A REVIEW OF THE YAMATO-80, -81 AND -82 METEORITE COLLECTIONS

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Abstract: Examination of the 355 meteorite specimens returned from Antarctica and comprising the 1980, 1981 and 1982 Yamato collections has resulted in the full classification of 51 specimens. These include two specimens of lunar origin, a graphite-rich ureilite, a C5 chondrite, a type 1 carbonaceous chondrite, seven CO3 chondrites, six diogenites, eight eucrites and two howardites. Mineral compositions are given for most of the classified meteorites.

1. Introduction

Since 1969, the recovery of meteorite samples from Antarctica has provided many new specimens for research, including several previously unknown meteorite types. This contribution reports the classification of some of the specimens collected by Japanese field parties in the Yamato Mountains area during the 1980–81, 1981–82 and 1982–1983 field seasons. Reports on the routes taken by these field parties and the localities visited have already been published: those of the 1980–81 season by K. SHIRAISHI (personal communication), of the 1981–82 season by YOSHIDA and SASAKI (1983) and those of the 1982–83 season by KATSUSHIMA *et al.* (1984).

Briefly, the Yamato-80 collection was found between the Motoi Nunatak and the southern end of the Yamato Mountains. The Yamato-81 material was collected partly from the same area but also from an area extending south-westwards from the Yamato Mountains to the Minami-Yamato Nunataks. The Yamato-82 collection was made during traverses in the area immediately south of the Yamato Mountains towards the Minami-Yamato Nunataks and further due south from these to latitude 72°29′S. Some parts of these areas had been sampled by earlier field parties, notably the 1975 and 1974 expeditions, (YANAI, 1978; MATSUMOTO, 1978) and it is quite possible that some of the material in the 1980 to 1982 collections may be paired with earlier recoveries (*cf.* YANAI *et al.*, 1984).

During the three field seasons reported here a total of 355 meteorite specimens was recovered. Much of this material consists of fragments of ordinary chondrites weighing less than 10 g. Several specimens that are larger than this have been fully classified using mineralogical data obtained from polished thin sections using the electron microprobe (JEOL 733) at the National Institute of Polar Research. Table 1 lists the general subdivisions of the meteorites recovered as ordinary chondrites, achondrites and carbonaceous chondrites. Some of the last type are kept in cold storage

Table 1. Meteorites collected during the 1980–81, 1981–82 and 1982–83 field seasons in the Yamato region of Antarctica.

Expedition	Ordinary chondrites	Carbonaceous chondrites	Achondrites
Yamato-80	11	—	2
Yamato-81	123	7	2
Yamato-82	179	10	21

Table 2. Classification of some Yamato meteorites from the 1980–81, 1981–82 and 1982–83 field seasons.

Specimen name	Weight (g)	Type	Olivine Fa	Pyroxene Fs	Feldspar
Yamato-8001	20.4	L6	23.8–24.7	19.8–22.0	An10.0–11.0
-8002	2.2	Achondrite	3.5–3.9	3.5–4.0	An27, An1.1 Ab84.3 Or14.9
-8004	77.5	L6	24.8	19.7	
-8010	109.3	L5	23.6	20.1	
-8011	571.1	v. Y-8010			
-81001	2.5	Diogenite			
-81020	270.3	CO3	0.2–65.9		
-81021	7.7	v. Y-81020			
-81022	3.1	v. Y-81020			
-81023	9.5	v. Y-81020			
-81024	31.4	v. Y-81020			
-81025	55.4	v. Y-81020			
-81124	10790	H5	16.3–18.3	14.3–15.9	
-81132	6607	H6	17.5–19.2	15.5–17.0	
-82009	6.2	Eucrite		25.2–67.3	An79.2–93.0
-82010	7.3	Eucrite		26.4–55.3	An64.7–91.6
-82015	3.8	Eucrite		26.6–55.6	An79.7–93.5
-82021	13.4	Diogenite			
-82022	23.0	Diogenite			
-82024	420.4	L6	23.4–24.3	19.6–21.0	An10.3
-82026	119.3	H5	16.6–20.6	15.0–17.1	
-82027	7.7	Diogenite			
-82036	307.6	L6	25.1	20.6	
-82037	45.4	Eucrite		45.2–59.3	An89.9–92.2
-82038	199.9	H3	1.3–30.1	3.0–13.6	
-82042	37.0	C2	0.2–35.4		
-82043	96.1	L6	23.7–25.3	19.4–21.2	An6.0–10.7
-82049	115.3	Eucrite			
-82052	70.3	Howardite		19.9–64.5	
-82055	946.7	L3	8.8–25.9	3.3–38.1	An79.2–95.9
-82058	127.9	L3	15.0–24.2	3.9–19.3	
-82061	148.7	H4	17.8–19.8	15.0–18.6	
-82066	191.4	Eucrite		53.6–59.1	An88.6–93.2
-82071	13.8	L4	22.7–24.6	18.7–23.3	
-82074	10.0	Diogenite			
-82075	9.2	Diogenite			
-82082	662.2	Eucrite		55.2–60.8	An62.8–93.7

Table 2 (continued).

