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ANGRITE ASUKA-881371: PRELIMINARY EXAMINATION OF A UNIQUE METEORITE IN THE JAPANESE COLLECTION OF ANTARCTIC METEORITES

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Abstract: A new angrite-type achondrite was discovered at a new site of meteorite concentrations in Antarctica by the Japanese expedition party in December 1988. Antarctic meteorite Asuka-881371 (previously Asuka-9) is an angrite-type achondrite, which is a rounded individual stone, almost completely covered with a dull-black fusion crust. Pale green, relatively large porphyritic olivine crystals can be seen on the exposed face of the interior. Asuka-881371 is an unbrecciated, igneous rock with typically ophitic (doleritic) texture, consisting mainly of olivine, pyroxene (fassaite) and plagioclase with spinel. From its texture, mineral assemblages and chemical composition, Asuka-881371 is identified and classified as an angrite. However, based on several characteristics, especially bulk chemical composition, Asuka-881371 is different from Angra dos Reis, LEW86010 and LEW87051 angrites which are the three previously known angrites collected from non-Antarctic and Antarctic regions.

1. Introduction

The Asuka-88 meteorites were collected by the 29th Japanese Antarctic Research Expedition (JARE-29, 1987–1989) on the bare icefield around the Sør Rondane Mountains (71°–73°S, 21°–29°E) in Queen Maud Land, East Antarctica (YANAI, 1989; YANAI and The JARE-29 ASUKA PARTY, 1989; YANAI *et al.*, 1993; NARAOKA *et al.*, 1990; CASSIDY *et al.*, 1992) (Fig. 1). Almost 2000 new specimens were recovered by the expedition and were initially processed at the National Institute of Polar Research (NIPR) in 1989–1992 (YANAI, 1993; YANAI and KOJIMA, 1992; YANAI *et al.*, 1993).

During the initial processing and preliminary identification, some unique-unusual specimens of these meteorites were identified. Among the almost 2000 specimens of the Asuka-88 collection, Asuka-881371 is one of the more unique specimens. It consists of an olivine-fassaite-plagioclase assemblage with complete crystalline igneous texture. Asuka-881371 is identified as an angrite-type achondrite, but the specimen is fairly different from the original angrite, Angra dos Reis (ADOR), based on its texture, mineral assemblage and bulk composition. However, the two meteorites are similar in their mineral compositions (PRINZ *et al.*, 1977).

