A CLASSIFICATION OF THE YAMATO-75 CHONDRITES BASED ON CHEMICAL COMPOSITIONS OF OLIVINES AND PYROXENES

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***Abstract*:** Electron microprobe studies have been made of olivines and pyroxenes in fifteen Yamato chondrites which were collected from the Yamato Mountains area, East Antarctica by the 16th Japanese Antarctic Research Expedition (1974–1976). Of these meteorites, thirteen chondrites are described for the first time, and two other chondrites (Yamato-75028 and -75102) were already reported by YANAI *et al.* (Mem. Natl Inst. Polar Res., Spec. Issue, **8**, 110, 1978). The very small fragments used for the analyses were so chipped from the meteorites that contamination to the original materials is minimal. On the basis of histogram of iron contents of olivines and orthopyroxenes, the following predominance have been identified: *viz.*, 1 unequilibrated chondrite; 2 H type and 3 L type moderately equilibrated ordinary chondrites; and 4 H type and 5 L type equilibrated chondrites. The absence of the E type chondrite and the predominance of the H and L type chondrites are notable features but may not be significant at this stage of identification.

1. Introduction

As a part of preliminary examination of the Yamato meteorites collected in

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1975 (MATSUMOTO, 1978), microprobe analyses of olivines and pyroxenes in the chondrites have been carried out. A primary purpose of this study is to compile a catalogue of the Yamato meteorites, which will be used as a guidebook in processing, allocation and distribution of the meteorites for investigators in various fields. Many of these meteorites have been preserved at low temperatures under exceptionally clean circumstances. Therefore, we had to select a method of investigation that would allow minimal contamination, even at the expense of some uncertainties of the classification.

For this purpose, very small amounts of sample have been chipped from near the surface. In addition, the method of sample preparation and microprobe analyses had to be carried out in an efficient manner. The SiO_2, CaO, MgO and FeO contents of olivines and pyroxenes in one to four polished grain mounts have been determined at one time to obtain histograms of iron contents in two minerals such as given by DODD *et al.* (1967). Because of the limitation of this method, we admit that a chemical and petrologic classification (VAN SCHMUS and WOOD, 1967) of the Yamato meteorites given in this paper is a preliminary one.

Statistics on the classification of the Yamato chondrites may be used to deduce the distribution of chondrite falls among different chemical and petrologic types. However, the number of meteorites thus far identified may be still too small to draw any definite conclusions on this subject.

2. Experimental Method

The samples used for this study were selected on the basis of the following criteria:

1) Chondrites weighing more than 50 g.

2) Yamato-75071 chondrite is one of 57 meteorites (from Yamato-75034 to Yamato-75090), which were found in the small area of about 50×200 m as concentrated meteorite fragments belonging in the same kind chondrite in appearance, a total weight of these meteorites being 110.8 g (MATSUMOTO, 1978).

3) The Yamato-75108 and Yamato-75110 chondrites are two of 150 meteorites (from Yamato-75108 to Yamato-75257), which were found in the limited area of about 10×50 m, as concentrated meteorite fragments belonging in the same kind chondrite in appearance. It is considered that one original meteorite was broken into many fragments, a total weight of these meteorites being 3969.5 g (MATSUMOTO, 1978).

About 0.01 g fragments were chipped from the original meteorite samples. Many of these samples were covered with crusts of iron oxides or hydroxides, and even in the interior of many samples some oxidized portions were found. For those meteorites from which only small fragments were supplied polished grain mounts have been prepared for the microprobe analysis. Several fragments were mounted in araldite resin or acrylic resin about 5 mm in diameter; the final samples used were in the form of 3 mm square polished sections mounted on glass. The polished sections were prepared for microprobe analyses by coating with carbon.

The quantitative chemical analyses of olivines, orthopyroxenes and augites were made with a JEOL JXA-5 or JEOL JXA-5A electron probe X-ray micro-analyzer with a 40° take off angle. The method was the same as that described by NAKAMURA and KUSHIRO (1970). The SiO_2, CaO, MgO and FeO contents (weight percentage) were all determined at one time. The sodium, aluminum and calcium contents have been checked to identify plagioclase grains in the chondrites of petrologic type 6.