Specimen name	Weight (g)	Type	Olivine Fa	Pyroxene Fs	Feldspar
Yamato-82091	108.3	Howardite		22.1–69.0	An64.7–95.4
-82094	216.5	CO3	0.2–30.9	0.5– 1.3	
-82095	710.1	L3	18.1–27.2	4.8–21.4	
-82096	168.5	v. Y-82095			
-82100	12.3	Ureilite	2.8–17.6		
-82104	9.8	C5	29.9		An19.5–61.4
-82133	93.2	H3	0.6–22.5	0.5– 8.8	
-82161	757.5	H6	17.5–19.5	15.6–24.4	
-82162	41.6	C			
-82182	227.6	H5	17.4–23.9	15.3–23.0	
-82192	36.6	Anorthositic, breccia	6.8–89.1	8.1–57.6	An83.0–98.2
-82193	27.0	Anorthositic, breccia	48.7–81.1	16.2–47.0	An88.3–97.8
-82208	5.3	H3	5.0–30.0		
-82210	36.6	Eucrite		25.5–62.7	An78.1–93.5

and were not available for full characterisation. Details of the fully classified material are given in Table 2. Probable pairings are indicated but not all the specimens listed in Table 2 have been examined in thin section. No iron meteorites were found by the expeditions reported here. Some of the Yamato-80, -81 and -82 material is described below using meteorite type as a basis for description.

2. Description

2.1. *Chondrites*

2.1.1. H3

Yamato-82133 is a very weathered, partly crusted and friable mass consisting of abundant chondrules and chondrule fragments which protrude from a fractured surface. In thin section the stone consists of a closely packed aggregate of chondrules and clastic fragments set in a network of brown-yellow iron oxides and residual sulphide. Abundant pink, partly devitrified glass occurs within chondrules and twinned low-Ca pyroxene is common. Troilite is mainly present as porous aggregates of partly oxidized material but a few small, unoxidized troilite fragments occur within chondrules. Metal is present as small, well distributed fragments.

Yamato-82208 is a small (5.3 g), almost completely crusted, individual. The crust is cracked by weathering and has partially lost its shiny, glassy surface which has been wind polished and is coated with iron oxides. In thin section the stone consists of abundant chondrules (0.3–1.5 mm in diameter) and chondrule fragments set in a dark, iron oxide- and sulphide-rich matrix. Many of the chondrules contain a pale brown, microcrystalline material. Though texturally this stone is a type 3 chondrite, the lack of clear glass suggests a type 4 classification. The silicates are unequilibrated, however, and thus require a type 3 classification. Twinned low-Ca pyroxene is easily seen but not abundant. The troilite shows much partial oxidation and very little free metal remains. A few rounded blebs of metal around 20 μm across are preserved within chondrules.

2.1.2. H4

Yamato-82061 is an angular fragment with one rounded, thinly crusted face. The interior is discoloured in parts by weathering and consists of abundant chondrules set in a fine-grained, grey matrix which has weathered out emphasizing the chondrules. The thin section shows numerous chondrules and abundant chondrule and mineral fragments set in a partly recrystallized, relatively fine-grained matrix. Porphyritic olivine and radiating pyroxene chondrules are present ranging from 1 mm to 0.1 mm across, and monoclinic low-Ca pyroxene is common. The opaque phases consist of metal, troilite, iron-rich oxidation products and minor Cr-rich spinel. Metal occurs as angular grains up to 0.5 mm across; troilite is present as slightly smaller similarly angular grains. Both metal and troilite show oxidation at their surfaces and these phases are often at the centres of a red-brown stained area.

2.1.3. H5

Yamato-81124 is an almost complete, crusted individual which is penetrated by number of deep cracks. The interior of the stone is mainly pale grey but also shows abundant brown staining with limonitic oxidation products. In thin section the stone consists of chondrules and chondrule fragments set in a granular matrix of olivine and pyroxene crystals interspersed with grains of metal and troilite. The degree to which the chondrules are integrated with the matrix varies widely, some boundaries being very clearly defined while others are quite indistinct. Within the chondrules the intercrystal material, once glass, is now micro-crystalline and weakly birefringent. Twinned monoclinic pyroxene is rare. Metal and troilite grains are highly irregular and often contain cracks filled with oxidation products. The metal grains are commonly surrounded by red-brown alteration products and in some areas the silicates are stained yellow-brown. Pale red-brown and opaque spinels are present.

