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BULK COMPOSITION AND CLASSIFICATION OF THE TAHARA METEORITE WHICH FELL IN CENTRAL JAPAN IN MARCH 1991

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Abstract: The Tahara meteorite which fell on March 26, 1991 on a ship's deck anchored at Tahara, Aichi-ken, Japan was found at Matsue-shi, Shimane-ken on December 28, 1992. It has been classified as an H4–5 chondrite using optical and electron microscopy and bulk chemical analysis. This equilibrated chondrite is completely different from the Mihonoseki L chondrite which fell on December 10, 1992 in the same area of Japan, Shimane-ken. The retrieval process of new Japanese meteorites is similar to Antarctic meteorites of different origins which are collected in the same area.

1. Introduction

On March 26, 1991, the Tahara meteorite fell without witness on the deck of a car-transport ship that was anchored in Tahara, Aichi-ken, Japan, as shown in Fig. 1. The impact created a 40 cm diameter quasi-crater and eleven pieces of the meteorite were found by the crew members, although the main mass fell into the sea. The estimated mass of the meteorite is *ca.* 6 kg, shown in Table 1.

One of the crew members took the largest piece with partial fusion-crust of the Tahara meteorite (Tahara-1 in Table 1) to his house near Matsue-shi, Shimane-ken, Japan and drew attention to the sample on December 28, 1992, after he heard accidentally about the fall of the Mihonoseki meteorite at Mihonoseki (near Matsue-shi) on December 10, 1992 through the newspaper and television (Fig. 1). The main purposes of this paper are bulk composition, classification as to find or fall meteorite and relation of the Tahara meteorite to the accumulation mechanism of Antarctic meteorites.

The first meteorite which fell on a ship's deck in 1648 on the ship "Malacca" during a voyage from Holland to Java (WILLMAN, 1992) was not retained. The Tahara meteorite is the first remained meteorite in the world which fell on a ship's deck, and the 42nd meteorite known to have fallen in Japan.