Measurements for each meteorite grain mount were made on about 20 to 80 points on different chondrules, grains or crystals of olivine and pyroxene. Random selections of points have been tried in order to obtain about 40 orthopyroxene measurements and a comparable number of olivine measurements in each sample. However, some polished grain mounts contained only a small number of mineral grains, and some sections contained very large chondrules. The homogeneity of the compositions for equilibrated chondrites was checked by monitoring the intensities of the nine elements (Si, Ti, Al, Fe, Mn, Mg, Ca, Na, K) on the scan chart, and only a few representative values were recorded. In this case the actual number of the examined grains is larger than the number of analyzed points.

Grains with total weight percents ($CaO+MgO+FeO+SiO_2$) outside the range between 95 to 102% were interpreted as glass or another mineral phase, or ascribed to inaccurate analyses and were rejected. Any analyses in which the Ca, Mg, Fe and Si contents were inappropriate to either olivine or pyroxene were also discarded. Thus, the total number of measurements was generally smaller than 50.

After the data were screened for spurious measurements, the weight percents of the metal oxides in the olivine or pyroxene at each sample point were used to calcurate atomic % calcium, magnesium, and iron in the olivine or pyroxene. Mean concentrations of these three elements was calculated for the olivines and pyroxenes in each sample, and the "percent mean deviation" proposed by DODD *et al.* (1967), were determined for the olivines and pyroxenes of various ordinary chondrites. But in this paper, according to the previous example (YANAI *et al.*, 1978), calculation of the mean deviation and the "percent mean deviation" were used the atomic % of iron.

Although the parameter "percent mean deviation" has been used as an index of olivine or pyroxene heterogeneity by the above authors (DODD *et al.*, 1967), it was found that for the method of measurements we employed in this reconnaissance study a histogram of percent of measurements against atomic % iron is a good measure of the spread of the frequency distribution. The smaller number of analyzed points is due to the small number of grains available for the analyses in one case and is due to selected analyses of the homogeneous samples in other cases. First, actual number of measurements was plotted at 1% intervals of atomic percent iron. Then, percent of measurements was computed by normalizing the total number of measurement to 100%.

3. Classification of the Yamato-75 Chondrites

Histograms of iron contents, in atomic percent, of olivines and orthopyroxenes for twelve Yamato-75 chondrites are given in Figs. 1 to 3. In accordance with the previous example (YANAI *et al.*, 1978), the histograms are arranged in three major groups, according to their petrologic types, and they are further classified according to their chemical groups. In these figures, the ranges of atomic percent of iron for the known H6, L6 and LL6 type chondrites are shown at the top of Figs. 1 to 3.

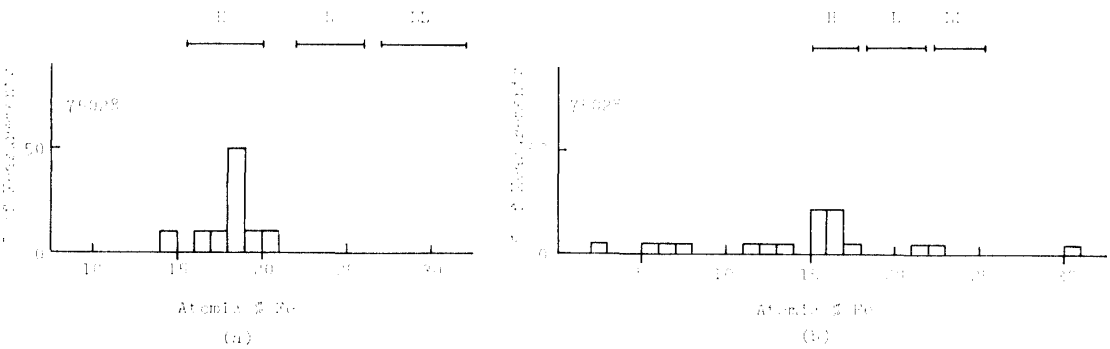

Fig. 1. Iron contents of (a) olivines and (b) orthopyroxenes in unequilibrated H group chondrite. The number is name of the Yamato meteorite sample. The data of this chondrite are after YANAI *et al. (1978).*