Yamato-82182 is a nearly complete, angular individual whose fusion crust is beginning to oxidize and spall. The interior of the stone is moderately oxidized and contains chondrules which project from a fracture surface. In thin section the stone consists olivine and pyroxene crystals around 0.1 mm across forming a partly recrystallized groundmass containing numerous chondrules many of which have indistinct boundaries. Barred olivine, radiating pyroxene and granular olivine chondrules occur. Also present is a little striated low-Ca pyroxene. Metal occurs as angular interstitial grains averaging about 50 μm in diameter. Troilite is less abundant than metal, is well dispersed and often shows small cracks filled with oxides. Chromite grains up to 0.2 mm across occur but 50 μm is the more usual diameter. The silicates are lightly stained yellow-brown but there is no veining.

2.1.4. H6

Yamato-81132 is a complete, elongated, individual with small patches of fusion crust remaining on two faces. Weathering has removed most of the fusion crust exposing a brown, very oxidized interior. In thin section this stone is a granular aggregate of olivine and pyroxene crystals averaging about 0.2 mm across and there is very little interstitial, finer grained material. Chondrules are rare and their boundaries are very poorly defined. The silicates are equilibrated and phosphates, both apatite and merrillite, are present. Metal and troilite are homogeneously distributed as sub-rounded grains up to 0.1 mm across with 0.04 mm the more usual size. The section contains a little brown veining and in some areas the silicates are heavily stained by oxidation products.

Yamato-82161 is an exterior fragment of a larger mass and retains one small area of fusion crust. It is very weathered and has a brown surface which shows pale green flecks of olivine and pyroxene. In thin section the stone consists of a granular aggregate of olivine and low-Ca pyroxene around 0.1 mm across. A little very fine-grained interstitial material present and a few ill-defined chondrules can be seen. Metal occurs as rounded to subrounded grains, the largest of which have a maximum dimension of about 0.1 mm, and is often associated with oxidation products. Troilite grains are generally smaller than the metal grains and somewhat less abundant. Some troilite shows slight cracking where it has been partly oxidized and some of the silicates have been stained pale brown.

2.1.5. L3

Yamato-82058 is a subangular, almost complete individual retaining about 50% of the fusion crust. It is moderately weathered with some cracking of the remaining fusion crust. The interior consists of abundant chondrules and chondrule fragments set in a dark, glassy-looking matrix. Inclusions and chondrules up to 4 mm across occur. In thin section the stone consists of a close-packed aggregate of chondrules, some of which are distorted, and a few chondrule fragments. There is very little fine-grained silicate matrix and much of the interstitial material is metal and troilite. Numerous chondrules contain pale, lilac coloured glass while others contain brown, microcrystalline material, and twinned monoclinic pyroxene is fairly common. Two distinct inclusions are visible in the section, one, 5 mm across, is partly rimmed with olivine and consists almost entirely of aluminous orthopyroxene with minor olivine. The other consists of zoned euhedral olivine phenocrysts up to 0.3 mm across set in a fine-grained matrix which is distinct from the main matrix of the stone. Both these inclusions are metal-free. Troilite occasionally has cracks filled with oxides and is sometimes present as very irregular aggregates.

2.1.6. L4

Yamato-82071 is a sub-angular, partly crusted fragment comprising about half of an individual stone. The fusion crust is thin and discoloured in parts by weathering. The interior of the stone is pale grey with occasional small brown patches where metal or troilite has been partially oxidized. In thin section this stone consists of abundant chondrule fragments and a few chondrules which are set in a pale, slightly recrystallized, fine-grained matrix. Twinned monoclinic pyroxene is rare and some chondrules contain an interstitial phase which was once glass but is now microcrystalline. Metal grains up to 1 mm across are distributed throughout the section with many showing corroded borders. Troilite grains often have cracks which are now filled with oxidation products and some staining of the silicates has occurred, particularly around metal and sulphide grains.

2.1.7. L5

Yamato-8010 is an angular fragment with two adjoining crusted faces. The interior of the stone is pale grey and extensively crossed by thin, black, parallel-sided veins. In thin section the stone consists of a fine-grained aggregate of olivines and pyroxenes generally less that 0.02 mm across, with a few chondrules and larger olivines up to 1 mm across. Chondrules, both barred olivine and radiating pyroxene types, often have indistinct margins. Grains of phosphate up to 0.1 mm across are present. Metal and troilite grains are rounded to subangular and these often form the centres for yellow-brown staining of the surrounding silicates.

2.1.8. L6

Yamato-82024 is a partly rounded stone which is nearly completely covered with fusion crust and represents approximately half an individual which broke up very soon after entry into the atmosphere. The interior is moderately fresh and composed of a few poorly defined chondrules about 1 mm across set in an aggregate of olivine and pyroxene crystals. This matrix has a wide range in grain-size, 0.2–0.01 mm, and some areas show extensive staining by oxidation products. Metal is present as rounded to subangular grains, generally less than 0.1 mm across though some up to 0.1 mm across occur. Troilite is slightly oxidized and contains a few cracks which are filled with oxidation products. Phosphates, both merrillite and apatite, are easily seen as grains up to 0.3 mm across.