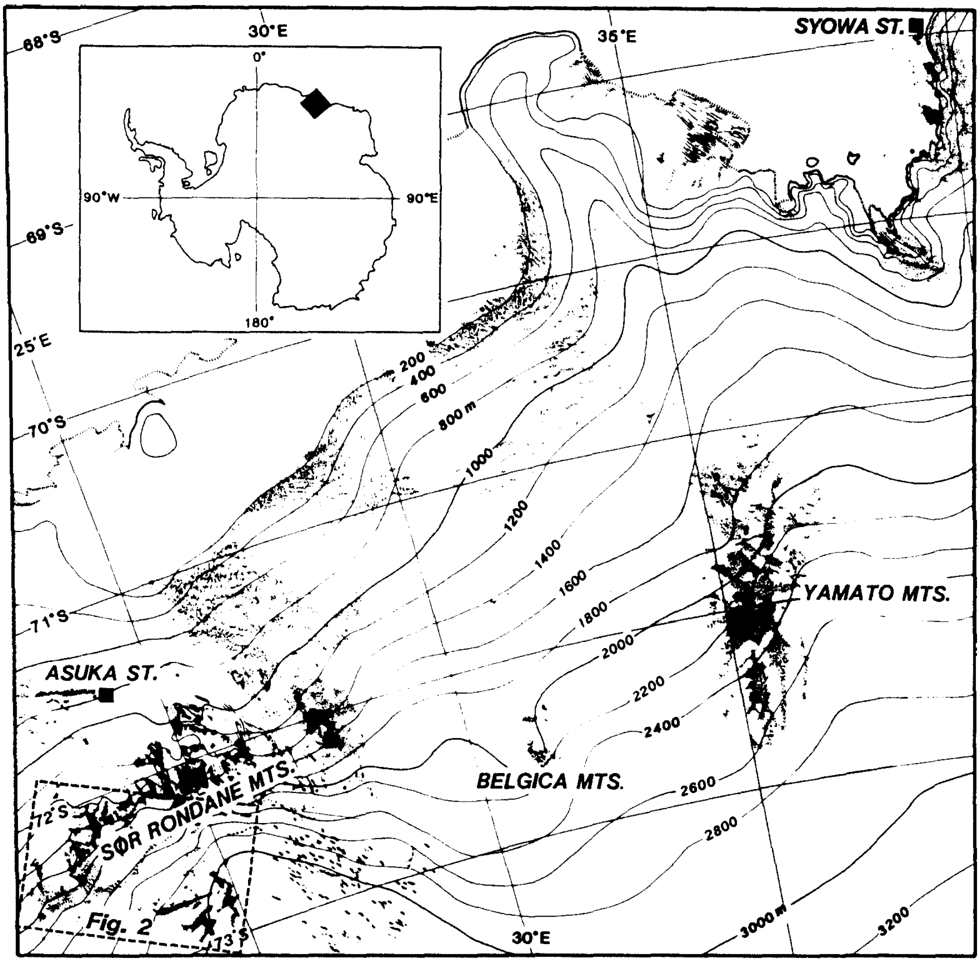


Fig. 1. Location map including the Yamato Mountains, Belgica Mountains and Sør Rondane Mountains in Queen Maud Land, East Antarctica. The map also includes the bare ice (blue ice) fields indicated as dotted areas. The location of the Japanese base "Syowa Station" (operated) and "Asuka Station" (closed in 1991) are noted.

2. Asuka-881371 Meteorite; Recovery and Initial Processing

The search party for Antarctic meteorites of JARE-29, led by the author, revisited the Nansenisen (Nansen Icefield) during the October 1988 and January 1989 austral summer season. The party recovered the Asuka-881371 meteorite on the main bare ice (approximately 72°45′S, 24°E) on the Nansen Icefield on December 1988 (Fig. 2). Asuka-881371 occurred on the bare ice surface, as do most other Antarctic meteorites, and it was collected and kept in a clean teflon bag in the same manner as other Antarctic meteorites.

Asuka-881371 was maintained together with other Asuka-87 and Asuka-88 meteorites in a frozen condition below $-20°C$ in the field, during transportation from Antarctica to Japan, and at NIPR. After its preliminary identification using polished thin sections (PTS), the author suggested that the specimen differs from all other meteorites in the collection, except several unique-unusual specimens includ-

Fig. 2. The site of discovery of Asuka-881371 (previously A-9) angrite (✪). Asuka-881371 was found on the main bare ice in the Nansen Icefield (Nansenisen), south of the Sør Rondane Mountains. Also shown is the find site of Asuka-881757 (A-31), a new lunar basalt (★). It is more than 300 km west of the Yamato meteorites main site. See Fig. 1 for location.