The numbers in each figure are the sample numbers of the Yamato meteorites, respectively. Except for the figure of unequilibrated chondrite (Fig. 1), the histograms are arranged in the order of decreasing petrologic types. If the histograms were arranged according to their iron content distribution independently of whether it is olivine or orthopyroxene, the same sample number would appear in different ranking. To mention only a few examples, in Fig. 2, Yamato-75277 is the fourth rank for olivine, but would be in the first rank for orthopyroxene. In Fig. 3, Yamato-75288 is the first rank for olivine, but would be in the fifth rank for orthopyroxene. These discrepancies imply ambiguity in the final classification of these meteorites. In such cases, the classification adopted in this paper is mainly based on their olivine values. In Fig. 3, Yamato-75102 appears in the olivine figure, but is left blank in the orthopyroxene figure, indicating that orthopyroxene com-

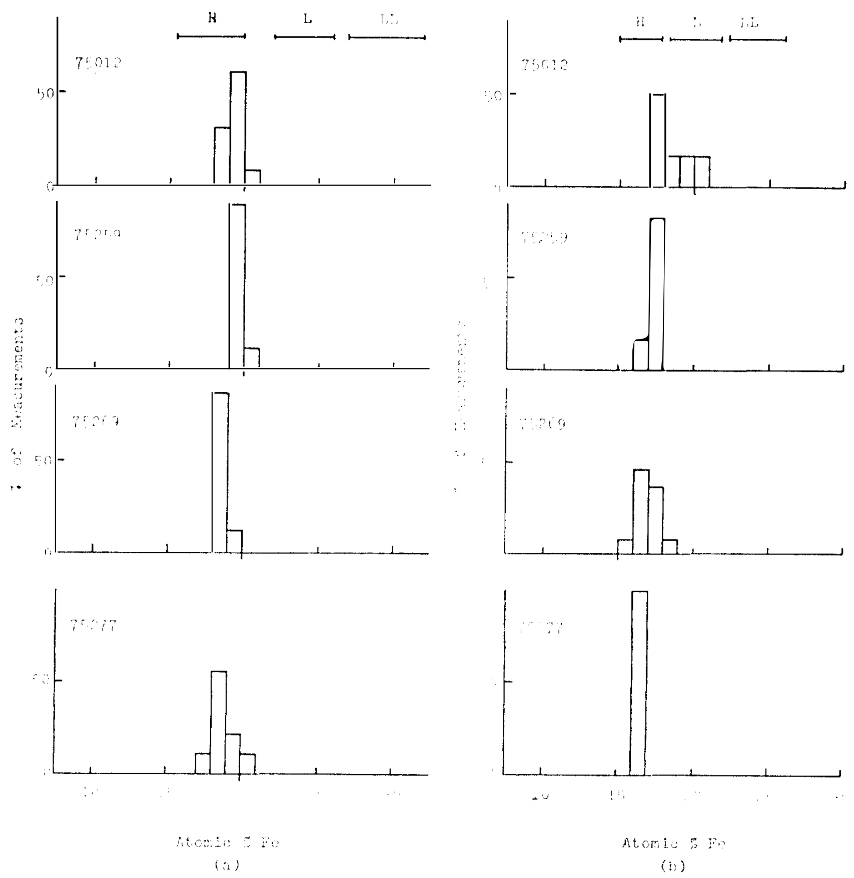

Fig. 2. Iron contents of (a) olivines and (b) orthopyroxenes in moderately equilibrated H group ordinary chondrites and equilibrated H group ordinary chondrites. The numbers are the names of the Yamato meteorite samples.

position could not be measured within the probe samples prepared for this chondrite.

The Yamato-75028 chondrite as an unequilibrated chondrite is given in Fig. 1 (YANAI *et al.*, 1978). The iron contents of its olivines and orthopyroxenes are irregularly distributed from 2 atomic % to as much as 30%, and this distribution lacks distinct modes. The petrologic type of this chondrite corresponds to 3–4. Moreover, the maximum of frequency for the iron contents is 18 atomic % for olivine, and is 16 and 17 atomic % for orthopyroxene. Consequently, the chemical group of this chondrite corresponds to H group.