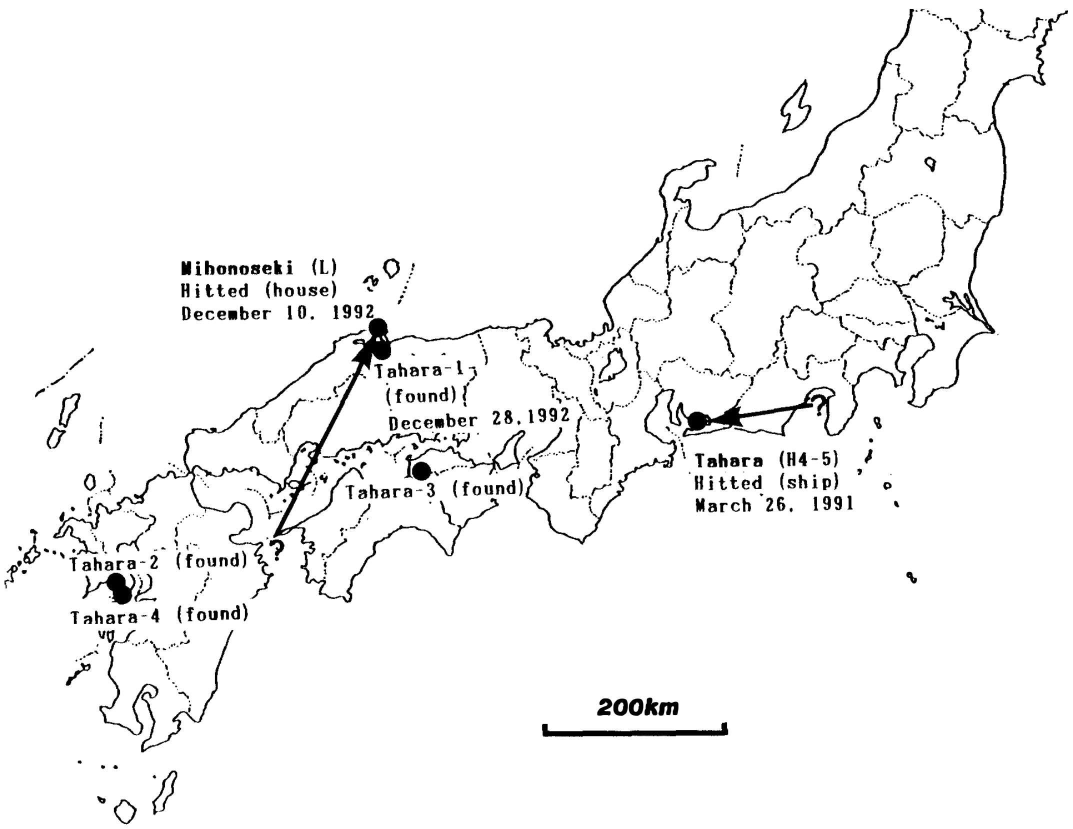

Fig. 1. Falling-sites and sample numbers of the Tahara and Mihonoseki meteorites.

Table 1. Main pieces of the Tahara meteorite.

Fragments	Collector	Size	Others
Tahara-1	Hidenobu Minao	422.5 g (9.0×6.0×4.0 cm)	Natl Museum
Tahara-2A	Tetsuyoshi Ayabe	217 g (8.2×4.3×4.2 cm)	
2B		145 g (6.9×4.8×2.3 cm)	
2C		80 g (5.4×3.9×2.9 cm)	Natl Museum
2D		39 g (4.5×3.5×2.8 cm)	In this study (51, 52)
Tahara-3	Minoru Hamaguchi	75 g (5.0×3.5×3.5 cm)	
Tahara-4	Hidetoshi Suzaki	5 g (2.7×1.1×1.1 cm)	
Tahara-5	Terutoshi Shimada	Lost	(Takasago, Hyogo)
Tahara-6	Mr. X	Lost	(Tokushima-ken)
Tahara-7	Mr. Y	Lost	(Kagoshima-ken)
Tahara-8	Mr. Z (Main mass)	Lost (more than *ca.* 5 kg)	(into the sea?)

2. Sample

The Tahara meteorite is classified as a found meteorite, because it was "collected but not seen to fall" (*cf.* MASON and MOOR, 1982). The sample used in this study was Tahara-2D, a 39 gram piece, Fig. 2, that we received from Mr. Tetsuyoshi AYABE who is one of the crew members of the car-transport ship and lives in Nagasaki-ken, Japan. Fragments of this piece, 51 (1.134 g) and 52 (2.069 g), were used to make a polished thin section and for bulk chemical analysis, respectively. A

(a)

(b)