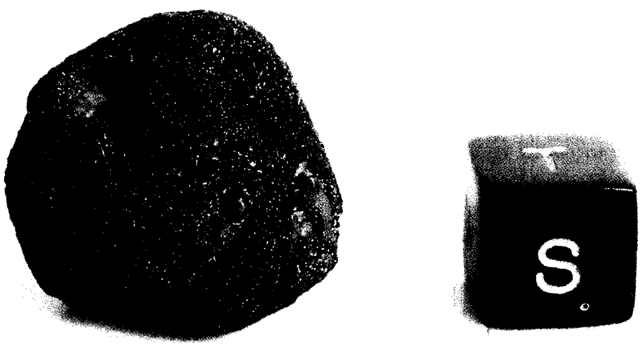


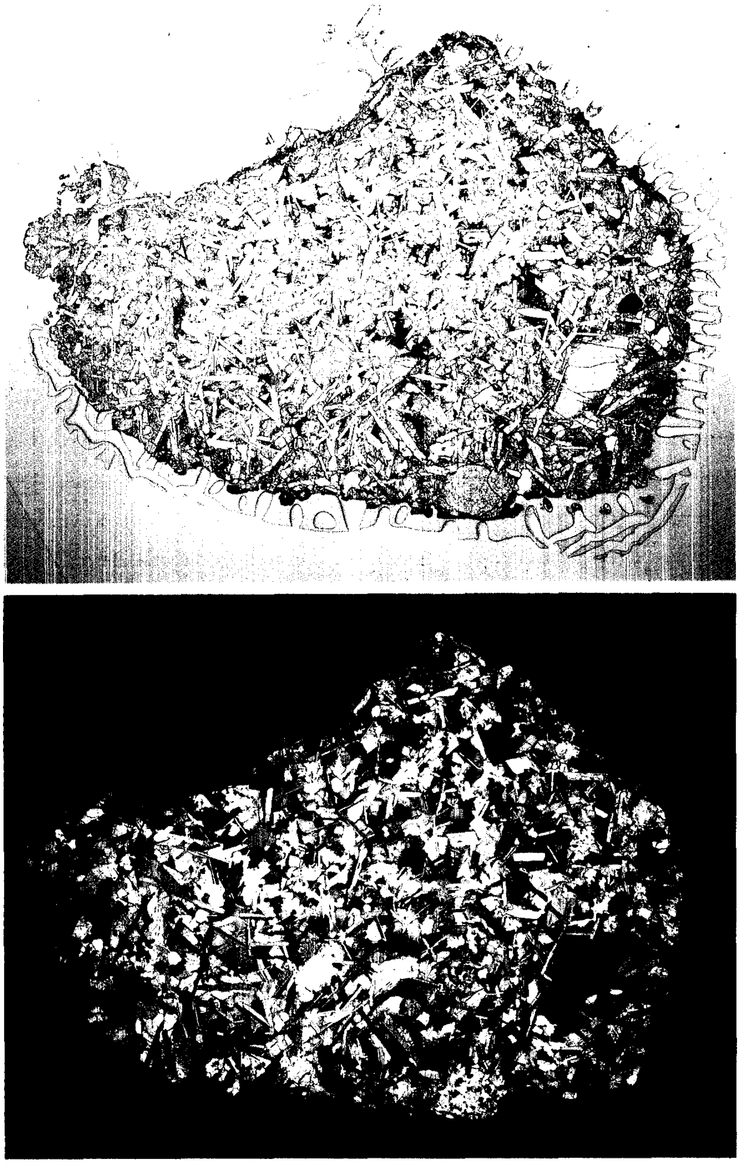
Fig. 3. The Asuka-881371 angrite-type achondrite is a rounded stone and almost completely covered with a dull-black fusion crust, showing pale green, relatively large porphyritic olivine crystals on the exposed interior. Scale cube is 1 cm.

ing the Asuka-881757 lunar meteorite (previously named Asuka-31).

The specimen was tentatively named Asuka-9 (A-9). Then it was officially named Asuka-881371, based on the naming system of the Japanese collections of Antarctic meteorites. Asuka-881371 weighed 11.270 g and measured 2.0 × 1.6 × 1.6 cm. The original volume of the specimen is 3.3 cm^3 and the specific gravity is 3.43 g/cm^3. Preliminary description and photography of the specimen were carried out by the author (YANAI, 1991, 1993).

The specimen is a rounded stone, almost completely covered with a dull-black

(a)



(b)

Fig. 4. Photomicrographs of thin section of Asuka-881371; field of view is 13 mm. Asuka-881371 is an unbrecciated, igneous rock with an ophitic (doleritic) texture, consisting mainly of euhedral granular olivine, prismatic plagioclase, intergranular pyroxene, and relatively coarse-grained porphyritic olivine. Pyroxen is strongly pleochroic, and some shows a brown color. (a) Plane polarized light. (b) Crossed polars.

fusion crust (not shiny) (Fig. 3). Relatively large, pale green porphyritic olivine crystals are seen on the exposed interior face. The photomicrograph of the thin section (Fig. 4) shows an unbrecciated and typically ophitic (doleritic) texture with euhedral olivine and plagioclase, intergranular pyroxene and Ca-olivine (kirschsteinite). Relatively coarse-porphyritic olivines are as large single grains and a mosaicized dunite-like fragment or inclusion. The sample contains some opaques and spinel as accessories.