Histograms for those meteorites which are grouped as moderately equilibrated ordinary chondrites (corresponding to moderately unequilibrated ordinary chondrites by YANAI *et al.*, 1978) (Fig. 2, Yamato-75277 and Fig. 3, Yamato-75097, -75108, -75110) show distinct modes in the olivine and orthopyroxene distributions. Their peaks occur at iron concentrations appropriate to the equilibrated H and L

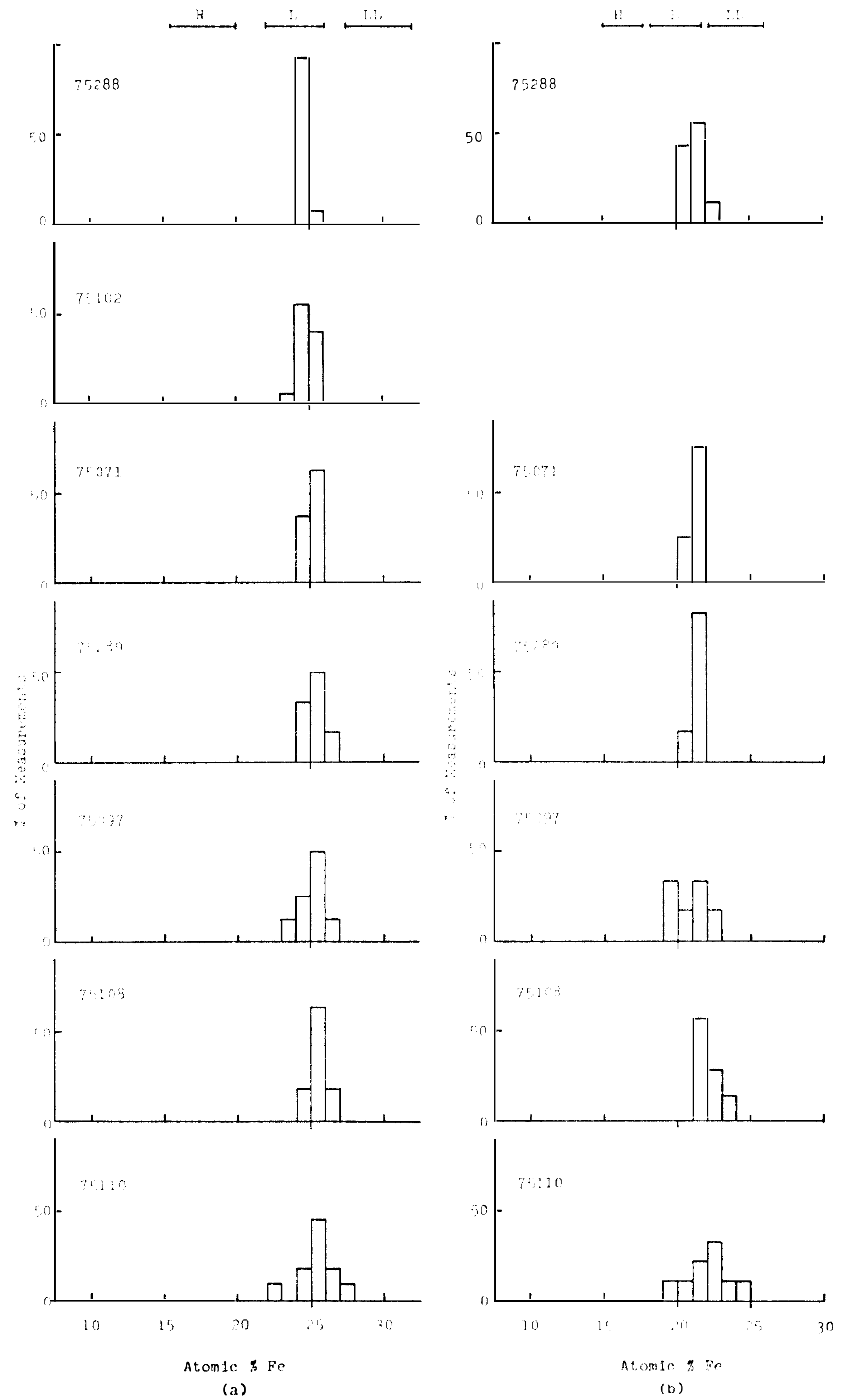

Fig. 3. Iron contents of (a) olivines and (b) orthopyroxenes in moderately equilibrated L group ordinary chondrites and equilibrated L group ordinary chondrites. The numbers are the names of the Yamato meteorite samples. The data of the Yamato-75102 chondrite are after Yanai *et al. (1978).*

