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YAMATO-8451: A NEWLY IDENTIFIED PYROXENE-BEARING PALLASITE

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Abstract: Yamato-8451 is an unusual meteorite which is newly identified as a pyroxene-bearing pallasite. It consists mainly of Fe-Ni metal, olivine and pyroxene, and shows a porphyritic texture typical of most olivine, the same texture as that of all known pallasite meteorites. Yamato-8451 might have been classified as one of the common pallasites because of its exotic texture and mineral assemblage, a unique feature of pallasites, but it is highly unusual because it contains pyroxene. Most olivine and pyroxene crystals are well rounded to subrounded, but angular grains and grain aggregates are also recognized in the metallic host. Pyroxenes are mm-sized and consist of three different types in Ca content. These are: (1) exceptionally Ca-poor polysynthetic twinned orthopyroxene (under Wo 1.0), (2) Ca-poor non-polysynthetic twinned orthopyroxene (Wo 1.0–3.5) and (3) clinopyroxene (over Wo 40). The olivine composition is Fo 89.6 on average, the most magnesian known in all pallasites.

1. Introduction

The Yamato-8451 meteorite was collected by the glaciological party of the 25th Japanese Antarctic Research Expedition (JARE-25, 1983–1985) on the bare icefield around the Yamato Mountains (71°–73°S, 34°–37°E) in Queen Maud Land, East Antarctica. A total of 59 specimens were recovered by the expedition; they were initially processed at the National Institute of Polar Reasearch (NIPR) in 1985–1987.

During the preliminary identification and classification, the Yamato-84 meteorite collection was found to consist of one pallasite, one ureilite, one crystalline eucrite, 3 CM2 chondrites, five E chondrites and remaining ordinary chondrites, with one unique chondritic meteorite consisting of mixed H and L components. Yamato-8451 was preliminarily classified as a pallasite meteorite based on its exotic texture and mineral assemblage of Fe-Ni metal and olivine. But we have now found that Yamato-8451 is unique because it contains abundant mm-sized pyroxenes as a minor phase. Here we describe the mineralogy and petrology of this unusual type of pallasite.

2. Initial Processing and Analytical Methods

Yamato-8451 was collected and kept in a clean teflon bag in the same manner as other Antarctic meteorites of the Japanese collections. It was maintained with the other Yamato-84 meteorites in a frozen condition, below −20°C, in the field, during

Fig. 1. Yamato-8451 meteorite is an arrowhead-shaped specimen, weighing 54.8 g, partly covered by fusion crust and showing brownish-black weathered Fe-Ni metal and light brownish silicates (mostly olivine grains). The scale of the cube is 1 cm.

transportation from Antarctica to Japan, and at NIPR. These meteorites were returned to room temperature in a dry nitrogen-field cabinet at the NIPR and processed in a clean flow bench. After processing, Yamato-8451 was initially identified as a pallasite-like meteorite from its surface appearance and density.

Yamato-8451 is a small and arrowhead-shaped specimen (Fig. 1), weighing 54.8 g and partly covered by fusion crust. On the exterior surface, this specimen exhibits brownish-black weathered Fe-Ni metal and light brownish subhedral silicates up to 7 mm across. After its preliminary identification, using polished thin sections, the authors suggested that the Yamato-8451 meteorite is a pallasite which differs from all other pallasite meteorites in its unusual mineral assemblage (YANAI and KOJIMA, 1987b).

A small fragment chipped from the exterior of Yamato-8451 was made into polished thin sections at the NIPR. The sections were studied under a polarizing microscope, in transmitted and reflected light, and quantitative elemental analyses and elemental mapping of the constituent minerals were carried out using an automated JEOL JCXA 733 and a JXA-8800M electron probe microanalyzer (EPMA) with five spectrometers, at the NIPR. The analytical procedures of the EPMA are the same as those of KUSHIRO and NAKAMURA (1970).