3. Sampling and Analytical Methods

A small fragment chipped from the exterior of Asuka-881371 was made into two polished thin sections at the NIPR. The sections were studied under the microscope in transmitted and reflected light. Quantitative elemental analysis and elemental mapping of the constituent minerals were carried out using an automated JEOL JCXA733 and 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).

A 700 mg interior chip was used for standard wet chemical analysis and it was chemically analyzed by H. HARAMURA at the NIPR.

4. Petrography and Mineral Compositions

Examination of thin sections shows that Asuka-881371 is an unbrecciated, igneous rock with a typically ophitic (doleritic) texture, consisting mainly of isolated porphyritic and euhedral olivine, intergranular pyroxene (fassaite), interstitial Ca-olivine. and euhedral plagioclase (not maskelynitized), with minor spinel (Fig. 4). The mode of Asuka-881371 is roughly 5% porphyritic olivine, 24% euhedral olivine in the groundmass, 20% pyroxene, 36% plagioclase and 15% Ca-olivine (kirschsteinite) in the groundmass and under 1% in other phases, including ilmenite and apatite (Figs. 5, 6 and 7). In the sections, Asuka-881371 shows a porphyritic texture with relatively coarse-grained olivines, 1 to 1.5 mm across, showing remarkable zonal texture in their rims. Cores of the porphyritic olivine are much more magnesian than cores of the euhedral olivines in the groundmass (Figs. 6a and 7). From its texture and striking of chemical zoning in olivine, it is clear that this meteorite originated from igneous activity on or near the surface of its parent body.

Olivine: Olivine occurs in three textual types: porphyritic grains, groundmass grains, and interstitial groundmass grains. Relatively coarse, porphyritic olivines occur as large single grains and a mosaicized inclusion-like fragment, with remarkable rims (Figs. 5, 6a). The porphyritic olivines are zoned from the most Mg-rich cores (almost Fo_{90} in the mosaicized olivine, but more typically averaging Fo_{85} in