Yamato-82043 is an orientated fragment of a discoid stone with anterior and posterior fusion crusts partly preserved. The interior is moderately weathered and consists of a crystalline matrix containing a few chondrules ranging up to 1 mm across. In thin section this stone contains ill-defined chondrules set in an aggregate of olivines and pyroxenes with occasional interstitial plagioclase. The grain-size of the major silicate components ranges from a maximum of about 0.5 mm across and 120° crystal junctions are common. Metal, troilite and chromite are evenly distributed throughout the section and much of the troilite contains cracks which are filled with oxidation products.

2.1.9. C2

Yamato-82042 is an angular, partly crusted fragment with the black glassy fusion crust showing little terrestrial oxidation. The interior of the stone is dull light grey with very few crystallites visible. A few inclusions about 1 mm across are present but most of the interior consists of very fine-grained silicates. One face of the stone has the fusion crust partly weathered away exposing a pale surface which appears to be coated with epsomite(?) and clay minerals. Red-brown staining is not visible in the hand specimen. In thin section (Fig. 1a) the stone consists of numerous small crystals around 0.03 mm across, a few larger crystals up to about 0.1 mm across and a very few chondrule-like objects up to 0.4 mm across, all set in a very fine-grained, pale yellow-brown matrix. The crystals are olivines, most of which are surrounded by narrow dark brown coronas, and carbonates, both calcite and dolomite. Pale yellow, low birefringence subhedral 'crystals' are common and are more iron-rich than the olivines but have no brown coronas. A histogram of the Fe/(Fe+Mg) data from this stone (Fig. 2) shows a bi-modal distribution of compositions. The olivines are almost entirely forsterite while the pale yellow phase, which may be altered olivine, is much more iron-rich and shows a range in Fe/(Fe+Mg). Opaque phases are rare and consist of iron oxide, troilite, pentlandite and metal. A few round metal grains up to 6 μm across occur within olivine crystals. There is slight cracking of the specimen near

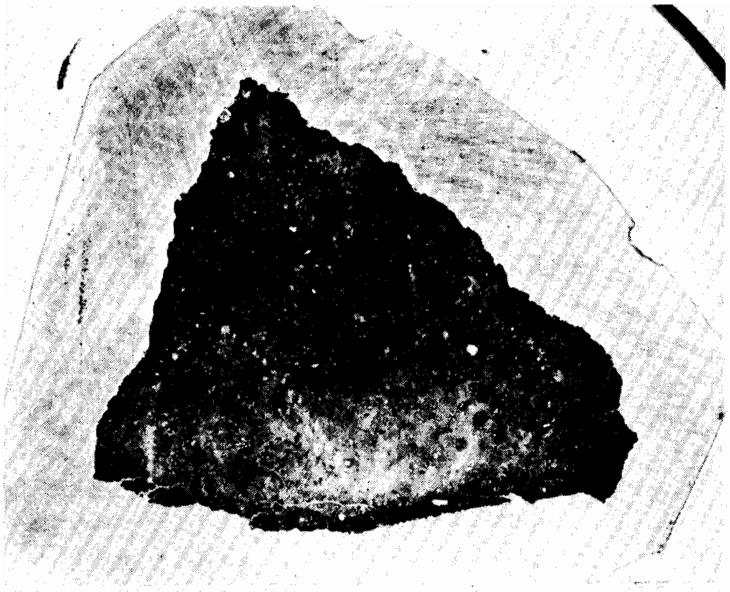

Fig. 1a. Texture of Y-82042. Long dimensionis 12 mm.

Fig. 1b. Texture of Y-81020. Long dimension is 12 mm.

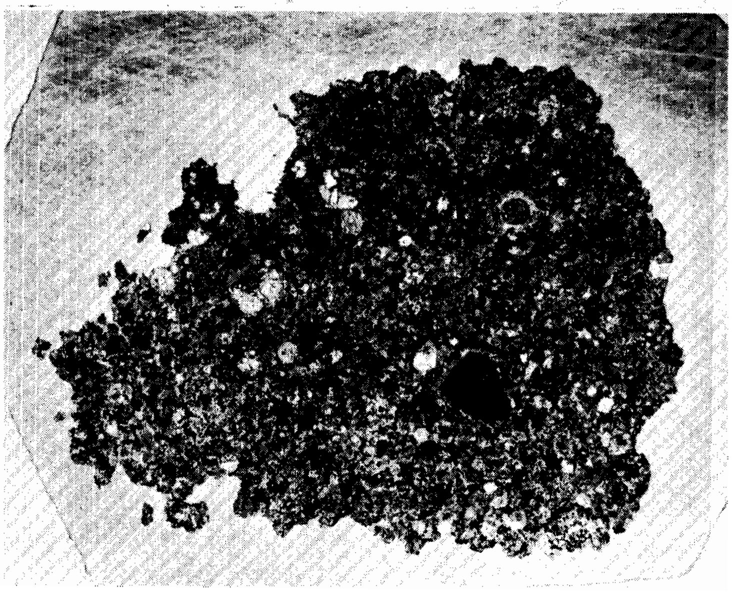

Fig. 1c. Texture of Y-82104. Long dimension is 13 mm.