group chondrites (DODD *et al.*, 1967; VAN SCHMUS, 1969; BUNCH and OLSEN, 1974). The entire range of the iron concentrations, however, falls outside the known range of the equilibrated chondrites. The petrologic type of the moderately unequilibrated ordinary chondrites corresponds to 4–5.

Histograms for those chondrites which are grouped as equilibrated ordinary chondrites are given in Fig. 2, Yamato-75012, -75259, -75269 and Fig. 3, Yamato-75288, -75102, -75071, -75289. These chondrites whose iron concentrations fall within the range of the known equilibrated chondrites are shown in those figures.

Table 1. Distribution of the analyzed meteorites among the chemical-petrologic types.

Unequilibrated chondrites (Type 3-4)
 H: 1 75028.
Moderately equilibrated ordinary chondrites (Type 4-5)
 H: 2 75100, 75277.
 L: 3 75097, 75108, 75110.
Equilibrated ordinary chondrites (Type 6, 5, 6-5 and 5-6)
 H: 4 75096, 75012, 75259, 75269.
 L: 5 75017, 75288, 75071, 75102, 75289.

Table 2. Mean compositions of olivines and percent mean deviations of their iron concentrations in the analyzed Yamato-75 chondrites.

Sample No.	Mean composition			No.	Mean deviation	% mean dev.	Remarks
	Ca	Mg	Fe				
Yamato-75096			17.39		0.203	1.17	H6
-75012	0.0	80.86	19.14	13	0.300	1.57	H5-6
-75259	0.0	80.36	19.64	9	0.314	1.60	H5-6
-75269	0.0	81.14	18.86	8	0.269	1.43	H5
-75100			18.32		0.399	2.18	H4-5
-75277	0.0	81.18	18.82	9	0.776	4.12	H4-5
-75028*	0.1	80.5	19.4	14	2.6	13	H3-4
-75017			24.05		0.343	1.43	L6
-75288	0.0	75.39	24.61	14	0.178	0.72	L6
-75071	0.0	74.88	25.12	8	0.298	1.18	L6-5
-75102*	0.0	75.3	24.6	14	0.36	1.5	L6-5
-75289	0.0	74.81	25.19	6	0.388	1.54	L5-6
-75097	0.0	74.98	25.02	8	0.609	2.43	L4-5
-75108	0.0	74.49	25.51	11	0.409	1.61	L4-5
-75110	0.0	75.69	24.31	11	0.878	3.61	L4-5

No.: Number of measurements.
*: The data of this chondrite depend on YANAI *et al.* (1978).

Table 3. Mean compositions of orthopyroxenes and percent mean deviations of their iron concentration in the analyzed Yamato-75 chondrites.

Sample No.	Mean composition			No.	Mean deviation	% mean dev.	Remarks
	Ca	Mg	Fe				
Yamato-75096	1.2	82.9	15.9		0.840	5.30	H6
-75012	0.0	81.60	18.40	6	0.842	4.57	H5-6
-75259	0.08	82.70	17.22	12	0.276	1.60	H5-6
-75269	0.10	82.89	17.01	13	0.542	3.18	H5
-75100	1.5	81.7	16.7		1.11	6.65	H4-5
-75277	0.0	83.72	16.28	7	0.181	1.11	H4-5
-75028*							H3-4
-75017	1.6	78.0	20.4		0.385	1.88	L6
-75288	0.21	78.70	21.09	9	0.401	1.90	L6
-75071	0.0	78.86	21.14	6	0.227	1.07	L6-5
-75102*							L6-5
-74289	0.0	78.79	21.21	6	0.212	1.00	L5-6
-75097	0.30	88.78	20.92	6	0.767	3.66	L4-5
-75108	0.21	77.77	22.02	7	0.479	2.17	L4-5
-75110	0.0	77.96	22.04	9	1.161	5.27	L4-5

No.: Number of measurements.
*: The data of this chondrite depend on YANAI *et al.* (1978).