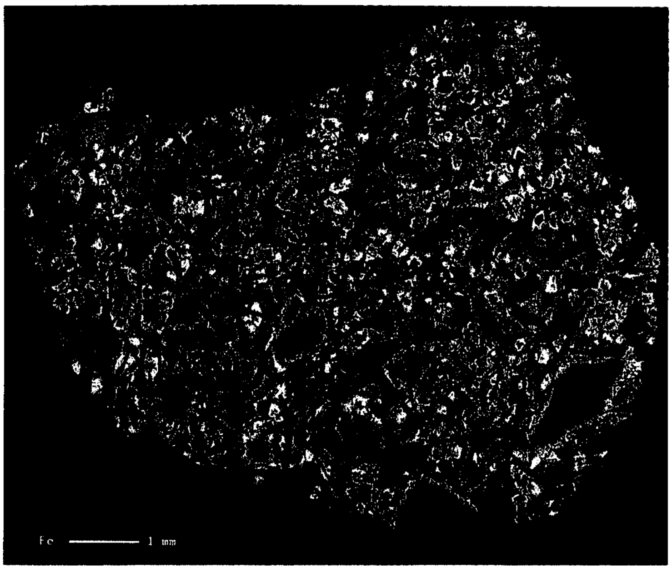
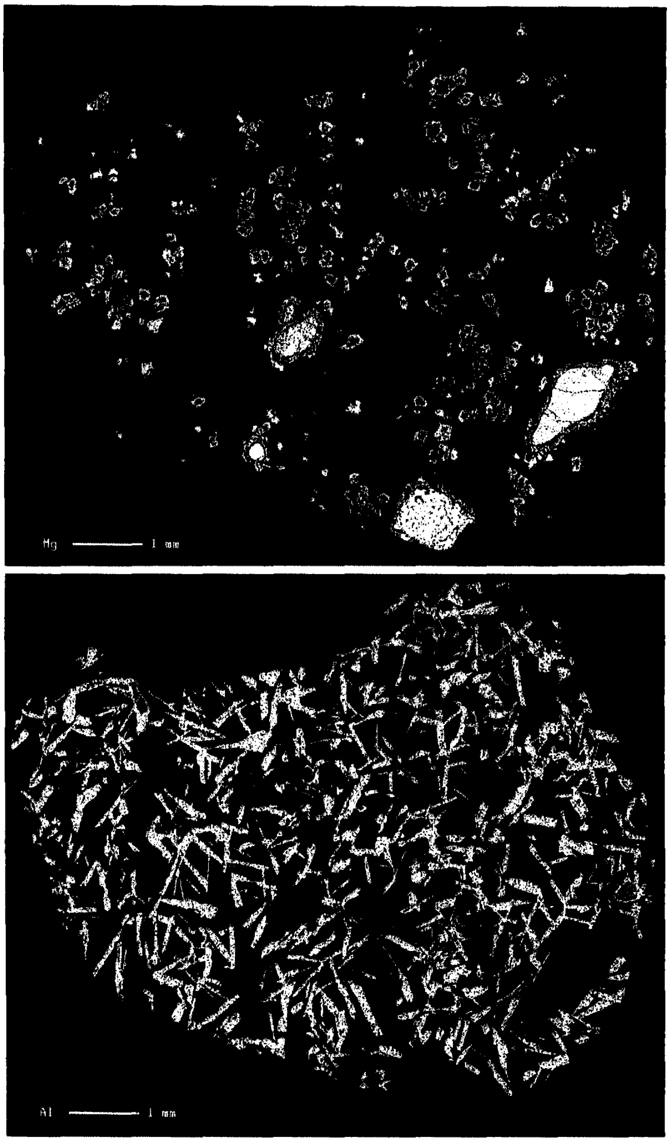


Fig. 5. Photograph showing Fe elemental map of the constituent minerals of Asuka-881371, analyzed with an JXA-8800M electron probe microanalyzer for almost 800000 analytical points. Olivine is indicated as blue-green-yellow-red color. Blue with dark blue core is fassaite. Plagioclase is black.

(a)



(b)

Fig. 6. Elemental maps showing olivine and plagioclase. (a) Mg map showing olivine. There are two types of olivine: porphyritic olivine with Mg-rich cores (white) and thin Fe-rich rims (red), and isolated groundmass olivine grains (red-yellow-blue) with compositional zoning. (b) Al map showing plagioclase (yellow) distribution.

other porphyritic grains) to compositions that are as Fe-rich as the cores of euhedral olivines in the groundmass. The rims of the porphyritic olivines, varied in composition from intermediate ($\sim Fo_{45}$) to extremely Mg-poor ($Fo_{0.0}$) immediately adjacent to the groundmass. Futhermore, euhedral olivines in the groundmass are zoned from less Mg-rich cores ($\sim Fo_{66}$) to very Fe and Ca-rich ($\sim$50% Fe, $\sim$50% Ca) rims. Interstitial groundmass olivines are kirschsteinite.

Pyroxene: Pyroxene occurs as intergranular grains. They are strongly pleochroic, ranging from nearly colorless in the cores to dark-brown in the rims. Pyroxene is extremely high in CaO (over 22%), and variable in Al_2O_3 (3.5–9.9%) and TiO_2 ($4.8 \times 0.8\%$) (Table 1). Most pyroxenes have uniform CaO, but show zoning from Mg-rich cores to Fe-rich rims, which corresponds to their pleochroic features. The pyroxene is fassaite, but only a few of the pyroxenes plot in the pyroxene quadrilateral where all known pyroxenes in lunar basalts plot (Fig. 8a).

Fig. 7. Back-scattered image of a porphyritic olivine in Asuka-881371. Olivine shows Mg-rich core surrounded by a thin layer of an Fe-rich rim. Field of view is 1.5 mm.

The pyroxenes have a remarkably high FeO/MnO ratio, and several grains lie within the range of average lunar pyroxenes, but most are clearly different from pyroxenes of lunar and basaltic achondrites (Fig. 9).