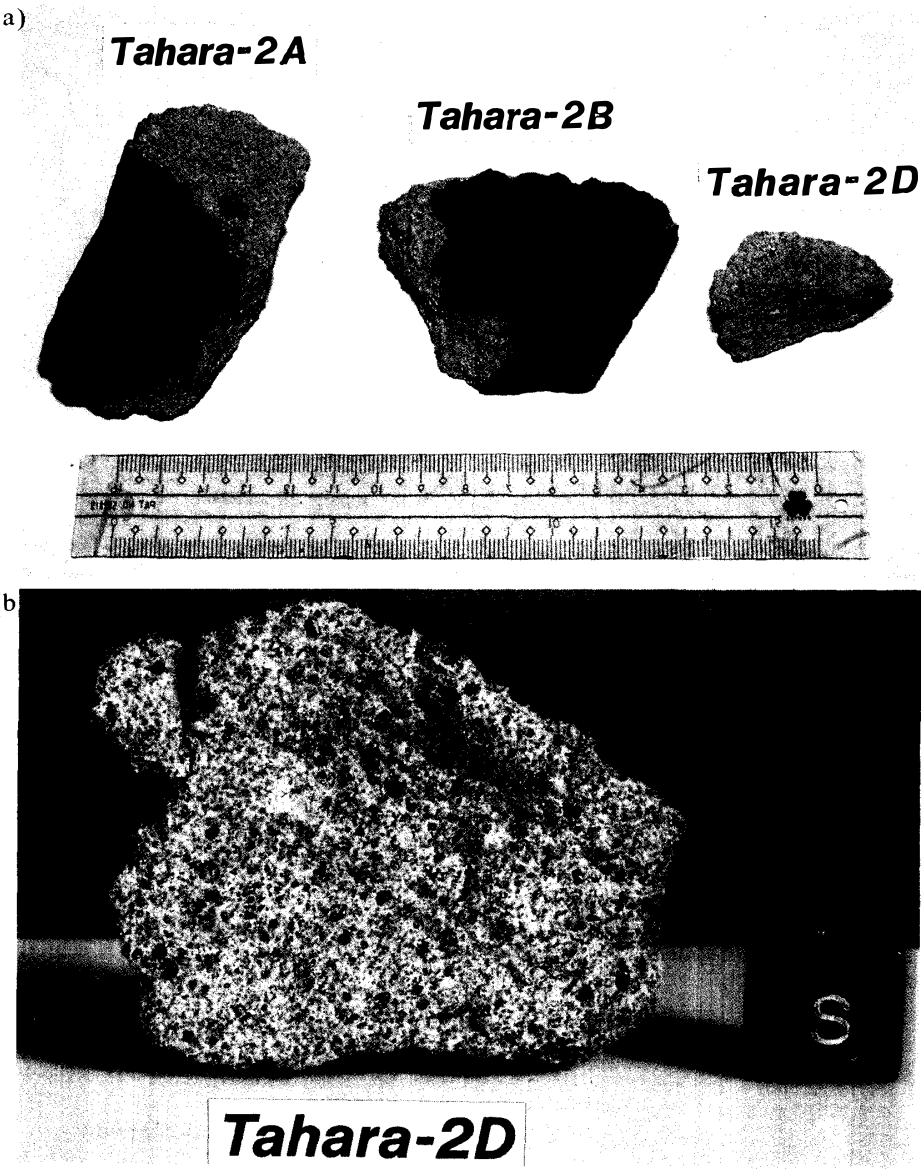

Fig. 2a. Three Tahara meteorite fragments were preserved by Mr. T. AYABE, Nagasaki-ken, in March 1993.

Fig. 2b. Tahara-2D, 39 g is one of the fragmental pieces with dull black fusion crust, from the Tahara meteorite.

bulk wet chemical analysis was used for classification by chemical group. Electron microprobe analysis of the National Institute of Polar Research (NIPR) and Yamaguchi University were used to classify this meteorite, especially for petrologic type.

3. Analytical Method

A small chip, Tahara-2D,51 (1.134 g), removed from near the surface of the Tahara meteorite, was cut into polished thin sections (PTS) at the NIPR. Two PTS were studied under the microscope in both transmitted and reflected light. Quantitative chemical analysis of the constituent minerals was carried out by an automated electron microprobe analyzer (EPMA) JEOL JCXA 733 and JXA-8800M with five spectrometers at the NIPR. The method of the EPMA is the same as that of KUSHIRO and NAKAMURA (1970). The constituent minerals of the PTS were also studied by a JEOL JSM-5400 (with JED 2001 energy dispersive analysis) analytical scanning electron microprobe of Yamaguchi University.

A small interior chip, Tahara-2D,52 (2.069 g), removed from the specimen was used for standard wet chemical analysis by one of the authors (H.H.) at the NIPR. The sample was first ground to less than 250 mesh, except for metal grains. The fine-grained powder was separated by a hand magnet into magnetic and non-magnetic fractions. The former consists of metal and some silicates, whereas the latter consists essentially of silicates. The magnetic fraction was divided into three portions. Two portions were used for determination of S and P, respectively. The third portion was dissolved in a mixed acid (3 parts HNO_3 and 1 part HCl). Ten elements (Fe, Ni, Ti, Al, Ca, Mg, Mn, Cr, Na and K) were determined in the acid-soluble portion. The acid-insoluble portion, which consists of silicates, was analyzed for Si, Al, Ni and Mg. The non-magnetic fraction was analyzed for 13 elements and water with the same method as that for analyzing terrestrial rocks. In this fraction, however, very fine-grained metal grains are included, resulting in a slight overestimation of Fe and Ni. The amount of such fine-grained metal is estimated to be less than 0.5 wt% and does not seriously affect the iron content of this fraction. Figure 3 shows the elements analyzed for each fraction. The above