The petrologic types of these chondrites are 6 or 5. Only a few meteorites contain either olivines or pyroxenes having iron contents outside the above range.

The numbers of newly identified Yamato-75 chondrites together with two chondrites (Yamato-75028 and -75102) (YANAI *et al.*, 1978) for each chemical-petrologic group are summarized in Table 1. The mean compositions (Ca, Mg and Fe), the mean deviations of iron concentrations and the percent mean deviations (% M.D.) of iron concentrations in their olivines and orthopyroxenes are given in Tables 2 and 3.

The Yamato-75028 chondrite with % M.D. of 13 for olivine is assigned to petrologic type 3–4 and is grouped as unequilibrated chondrites in Table 1.

Except for one meteorite (Yamato-75108), those chondrites with % M.D. for olivine of 2 to 5 are classified as moderately equilibrated ordinary chondrites, and are assigned to petrologic type 4. The % M.D. for olivine of the Yamato-75108 chondrite is 1.61, and that for orthopyroxene is 2.17. Moreover, this chondrite is one fragment same as the Yamato-75110 chondrite that is one fragment of 150 meteorites. These meteorites were found in the limited area as concentrated meteorite fragments belonging in the same kind chondrite in appearance. It is considered that one original meteorite was broken into many fragments. The

Yamato-75110 chondrite with % M.D. of 3.61 for olivine and 5.27 for orthopyroxene is assigned to petrologic type 4–5 and is grouped as moderately equilibrated ordinary chondrite. For the same reason, the Yamato-75108 is determined as moderately equilibrated ordinary chondrite, and is assigned to petrologic type 4–5.

Those chondrites with % M.D. for olivine of less than 2 are classified as equilibrated chondrites, and are assigned to petrologic type 5 to 6.

The meteorite classification based on the histograms of the iron concentrations of olivines is consistent with that by % M.D. for olivine except for the Yamato-75108.

4. Conclusion

It was required that the identification of the meteorite type should be done quickly and the method consume the least amounts (about 0.01 g) of the samples, while not introducing any contamination into the original samples. As a consequence, we have to admit that the chemical and petrologic types thus deduced may still have some ambiguities, though the types are useful for curatorial work. Further detailed studies are required on the bulk chemistry and the texture of those meteorites in order to obtain accurate classification where two alternate types are given by the data available at present.

One difficulty in classifying the chondrites by their olivine and orthopyroxene compositions is that the chemical groups of the type 3 chondrites are indistinguishable. In addition, many samples used are the least amount of the oxidized crusts. When the total number of chondrules or mineral fragments that can be analyzed is small, we cannot obtain an unbiased statistical distribution of their iron concentrations. The presence of iron oxides or hydroxides makes it difficult to observe their texture and tends to give higher iron contents when the electron beam irradiates the oxidized portion. Sometimes even the interiors of the meteorites are heavily oxidized. Severe oxidation by weathering is one of the characteristics of the Yamato meteorites.

The result of the preliminary examination on the classification of the Yamato-75 chondrites by microprobe analyses of olivines and pyroxenes is summarized as follows.

1) Histograms of iron contents, in atomic percent, of olivines and orthopyroxenes for Yamato-75 chondrites are given in Figs. 1 to 3.

2) The numbers of newly identified thirteen Yamato-75 chondrites together with two Yamato chondrites (Yamato-75028 and -75102, YANAI *et al.*, 1978) for each chemical-petrologic group are summarized in Table 1.

3) The mean compositions (Ca, Mg and Fe), the mean deviation of iron concentrations and the percent mean deviations of iron concentrations in their olivines and orthopyroxenes are given in Tables 2 and 3.

4) Generally, the chemical and petrologic types of the Yamato-75 chondrites are the same with those of the Yamato-74 chondrites (YANAI *et al.*, 1978).

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