3. Petrography and Mineral Composition

Examination of 29 thin sections shows that Yamato-8451 is coarse-grained, unbrecciated, and heterogeneous rock with a typically porphyritic texture. It consists mainly of Fe-Ni metal and olivine, with pyroxene, troilite, merrillite, schreibersite and brown iron oxides around metal grains (Fig. 2). The specimen is fairly heterogeneous, but the mode (in vol%) is roughly 55% olivine, 43% Fe-Ni metal, 1% troilite, 1% pyroxene, and less than 1% other phases. In thin section, Yamato-8451 has a typical porphyritic texture with well rounded olivine and pyroxene grains, 1 to 6 mm across, which are buried in metallic iron, with or without troilite and schreibersite.

Olivine: Olivine is the major phase within Yamato-8451 and it occurs as well rounded to subrounded individual grains and aggregates with numerous fractures, a few mm to under 10 mm across, in the metal matrix (Fig. 3a). In rare cases, well-rounded small olivine grains, without fractures, occur poikilitically included in pyroxene grains (Fig. 3b), and others occur as small grains in pyroxene (Fig. 3c).

Microprobe analyses show that the main olivine is compositionally homogeneous and Mg-rich (average Fo 89.5) when compared with those of other known pallasite meteorites. Olivine included in, or associated with, pyroxene has almost the same composition as that of the main olivine (Table 1).

Pyroxene: Pyroxene is not a major phase in Yamato-8451. It has three different types of occurrences, including polysynthetic twinned orthopyroxene (Opx-1) and non- polysynthetic twinned Opx (Opx-2). Polysynthetic twinned Opx grains are more common (Figs. 4a, 4b), are up to 2 mm across, and show well-rounded/rounded-

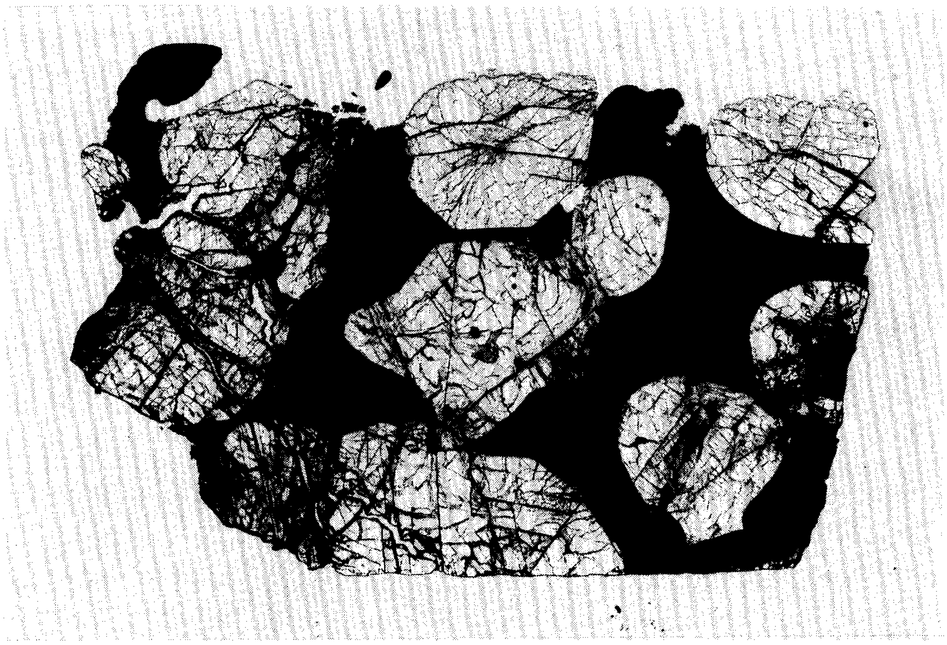

Fig. 2. Photomicrograph of a thin section of Yamato-8451, 50B-6, with a field of view of 9 mm. Yamato-8451 shows a typical porphyritic texture, consisting of rounded-subrounded olivine (major) and pyroxene (minor) buried in the Fe-Ni metal matrix. Plane polarized light.