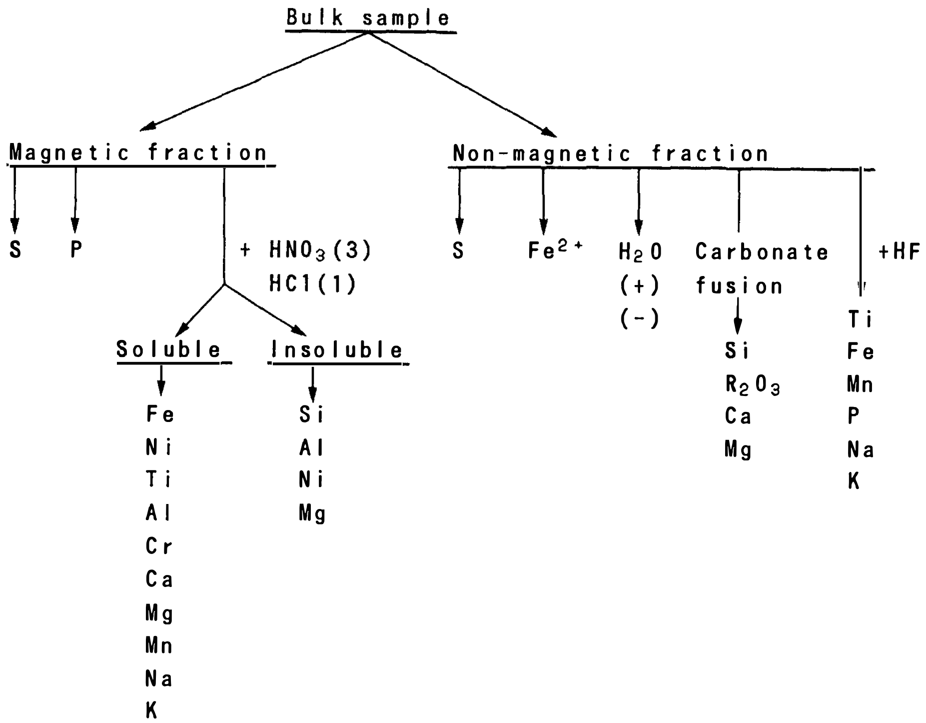

Fig. 3. Analytical procedures and elements analyzed in respective fractions.

analytical method was checked by analyzing an artificial mixture of powdered peridotite and metallic iron with known compositions and was found to be satisfactory. One problem is that some meteorites contain ferric iron and part of it may be reduced by S during analysis. Ferric iron in the sample (if any) may, therefore, be underestimated. This effect was checked by analyzing mixtures of magnetite + pyrrhotite and basalt + pyrrhotite. The amount of ferric iron reduced was about 3% of the total ferric iron present, and does not affect the analysis of the meteorites which contain less than 3 wt% Fe_2O_3.

4. Bulk Chemical Composition

The bulk chemical composition of the Tahara meteorite is listed in Table 2.

Table 2. Bulk composition of the Tahara-2D,52 meteorite by standard wet chemical analysis method in wt%.*

Oxides/elements	Tahara-2D,52	Oxides/elements	Tahara-2D,52
SiO_2	36.77	H_2O (−)	0.00
TiO_2	0.07	H_2O (+)	0.00
Al_2O_3	1.63	P_2O_5	0.22
Fe_2O_3	0.29	Cr_2O_3	0.33
FeO	10.62	FeS	6.34
MnO	0.31	Fe	15.18
MgO	24.67	Ni	1.41
CaO	1.68	Co	0.081
Na_2O	0.77		
K_2O	0.08	Total	100.45

* Analyzed by H. HARAMURA.
Analytical method and the error in the measurements are the same by HARAMURA *et al.* (1983).