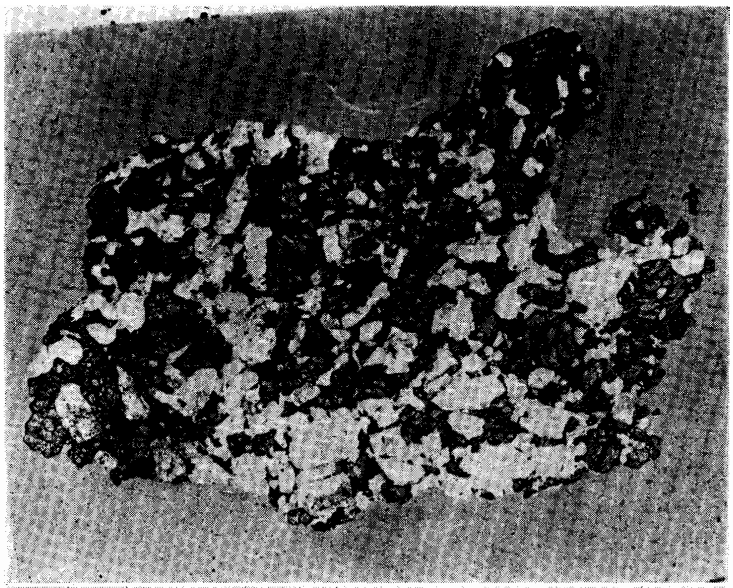

Fig. 1d. Texture of Y-82037. Long dimension is 13 mm.

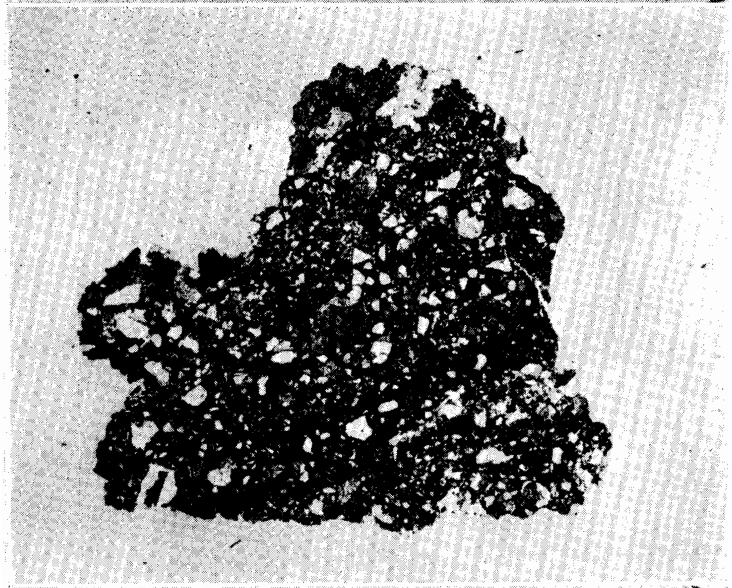

Fig. 1e. Texture of Y-82066. Long dimension is 7 mm.

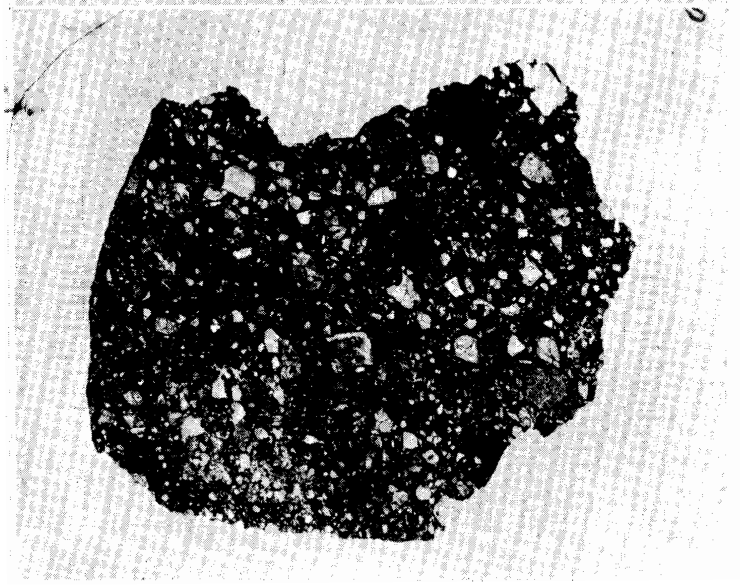

Fig. 1f. Texture of Y-82052. Long dimension is 12 mm.