Plagioclase: Plagioclase is the most abundant mineral, almost completely homogeneous in composition, and is virtually pure anorthite of An_{99} (Fig. 8c). It is more calcic than that found in all known achondrites (except angrites) and in lunar basalts. No evidence of zoning or maskelynitization is found.

5. Bulk Chemistry

The results are presented in Table 2, with data for Angra dos Reis (ADOR), LEW86010 and LEW87051 angrites for comparison. The composition of Asuka-881371 is generally similar to that of LEW86010 and LEW87051 collected from Antarctica, but it differs markedly from the original angrite, Angra dos Reis, found in Brazil in 1869.

In detail, the composition of Asuka-881371 is higher than that of LEW87051 for Al_2O_3, FeO and CaO, but lower in SiO_2 and MgO. Asuka-881371 is remarkably high in FeO and MgO, but low in SiO_2, TiO_2 and CaO compared with ADOR. Asuka-881371 is also much higher in FeO and MgO and lower in SiO_2, TiO_2, Al_2O_3 and CaO than LEW86010 (MITTLEFEHLDT and LINDSTROM, 1990). Therefore Asuka-881371 might have originally differed from ADOR, LEW86010 and LEW 87051 angrites.

6. Discussion and Conclusions

Asuka-881371 is an unbrecciated, igneous rock with typical ophitic (doleritic)

Table 1. Microprobe analyses of major mineral phases in the Asuka-881371 angrite in weight percent.

	Olivine					Pyroxene					Plagioclase
	Mg-rich porphyritic (core)	Porphyritic (rim)	Euhedral in groundmass (core)	High-Ca groundmass (*)	Low-Ca Mg-poor, Fe-rich, groundmass	Mg-rich	Fe-rich, Al-poor or inter-mediate	Ti-rich or inter-mediate	Al-rich or inter-mediate	Ti, Al-poor or inter-mediate	Average (32)
SiO_2	39.9	33.3	34.1	31.0	29.7	45.6	44.5	40.7	42.4	49.9	43.3
TiO_2	0.00	—	—	0.03	0.10	1.58	2.42	4.75	2.75	0.81	0.02
Al_2O_3	0.04	0.02	0.07	—	0.05	9.13	3.91	8.26	9.79	3.51	36.50
Cr_2O_3	0.17	—	0.05	—	0.03	0.60	0.00	0.00	0.00	0.01	0.01
FeO	10.3	43.1	39.4	43.3	61.1	9.9	27.4	25.2	20.6	15.7	0.4
MnO	0.18	0.48	0.47	0.64	0.58	0.06	0.24	0.06	0.13	0.22	0.02
MgO	47.5	20.5	23.0	2.3	0.02	8.9	0.1	0.00	2.3	7.4	0.2
CaO	0.06	1.92	1.4	21.6	7.8	23.0	21.1	21.7	22.4	23.2	20.4
Na_2O	0.00	—	—	0.05	—	0.03	0.00	0.15	0.05	0.05	0.05
K_2O	0.00	—	0.00	—	—	0.01	0.00	0.0	0.03	0.00	0.01
Total	98.2	99.3	98.5	98.9	99.4	98.8	99.7	100.8	100.4	100.8	100.9
FeO/MnO	79.2	89.0	84.5	67.2	104.4	165.2	114.0	419.3	158.0	71.2	20.0
Mg	89.0	44.5	49.8	5.4	0.0	28.7	0.2	0.0	7.6	22.5	Ab 0.4
Fe	10.9	52.5	48.0	57.8	85.9	18.0	50.2	47.6	38.6	26.8	An 99.5
Ca	0.1	3.0	2.2	36.9	14.0	53.3	49.6	52.4	53.8	50.7	Or 0.1

* Kirschsteinite.