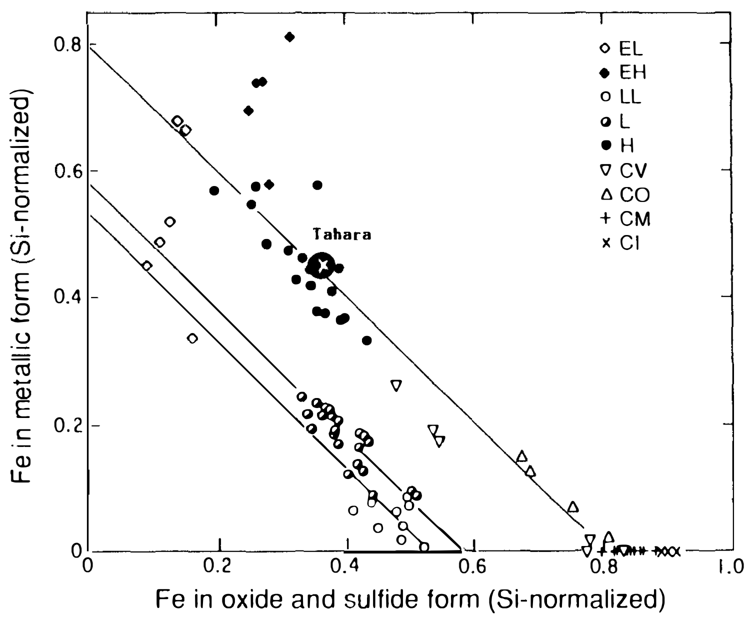

Fig. 4. Diagram of Fe in oxide and sulfide and Fe in metal of Tahara meteorite.

Iron content in metal and troilite or in oxides which were determined from magnetic and non-magnetic fractions reported by HARAMURA *et al.* (1983) shows 19.21 or 8.46 (wt%), respectively. The ratio Fe (in metallic form)/Si or Fe (in oxide and sulfide form)/Si is obtained as 0.44 or 0.36 respectively. These bulk chemical data are plotted in the center of the H chemical group reported by HARAMURA *et al.* (1983) and SEARS and DODD (1988), as shown in Fig. 4. Chemical data of iron in oxide, FeS and metal indicate that this chondrite belongs to the typical H chemical group.

5. Petrological Type of the Tahara Meteorite

Thin section examination revealed well defined chondrules in a microcrystalline (35%) or recrystallized (65%) matrix (Figs. 5, 6 and 7). Twenty chondrules, 0.5 to 1.5 mm in size, show radial (65%) and porphyritic (35%) textures, and readily defined (65%) and well-defined (35%) chondrules. Pyroxenes with radial or granular textures of chondrules are usually Opx, but some of the large ones are Cpx with Wo 7 (mol%). Troilite and Fe-Ni metal are present. Dark glassy grains in olivine chondrules are observed with olivine and plagioclase compositions. Several dark microcrystalline grains (10–50 μm) with plagioclase composition (An_{17-22}) were observed in porphyritic olivine ($An_{17}Or_8$ or $An_{22}Or_6$ with MgO = 2.4–4.1 wt%), though a granular pyroxene chondrule which contains microcrystalline glassy grains revealed Yagiite composition of Na-Mg type osumilite-group minerals (Mg/Mg + Fe) = 0.8, Na/(Na + Ca + K) = 0.6, MgO = 7.3 wt%) (Figs. 6 and 7). The shock stage reported by STÖFFLER *et al.* (1991) was obtained as S3 (10 Gpa). This is mainly because olivines with irregular fractures show almost clear (unshocked) or undulatory extinction (10–20 GPa) which is dependent on the