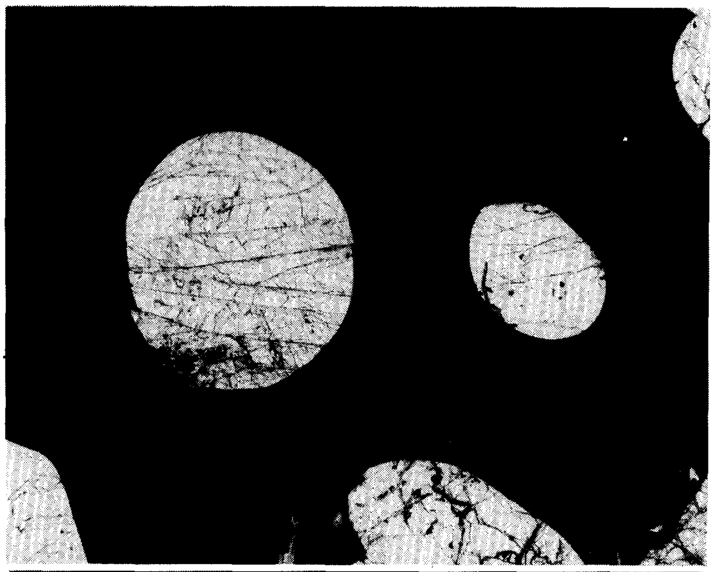

Fig. 3a. Well-rounded olivine grains, 1 to 1.4 mm across, set in the metal matrix. Plane polarized light.

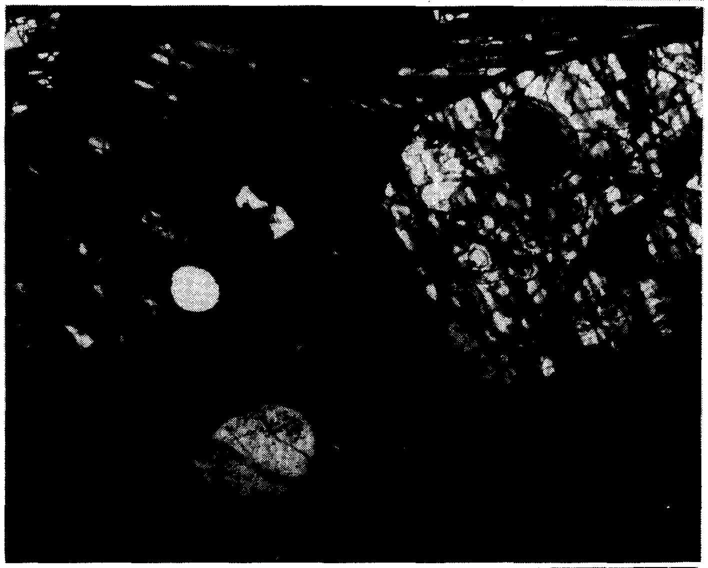

Fig. 3b. Olivine inclusions (Ol) in the exceptionally Ca-poor Opx (Opx-1, polysynthetic twinned). Well rounded olivine grains show clear rims and dusty cores. Size of olivine grains are 90, 150 and 200 μm across. Crossed polars.