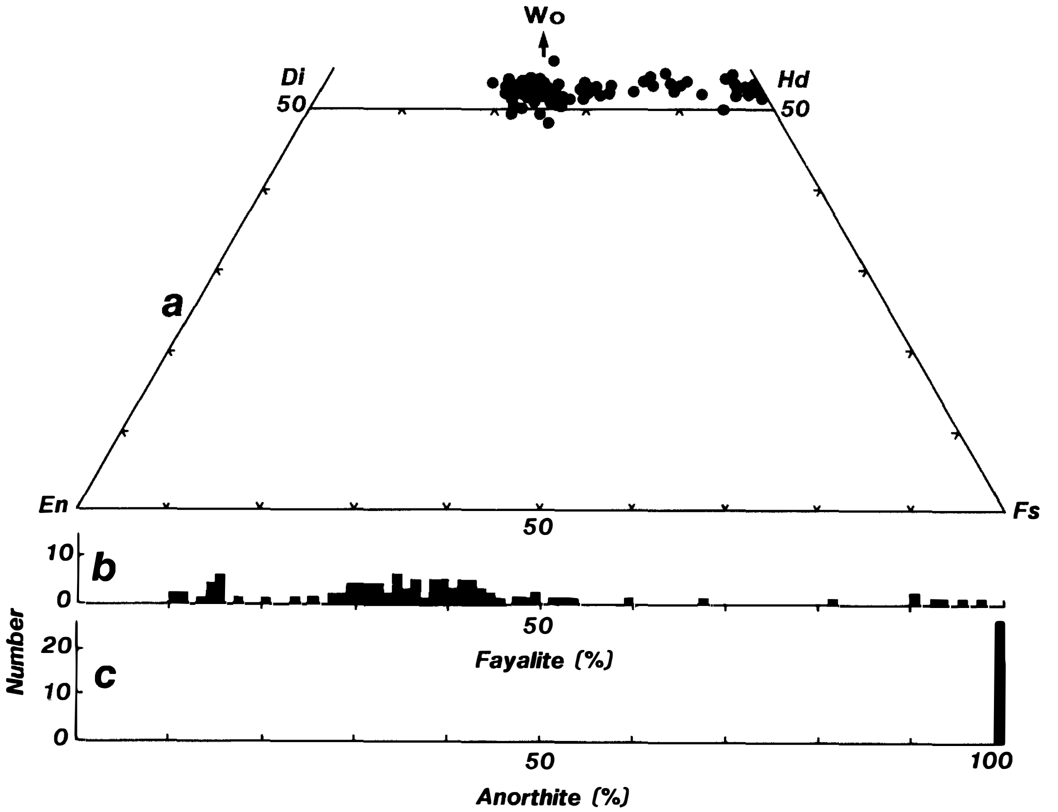


Fig. 8. (a) Plot of Asuka-881371 pyroxene compositions on the pyroxene quadrilateral. Wo is molar Ca/Ca + Fe + Mg and Fs is Fe/Ca + Fe + Mg. Most of these compositions are fairly Ca-rich and plot over Diopside-Hedenbergite tie-line in En-Fs-Wo diagram. Pyroxene is fassaite. (b) Distribution of olivine compositions varying a wide range of Fo contents. (c) Plagioclase is completely homogeneous and is virtually pure anothite.

texture, consisting mainly of olivine, fassaite pyroxene and almost pure anothite plagioclase. Some olivines with remarkable zoning form a porphyritic texture. These porphyritic olivines have highly Mg-rich cores, with narrow Fe-rich rims, and they are distinct from olivines in the groundmass, which are fine-grained, relatively iron-rich with less Mg-rich cores. Therefore, the porphyritic olivines might be xenocrysts.

Asuka-881371 is identified and classified as an angrite based on its mineral assemblage and Ca-pyroxene fassaite, texture, mineral compositions, and bulk chemistry. Asuka-881371 is different from Angra dos Reis (ADOR), LEW86010 and LEW87051 angrites based on their lithology, mineral compositions, and especially bulk chemical compositions (*e.g.* DELANEY and SUTTON, 1988; GOODRICH, 1988; KALLEMEYN and WARREN, 1989; MCKAY *et al.*, 1988a, b, 1990; MITTLEFEHLDT and LINDSTROM, 1990; PRINZ *et al.*, 1988, 1990; WARREN and KALLEMEYN, 1990). Therefore Asuka-881371 is an individual stone and is not paired with previously known angrites collected from non-Antarctic and Antarctic regions.