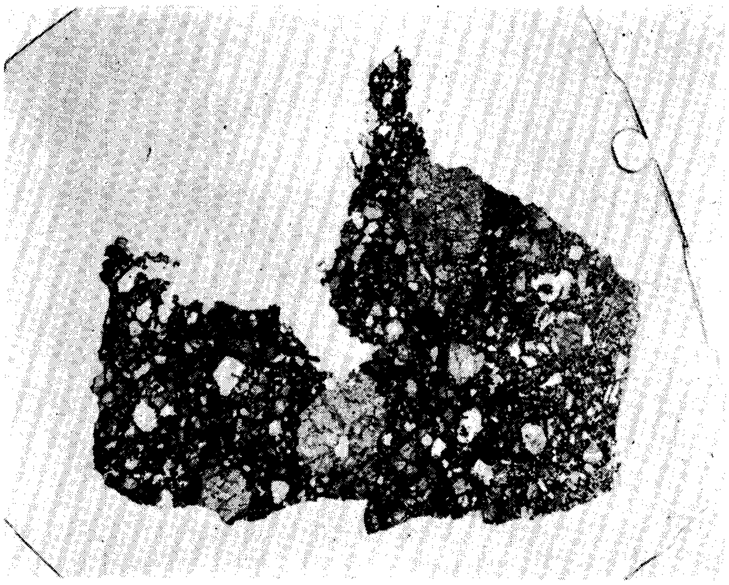

Fig. 1g. Texture of Y-82091. Long dimension is 12 mm.

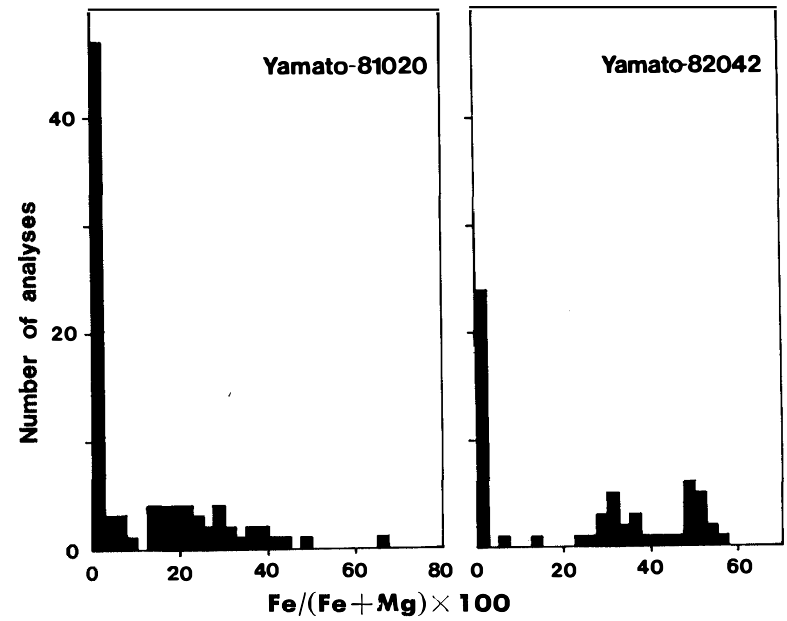

Fig. 2. Mineral Fe/(Fe+Mg)×100 frequency data for Y-81020, a type 3 carbonaceous chondrite and for Y-82042, a type 2 carbonaceous chondrite. For Y-81020 all the data are from olivine analyses. For Y-82042 only the data plotted between Fe/(Fe+Mg)×100=0–20 refers to stoichiometric olivines; the data more iron-rich than this refer to partly altered crystals which give low analytical totals using the microprobe (80–90%).

the fusion crust but there are no internal cross-cutting veins. The bulk composition of this stone (Table 3) lies between those of the CI and CM meteorites but is depleted in potassium, nickel and cobalt in comparison with these. The Mg/Si atomic ratio Y-82042 is 1.09, and the Fe/Si ratio is 0.85.