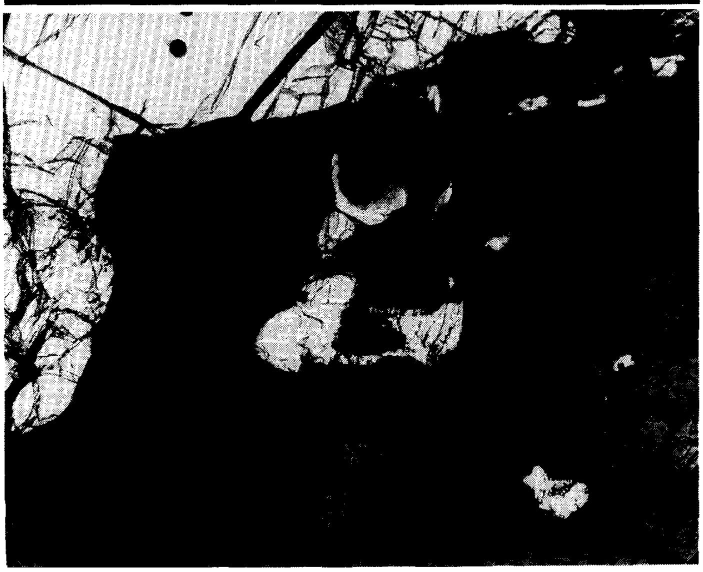

Fig. 3c. Very small olivine crystals (Ol) coexist with Ca-poor Opx (Opx-2, non-polysynthetic twinned). The olivine crystal is 50–150 μm across. Crossed polars.

Table 1. Microprobe analyses of major and minor silicate phases in the Yamato-8451 pallasite in weight percent.

	Olivine				Pyroxene				
	Ol-1	Ol-2	Ol-3	Ol-4	Px-1	Px-2	Px-3	Px-4	Px-5
	Main phase (60)	Inclusion in ex. low-Ca Opx (17)	Inclusion in low-Ca Opx (13)	With low-Ca Opx (3)	Ex. low-Ca Opx (main phase) (22)	Low-Ca Opx (main phase) (52)	Low-Ca Opx inclusion in Ol (9)	Low-Ca Opx in ex. low-Ca Opx (13)	Cpx in ex. low-Ca Opx (21)
SiO_2	40.23	40.17	40.45	39.97	57.04	57.51	57.15	56.68	54.86
TiO_2	0.01	0.01	0.01	0.01	0.03	0.05	0.04	0.04	0.06
Al_2O_3	0.01	0.02	0.02	0.01	0.16	0.19	0.26	0.17	0.29
Cr_2O_3	0.08	0.04	0.05	0.03	0.62	0.56	0.70	0.46	1.24
FeO	10.18	9.73	10.12	9.62	6.02	6.42	6.20	6.26	3.06
MnO	0.37	0.38	0.35	0.34	0.35	0.39	0.41	0.36	0.24
MgO	49.09	49.04	48.95	49.61	35.57	34.17	34.33	33.97	18.33
CaO	0.05	0.03	0.04	0.02	0.34	1.05	1.06	1.40	21.54
Na_2O	0.02	0.02	0.02	0.04	0.04	0.06	0.05	0.07	0.63
K_2O	0.01	0.01	0.02	0.01	0.01	0.01	0.01	0.02	0.01
Total	100.05	99.44	100.03	99.66	100.18	100.41	100.21	99.43	100.26
FeO/MnO	28.2	27.1	30.1	28.9	17.5	17.1	15.4	18.2	13.4
Mg*	89.5	89.9	89.5	90.2	90.8	88.7	89.0	88.3	51.6
Fe*	10.4	10.0	10.4	9.8	8.6	9.4	9.0	9.1	4.8
Ca*	0.1	0.0	0.1	0.0	0.6	2.0	2.0	2.6	43.6

*Atomic %, ex.: exceptionally

subrounded grains and typical polysynthetic twins. Non-polysynthetic twinned Opx occurs as inclusions in olivine, up to 0.7 mm (Fig. 4c) across and as aggregates up to 1.2 mm. Some occurs along the peripheries of polysynthetic twinned Opx grains (Fig. 4b). Clinopyroxene(Cpx) grains, up to 200 μm, are distinguished from non-polysynthetic twinned Opx grains (Fig. 4d).

Microprobe analyses show that Opx is present as three groups, based on their CaO values as shown in Figs. 5, 6 and Table 1. Polysynthetic Opx is an exceptionally Ca-poor pyroxene, with under 1 mol% Wo (under 0.4% CaO), and varies in composition from $Fs_{5.5-12.6}$ $Wo_{0-1.0}$ (Table 1, Px-1). On the other hand non-polysynthetic Opx is a Ca-poor pyroxene, with over 1 mol% Wo (over 1% CaO) ranging $En_{85.9-90.1}$ $Fs_{8.2-12.6}$ $Wo_{1.0-3.5}$ (Table 1, Px-2). Some pyroxenes, which are poikilitically included in the exceptionally Ca-poor Opx (polysynthetic) and olivine, show a non-polysynthetic twin texture and contain more CaO than those with the polysynthetic twins; but they are similar to those of the individual non-polysynthetic grains (Table 1, Px-3, Px-4). Very small grains of Ca-rich pyroxene (non-polysynthetic twinned), $En_{51.6}$ $Fs_{4.8}$ $Wo_{43.6}$, are found in the Ca-poor non-polysynthetic twinned pyroxene (Table 1, Px-5).

