10^{-8}	7.13×10^{-7}	4.61×10^{-7}	1.056×10^{-7}
^{4}He	4.74×10^{-6}	6.65×10^{-6}	1.55×10^{-6}	1.069×10^{-5}
^{20}Ne	3.63×10^{-8}	1.90×10^{-7}	1.15×10^{-7}	2.10×10^{-8}
^{21}Ne	7.89×10^{-9}	1.91×10^{-7}	1.20×10^{-7}	2.26×10^{-8}
^{22}Ne	11.60×10^{-9}	2.04×10^{-7}	1.27×10^{-7}	2.45×10^{-8}
^{36}Ar	3.69×10^{-7}	1.12×10^{-8}	2.77×10^{-8}	7.13×10^{-9}
^{38}Ar	6.97×10^{-8}	1.19×10^{-8}	1.92×10^{-8}	4.10×10^{-9}
^{40}Ar	7.22×10^{-6}	1.00×10^{-6}	1.83×10^{-5}	6.08×10^{-5}
^{21}Ne sp	7.8×10^{-9}	1.91×10^{-7}	1.20×10^{-7}	2.26×10^{-8}
Ne exposure age	1.7 my	31 my	25 my	4.3 my
He exposure age	1.3 my	35 my	23 my	5.5 my

The solidification ages of these meteorite samples also have been estimated by the K-Ar method. The solidification ages thus determined are 23, 44, 122 and 154 m.y. for Yamato (a), (b), (c) and (d) meteorites, respectively.

4. Trace Elements

The trace elements, W, Re, Os, Ir, Pt, Au, Hg, Tl, Bi, Th and U have been

Table 3. Trace elements in Yamato meteorities (in ppb).

Element	Yamato meteorite			
	(a)	(b)	(c)	(d)
W	320	93	250	260
Re	63	< 3	68	99
Os	1400	20	1240	1620
Ir	900	4	850	1030
Pt	1820	< 5	1880	2520
Au	490	< 1	150	360
Hg	510	1540	1280	640
Tl	240	45	16	33
Pb	2240	190	610	94
Bi	280	5.6	38	3.7
Th	45	4.9	73	57
U	14	< 0.4	18	17

(after HINTENBERGER *et al.*, 1973)

determined using a spark source mass spectrograph MS7 with an electrical iron detection. The abundances of the trace elements in Yamato (a), (b), (c) and (d) meteorites are similar to those of well-studied meteorites such as Abee (enstatite chondrite), Johnstown (achondrite), Allende (carbonaceous chondrite Type III) and Orgueil (carbonaceous chondrite Type I), and Allegan (bronzite chondrite).

Comparisons of the trace element abundances of Yamato (c) meteorite with those of Allende and Orgueil have revealed that Yamato (c) is close to Allende than to Orgueil. These chemical data therefore support the identifications of Yamato (a), (b), (c) and (d) meteorites to an enstatite chondrite, an achondrite, a carbonaceous chondrite Type III and a bronzite, respectively.

5. Mössbauer Analysis

The ^{57}Fe Mössbauer effect of fine powder samples of the four meteorite samples has been measured at room temperature by use of a Mössbauer spectrometer of Elron Electric Industry. The principal results of the Mössbauer analysis are summarized in Table 4.

Table 4. Mössbauer data of Yamato meteorites.

Meteorite	Mineral	Isomer shift(*) (mm/s)	Quadrupole splitting (mm/s)	Internal magnetic field (k. Oe)
Yamato (a)	Iron	0	0	334
Yamato (b)	Pyroxene	1.10	1.09	0
Yamato (c)	Olivine	1.12	1.49	0
	Magnetite	0.24 0.72	0 0.04	485 455
Yamato (d)	Pyroxene	1.10	1.09	0
	Olivine	1.12	1.49	0

(*) Remarks : The isomer shift is relative to that of metallic iron.

The observed Mössbauer spectra are somewhat complicated. In Yamato (a), three absorption lines are observable in addition to the six distinct lines of metallic iron. However, these lines have not yet been identified. In Yamato (c), two Mössbauer constants have been obtained for a magnetite-like phase, in addition to the definite olivine lines. It seems that a more precise determination of the magnetite phase is required. In Yamato (d), at least two groups of weak absorption lines are observable in addition to those of pyroxene and olivine. These groups may be ascribed to metallic iron and troilite, though definite values of their Mössbauer constants have not been obtained.

6. Conclusion

A preliminary mineralogical study of the four Yamato meteorites (SHIMA *et* *al.*, 1974), has shown that Yamato (a), (c) and (d) meteorites contain chondrule, whereas no chondrule can be detected in Yamato (b), in which the groundmass consists mostly of pyroxenes (En : Fs=74 : 26). The ground mass of Yamato (a) is composed mostly of opaque minerals (mostly metals), pyroxenes (En : Fs=98 : 2) and olivines (Fo : Fa=95 : 5), while the main components of the chondrules are pyroxenes (En : Fs=98 : 2) and opaque minerals. The main components of the groundmass of Yamato (c) are olivine (Fo : Fa=60 : 40), opaque minerals (mostly magnetites) and plageoclase, while those of the chondrules are olivine (Fo : Fa=60 : 40) and opaque minerals. It is difficult to make the mode analysis of the chondrules of Yamato (d), but its mineralogical composition can be represented by olivine (Fo : Fa=90 : 10), pyroxene (En : Fs=85 : 15) and opaque minerals (mostly metals).

Taking into consideration these mineralogical data together with the chemical data, one may conclude that Yamato (a), (b), (c) and (d) can be identified to enstatite chondrite, Ca-poor achondrite, carbonaceous chondrite Type III, and high-iron bronzite chondrite, respectively.

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