2.1.10. CO3

Yamato-81020 is a partly crusted individual with obvious spherical chondrules and pale whitish fragments set in a dark red-black and highly coherent matrix. In

Table 3. *Bulk chemical composition of Y-82042.*

SiO_2	25.5_2	K_2O	0.03
TiO_2	0.15	H_2O (−)	6.77
Al_2O_3	1.58	H_2O (+)	14.5_7
Fe_2O_3	15.1_4	P_2O_5	0.25
FeO	6.69	Cr_2O_3	0.43
MnO	0.26	FeS	6.90
MgO	18.7_9	Ni	0.53
CaO	1.69	Co	<0.03
Na_2O	0.48	Total	99.78

Analyst: H. HARAMURA.
Note: $H_2O(+)$ is all the volatiles lost up to 1100°C and includes 1.1%C, mainly present as carbonate.

thin section (Fig. 1b) this stone consists of abundant chondrules, crystal fragments and amoeboid aggregates set in dark, mainly opaque matrix. The chondrules are small, most commonly about 0.1 mm in diameter though a very few up to 0.6 mm across are present. Most of the crystal aggregates and many of the chondrules are speckled with blebs of opaque material, usually metal. Lilac-coloured glass is present in some chondrules and chondrule fragments. The dominant silicate is olivine though twinned monoclinic pyroxene is fairly common. The section also contains some highly irregular, very fine-grained aggregates consisting of a mosaic of melilite crystals with a little fassaite. The abundant opaque phases, mainly metal and troilite, occur as isolated, rounded inclusions within and between chondrules. A little opaque spinel is present and some of the sulphide grains have cracks which are filled with oxidation products. Y-81020 is paired with Y-81021 to Y-81025 inclusive although these stones do not fit together. Microprobe analyses of silicates in this stone are reported in Table 4.

2.1.11. C5

Yamato-82104 is a fragment with a little fusion crust which shows the characteristic deep weathering of Antarctic carbonaceous chondrites. In thin section (Fig. 1c) this stone consists of abundant dusty olivine crystals with poorly defined boundaries

Table 4. *Mineral compositions for Y-81020 carbonaceous chondrite.*

	1	2	3	4	5	6
	zoned olivine		low-Ca pyroxene		melilite	fassaite
SiO_2	41.6	36.7	58.1	55.8	29.6	33.3
TiO_2	—	—	0.31	—	—	12.6
Al_2O_3	0.16	—	1.31	0.18	22.9	20.6
Cr_2O_3	0.44	0.52	0.54	1.18	—	—
FeO	0.96	26.2	0.33	11.3	—	—
MnO	0.14	0.22	0.10	0.43	—	—
MgO	56.8	34.5	38.9	30.4	5.38	7.20
CaO	0.23	0.16	0.43	0.31	40.4	25.5
Na_2O	—	—	—	—	—	—
K_2O	—	—	—	—	—	—
Total	100.33	98.3	100.02	99.6	98.28	99.2

forming a matrix in which are set a few recrystallized olivine chondrules. Low-Ca pyroxene and fine-grained feldspar are rare, the latter shows a wide range in composition. Twinned monoclinic pyroxene was not observed. The opaque phases are mainly oxides with minor troilite and rare metal. The dusty nature of the silicates results from the presence of abundant round oxide particles 0.1 to 5 μm across. The silicates are not stained brown by oxidation products and it seems that these oxides are pre-terrestrial. Texturally the stone is similar to Karoonda but is much more coarsely crystalline.

2.2. *Achondrites*

2.2.1. Eucrite

Yamato-82037 is a subangular stone comprising about 70% of an individual. The shiny black fusion crust has become dull black in places due to weathering. The interior of the stone is composed of a granular aggregate of plagioclase and pyroxene. One indistinct clast having a finer texture than the matrix is visible but generally the texture is remarkably uniform. In thin section (Fig. 1d) this stone consists of a coarse aggregate of pyroxene and plagioclase crystals ranging in size up to 1 mm across in approximately equal modal proportions. The feldspar crystals are rounded and tend to be larger than the pyroxenes; the latter often occurring as an interstitial phase. The pyroxene has very narrow exsolution lamellae of sub-calcic augite, the preliminary microprobe data suggests continuous zoning between $Fs_{45}En_{36}Wo_{19}$ and $Fs_{60}En_{36}Wo_4$ (see Fig. 3). Both Cr-spinel and ilmenite occur, often in close association and in some cases the ilmenite has exsolved from the chromite.

Yamato-82066 is a partly crusted individual whose surface has been deeply eroded by weathering. It is generally fine-grained but contains clasts of more coarsely crystalline material; the boundary between these lithologies is not always well defined. In thin section (Fig. 1e) the stone is a fragmental breccia consisting of angular to subangular clasts set in a fine-grained matrix. The clasts are occasionally polymineralic, up to 1 mm across, but more commonly are angular monomineralic fragments around 0.3 mm across. The matrix pyroxenes and plagioclase fragments are much smaller in size, 0.03 mm across. The pyroxenes often show narrow exsolution lamellae and are generally clouded. Their compositions are bimodal (see Fig. 3): with augites averaging $Fs_{25}Wo_{44}$ and orthopyroxenes averaging $Fs_{57}Wo_4$. The plagioclase ranges from $An_{94}Ab_5$ to $An_{69}Ab_{27}$, the most common composition being $An_{91}Ab_8$.