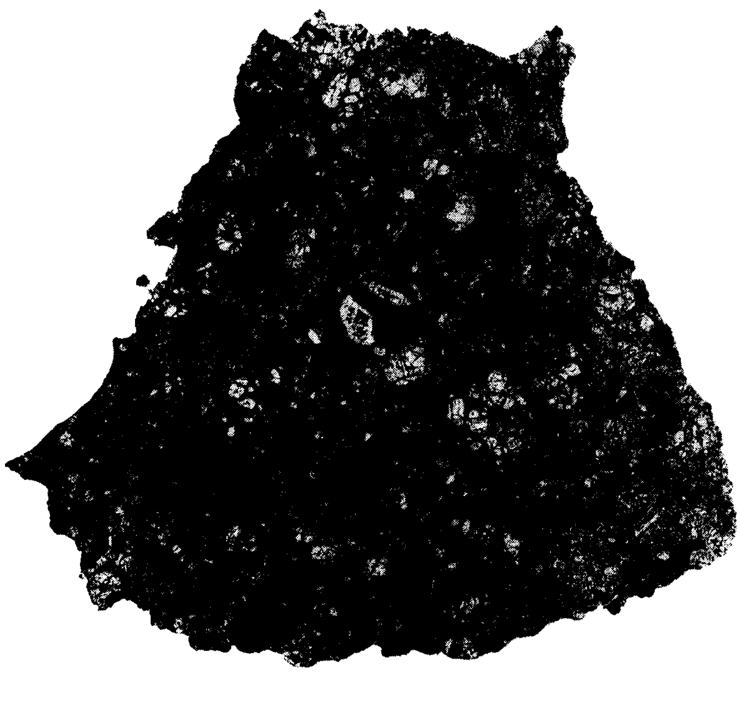

Fig. 5. Photomicrograph of the Tahara-2D,51 meteorite. Field of view is 10 mm.

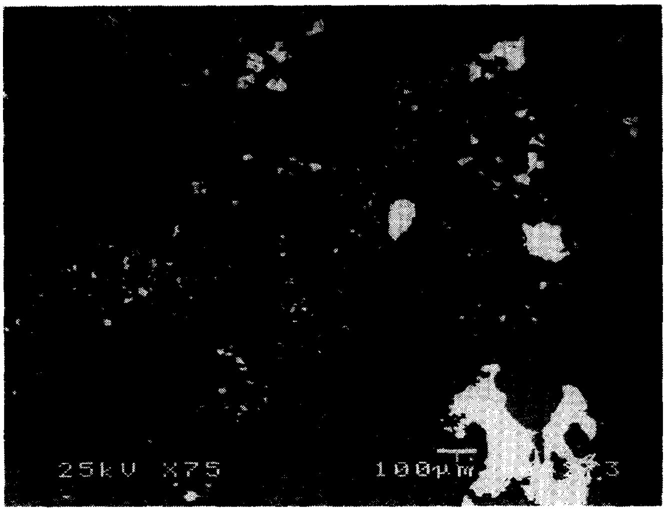

Fig. 6. Porphyritic olivine chondrule (center of figure) with plagioclase-like grains ($An_{22}Or_6$, with $MgO = 4.2$ wt%) in the Tahara-2D,51 meteorite (BEI image).

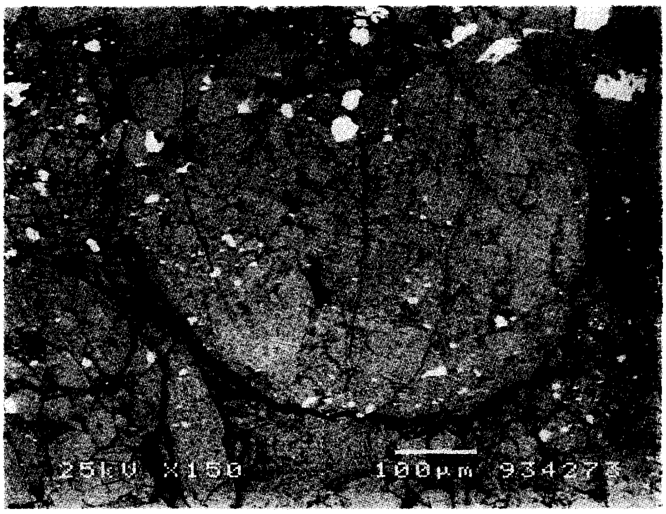

Fig. 7. Granular pyroxene chondrule (center of figure) with Yagiite-like grains of a Na-Mg type osumilite group mineral in the Tahara-2D,51 meteorite (BEI image).

chondrule, and because dark and plagioclase-like microcrystalline grains reveal undulatory extinction (10–20 GPa).