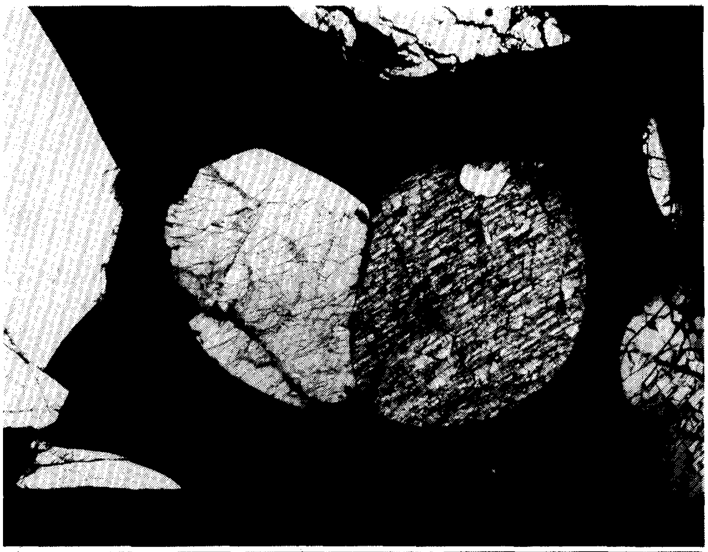

Fig. 4a. Well rounded exceptionally Ca-poor Opx (Opx-1, right), 1.6×2.0 mm and subangular olivine (left), 1.4×1.6 mm, in Fe-Ni metal (black). Orthopyroxene shows typical polysynthetic twinning, and includes olivine (white on top, 0.3 mm). Crossed polars.

Fig. 4b. Photomicrographs of three different coexisting pyroxenes, 1 mm across. Polysynthetic twinned exceptionally Ca-poor Opx (Opx-1, core) is mantled by non-polysynthetic Opx (Opx-2, rim). Clinopyroxene (Cpx) is included in non-polysynthetic Opx (right bottom). This photo corresponds to the elemental map (Fig. 5). The field of view is 1.6 mm. Crossed polars.

Other phases: Fe-Ni metal is the most common, and major, phase in pallasite meteorites. Yamato-8451 also contains Fe-Ni metal as the major phase, making up almost half of the meteorite. Most metallic phases are taenite, and plessite with kamacite, and they have been changed to brown limonitic iron oxide due to alteration. Metals along grain boundaries with silicates were especially oxidized. Troilite and schreibersite are minor phases. Most troilite occurs in the rims of metal grains, along silicate-silicate boundaries, and as tiny inclusions in silicates. Schrebersite occurs with troilite, as fine grains.

4. Comparison with Known Pallasites and Some Antarctic Lodranites

Olivine: Figure 7 shows the compositions of olivines in all known (main group and Eagle Station grouplet) pallasites (GRAHAM *et al.*, 1985), with some Yamato lodranites from Antarctica (YANAI 1981; YANAI and KOJIMA, 1987a). Olivine in