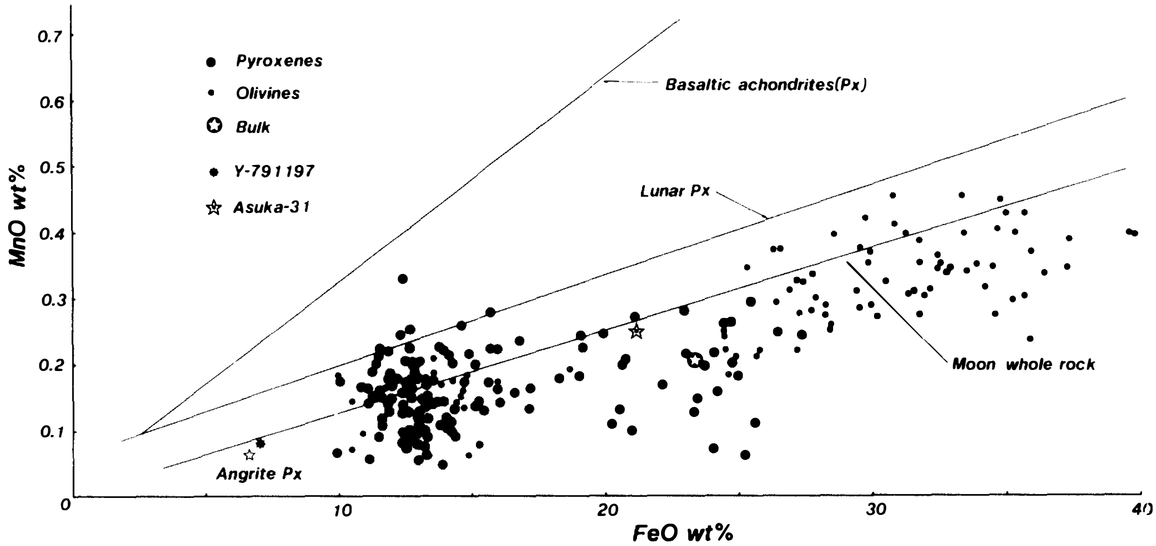


Fig. 9. FeO vs. MnO of olivine and pyroxene from Asuka-881371, compared to pyroxene trends in basaltic achondrites and lunar pyroxenes (indicated as lines). FeO-MnO ratios of bulkrocks are also plotted in this figure. Lunar meteorites (Y = Yamato, Asuka-31 = Asuka-881757).

Table 2. Major element compositions of four angrites in weight percent.

	Asuka-881371 (Asuka-9)	Angra dos Reis	Angra dos Reis*	LEW86010*	LEW87051*
SiO_2	37.30	43.22	43.7	39.6	40.4
TiO_2	0.88	2.33	2.05	1.15	0.73
Al_2O_3	10.07	8.92	9.35	14.1	9.19
Fe_2O_3	0.63	2.05	—	—	—
FeO	23.43	8.67	9.4	18.5	19.0
MnO	0.20	0.13	0.10	0.20	0.24
MgO	14.81	10.54	10.8	7.0	19.4
CaO	12.51	23.66	22.9	17.5	10.8
Na_2O	0.03	0.06	—	—	—
K_2O	0.02	< 0.02	—	—	—
H_2O (−)	0.00	0.00	—	—	—
H_2O (+)	0.0	0.1	—	—	—
P_2O_5	0.17	0.09	0.13	0.13	0.08
Cr_2O_3	0.13	0.20	0.21	0.11	0.17
Ni	233 (ppm)	260 (ppm)	—	—	—
Co	—	< 30 (ppm)	—	—	—
S	0.59	0.53	—	—	—
Total	100.77	100.52	98.7	98.3	100.0

Standard wet chemical analysis. Analyst: H. HARAMURA.
* Fused bead-electron microprobe analysis (MITTLEFEHLDT and LINDSTROM, 1990).

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