Analysis of 77 olivine grains shows a variation in composition from 17.5 to 19.6 (Avg. 18.6; PMD 1.5%) (Fig. 8; DODD, 1981). Thirty-six pyroxene grains show a range in composition from Fs 15.6 to 17.0 (Avg. 16.3; PMD 1.8%) (Fig. 8 and Table 3). Based on the petrographic data, the Tahara meteorite is classified as

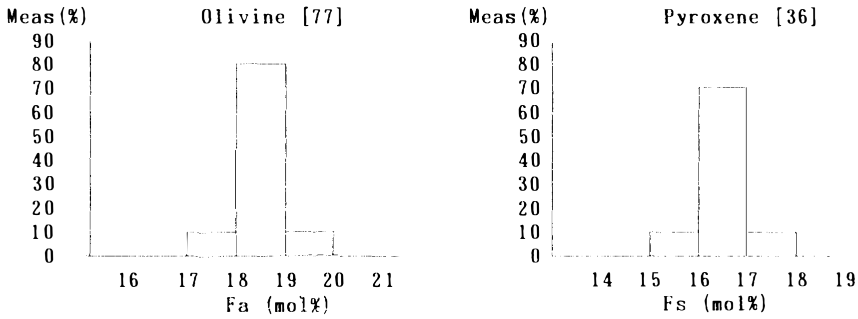

Fig. 8. Histogram of iron-contents of olivine and orthopyroxenes in the Tahara-2D,51 meteorite.

Table 3. Petrologic type determined by textural characteristics of the Tahara meteorite.

Texture of chondrule	Texture of matrix	Glass in chondrule	Development of feldspar	Low-Ca pyroxene	PMD. (Avg.)	Petr. type
Readily delineated and well-defined	Micro-crystalline and re-crystallized	Devitrified glass and absent	Microcrystalline aggregates ($10\times20\,\mu$m; $20\times50\,\mu$m)	opx + cpx (~7%)	Fa: 1.5 Fs: 1.8	
(4.7)	(4.7)	(4.5)	(4.5)	(4.3)	(4.5)	4~5* (Avg. 4.6)

* Similar petrologic type of Antarctic Yamato-75 chondrites (MIURA and MATSUMOTO, 1982).

petrologic type 4–5 (or 4.6 in average total) (*cf.* Table 3).

6. Retrieval Process of the Meteorites

The Tahara meteorite is classified as an H4–5 chondrite based on the chemical and petrographic study. The Tahara-1 chondrite was first reported as an H5 (or L5) based on electron microprobe analysis (*cf.* SHIMA *et al.*, 1993a). More pieces of the meteorite should be studied to determine whether Tahara-2D is representative of the entire meteorite or not.

The Mihonoseki meteorite fell on December 10, 1992 in Matsue-shi, Shimane Japan. Although this meteorite was found near the same area of Shimane-ken, it is not the same meteorite but a different heterogeneous meteorite classified as an L chondrite (MIURA and NOMA, 1993; SHIMA *et al.*, 1993b).

Antarctic meteorites are considered to be found meteorites, being fallen at various falling sites in limited areas and transported by the glacier movement (YANAI, 1978). Classifications and terrestrial ages of these meteorites are, therefore, significant to determine the falling time and falling site. From the collecting process of view, the two found meteorites Tahara-1 and Mihonoseki show different falling sites, times and classifications. The Tahara meteorite was deliberately transported by one of the crew members to Shimane-ken, Japan. The other small fragments of Tahara-2 to -5 were pointed out at several places in western Japan after the larger Tahara-1 fragments were found. So, the finding history of the Tahara-1 and Mihonoseki meteorites resembles those of Antarctic meteorites except that the iceflow transportation was replaced by people.

7. Conclusions

The results of this study are summarized as follows:

(1) Based on electron probe microscopy, optical microscope and bulk chemical analysis the Tahara meteorite is classified as an H4–5 chondrite.

(2) The Tahara meteorite is the first retained meteorite which fell on a ship's deck, because the first one that fell in 1648 on the ship "Malacca" during a voyage from Holland to Java is now missing.

(3) Although the Tahara and Mihonoseki chondrites were found accidentally in the same locality and time, they are of completely different falling sites, -times and classifications. The retrieval process of these "found" meteorites is similar to Antarctic meteorites, glacier movement being replaced by the crew members.

(4) The Tahara chondrite is the 42nd meteorite known to have fallen in Japan.

Acknowledgment

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