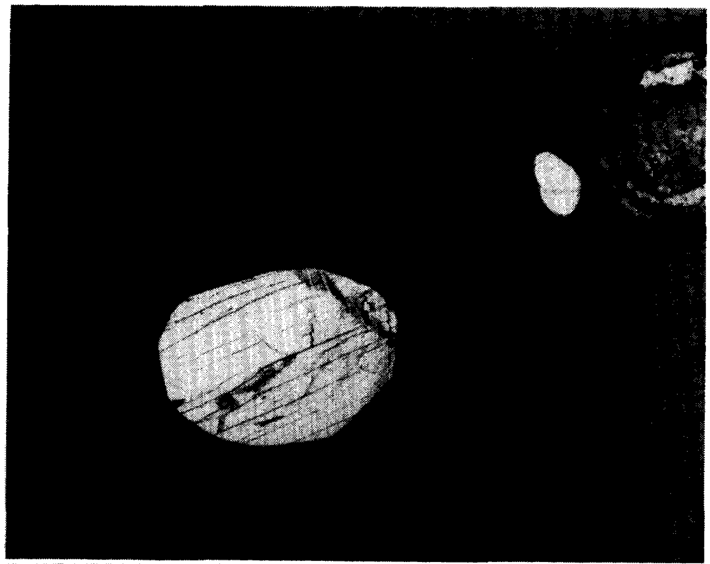

Fig. 4c. Photomicrograph showing inclusions in olivine (Ol). Two inclusions of non-polysynthetic twinned Ca-poor pyroxene, 20–700 μm across, are included in olivine with parallel fractures.

Fig. 4d. Clinopyroxene (Cpx) crystal in Ca-poor Opx (Opx-2, non-polysynthetic), 150–200 μm.

Yamato-8451 is more magnesian than that in all other pallasites, but it is similar to the olivine in some lodranites. However, while lodranites consist mainly of olivine, pyroxene and Fe-Ni metal, their textures are quite different from those of the Yamato-8451 meteorite, and therefore we call it a pallasite.

Pyroxene: It was believed for a long time that pyroxene is absent from pallasites. However, BUSECK (1977) showed that pyroxene (not previously described from pallasites) occurs in seven pallasites. All of those pyroxenes in pallasites occur as symplectic intergrowths, are micron-sized and are exceptionally Ca-poor (0.1–0.2 wt%). As already described in this paper, the Yamato-8451 meteorite contains relatively large pyroxene crystals, up to 2 mm across. Although the pyroxenes are not a major phase, one to several grains are observed in each thin section, as well rounded-subangular grains similar to those of the olivine grains. As stated above, there are three different types of pyroxene: (1) polysynthetic twinned exceptionally Ca-poor Opx, (2) non-polysynthetic twinned Ca-poor Opx, and (3) clinopyroxene.

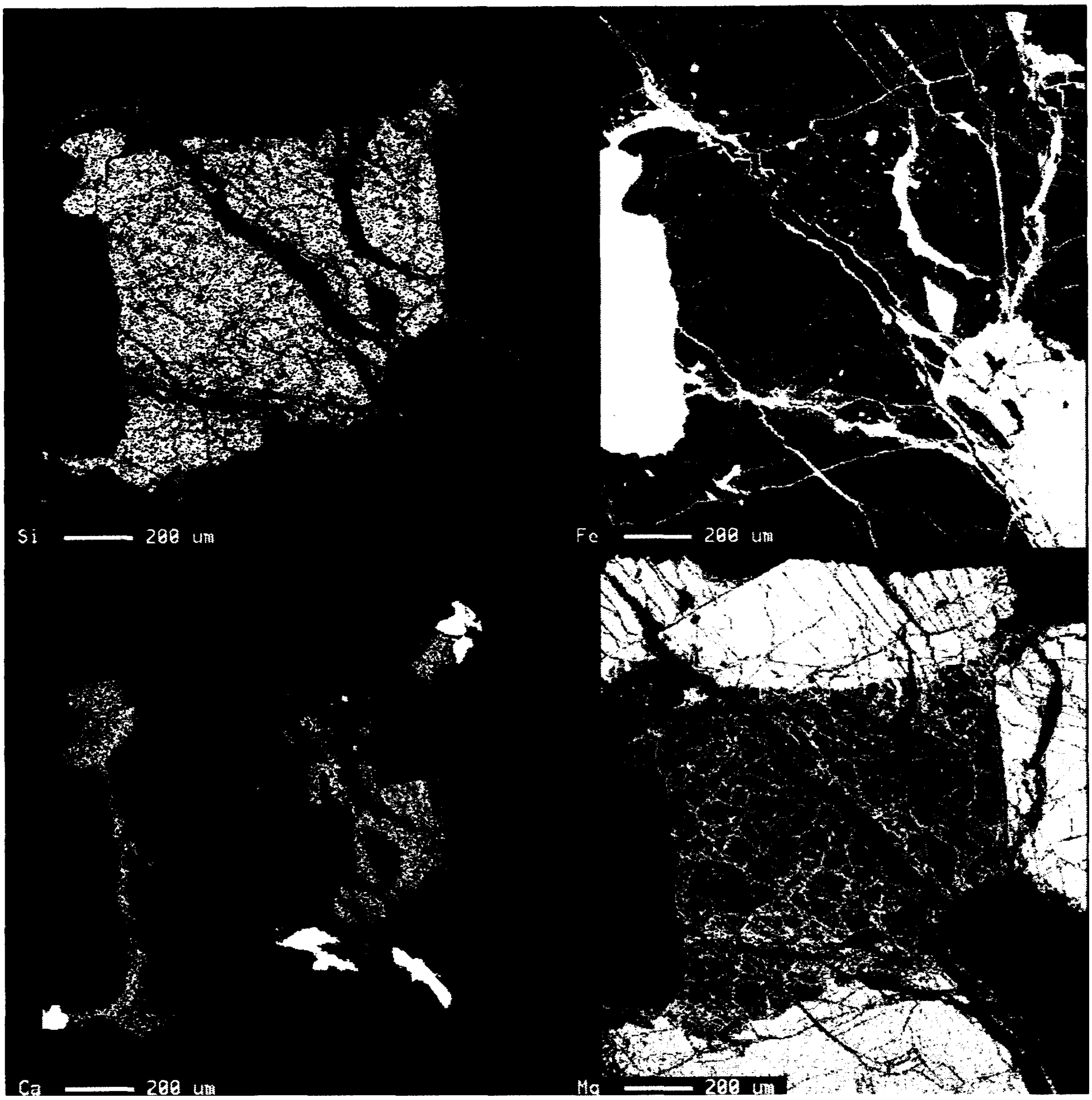

Fig. 5. Photographs showing Si, Fe, Ca and Mg elemental maps of the constituent minerals (mostly pyroxene) of Yamato-8451, analyzed with a JXA-8800M electron probe microanalyzer for almost a million analytical points. An almost square pyroxene crystal, set in the center, in which three different pyroxenes are clearly distinguished as dark blue (polysynthetic twinned exceptionally Ca-poor Opx), red-yellow-green-pale blue (non-polysynthetic Ca-poor Opx), and white (Cpx) (lower center) in Ca map. Other white areas are merrillite. This photograph corresponds roughly to Fig. 4b.

5. Summary and Conclusions

Yamato-8451 is identified as a pallasite which includes some pyroxene coexisting with olivine, because of its exotic texture and constituent minerals. The texture of Yamato-8451 is typically porphyritic, consisting of rounded olivine and pyroxene grains buried in an Fe-Ni metal matrix. This exotic texture is the same as that of all

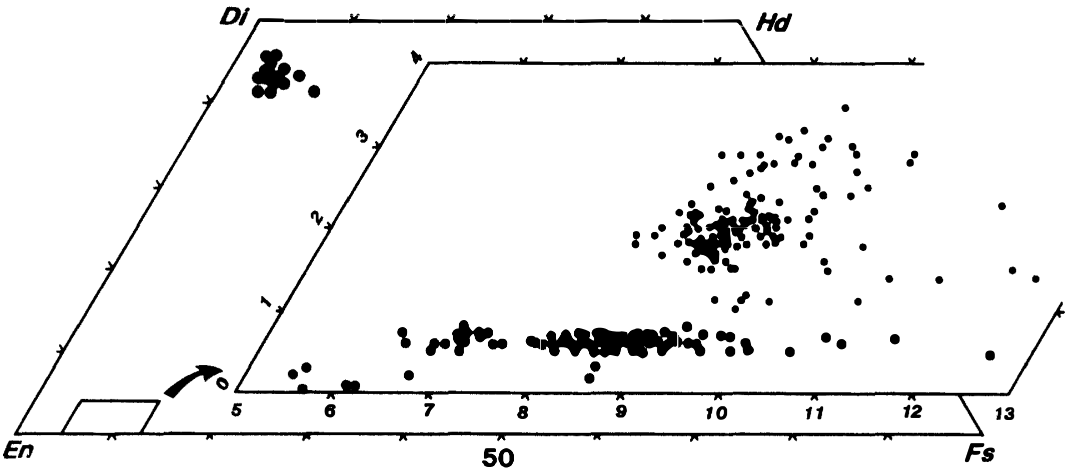

Fig. 6. Plot of Yamato-8451 pyroxene compositions on the pyroxene quadrilateral. Pyroxenes belong to different groups of Ca-rich (diopside, large solids) and Ca-poor pyroxenes. Ca-poor orthopyroxene is clearly separated into Ca-poor Opx (small solids) and exceptionally Ca-poor Opx (intermediate solids), which correspond to their textures. En: enstatite, Fs: ferrosilite, Di: diopside, Hd: hedenbergite.

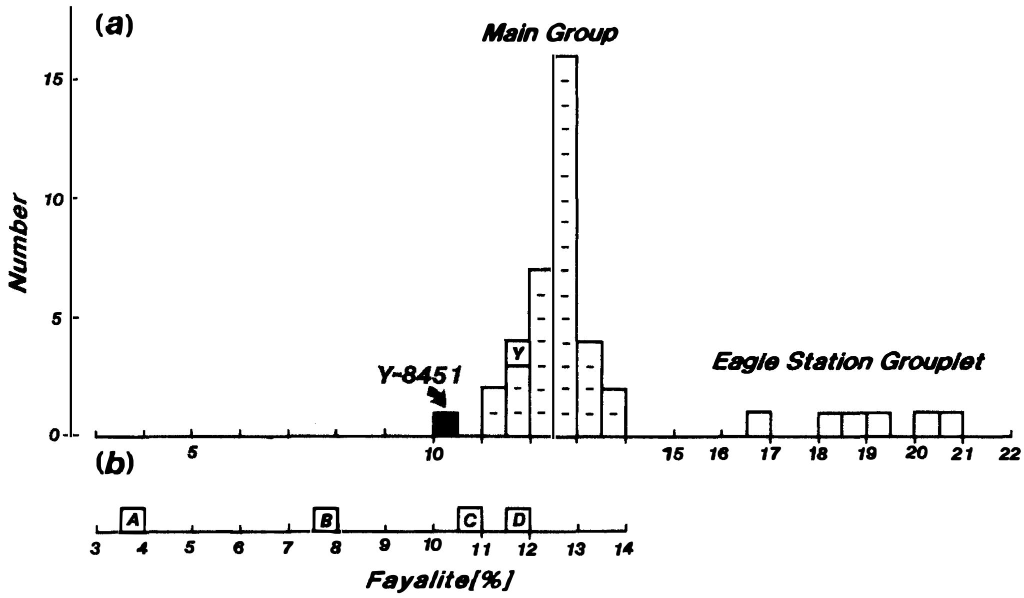

Fig. 7. Histograms showing the fayalite % of olivines in (a) all known (main group and Eagle Station grouplet) pallasites and (b) some Yamato lodranites. The olivine in Yamato-8451 is the most magnesian in all known pallasites. Y: Yamato-74044 pallasite. A-D: Lodranites (A: Yamato-75274, B: Yamato-74357, C: Yamato-791491, D: Yamato-791493).

other known pallasite meteorites. This is the first time that large pyroxene crystals coexisting with olivine have been identified in a pallasite, as a common occurrence. Moreover, three different pyroxenes with distinct textures and mineral compositions are distinguishable.

Yamato-8451 meteorite is an unusual specimen classified as pyroxenes bearing pallasite.

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