Yamato-82082 is an almost completely crusted individual whose crust has retained nearly all its shiny, glassy surface. Flow lines in the fusion crust radiate from the front and along the sides of the stone. The interior is fine-grained and mid-grey with a few more coarsely crystalline areas. In thin section the stone consists of brown pyroxenes and angular fragments of partly clouded plagioclase crystals set in a very fine-grained matrix. The pyroxenes range up to 0.7 mm across and show narrow exsolution lamellae. The feldspars range up to 0.4 mm across and often show slightly corroded borders. A few basaltic clasts are present, up to 2 mm across, the borders of which are very poorly defined. Metal and sulphide grains are rare but iron oxides and small Cr-rich spinels are easily seen. The pyroxene compositions are commonly around $Fs_{57}Wo_3$ but there are a few analyses extending to more calcic compositions,

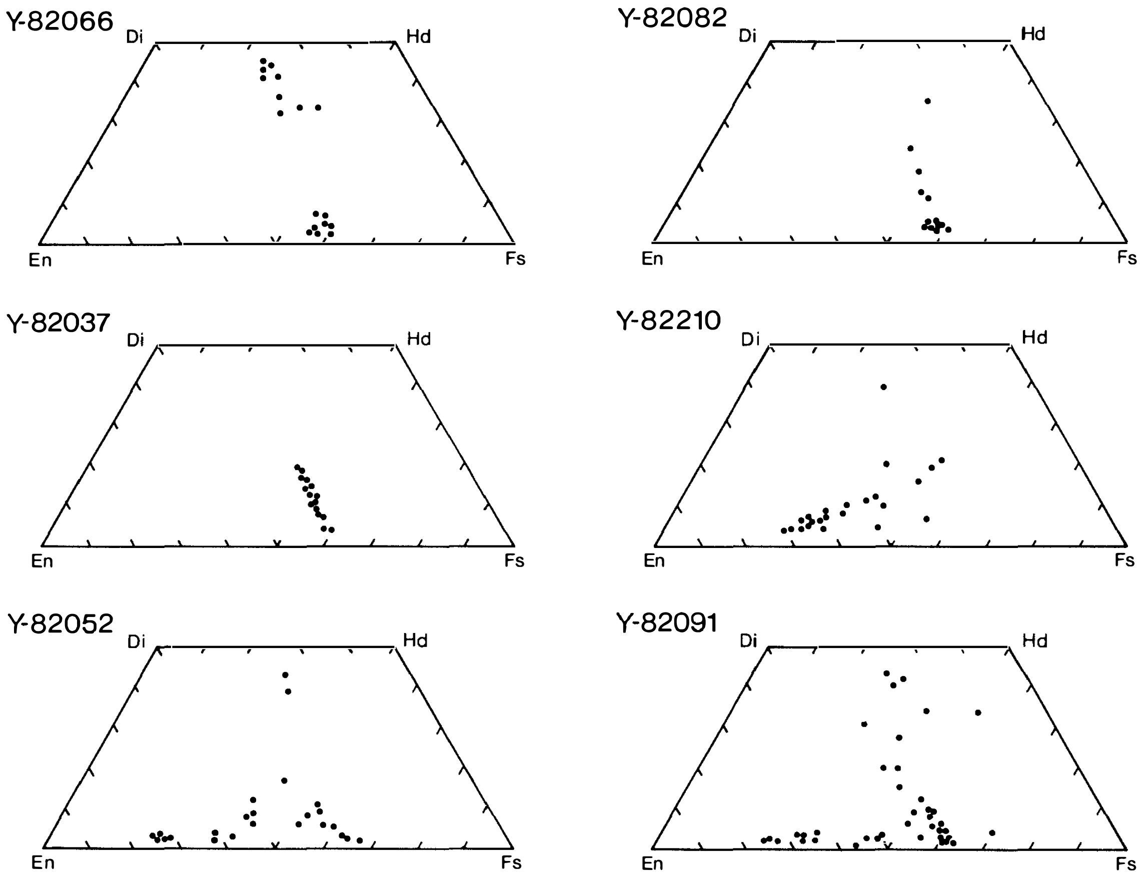

Fig. 3. Pyroxene composition diagrams for basaltic achondrites from the Yamato-82 collection. Y-82066, Y-82082, Y-82037 and Y-82210 are eucrites; Y-82052 and Y-82091 are howardites.

up to $Fs_{43}Wo_{23}$ (see Fig. 2). Feldspar ranges from $Ab_{20}An_{78}$ to Ab_7An_{93}.

Yamato-82210 is a partly crusted fragment forming about 30% of an individual stone. The fusion crust is shiny and vesicular with no flow lines. Internally the stone is a fine-grained breccia with a few basaltic inclusions. In thin section the stone consists of abundant, coarse-grained basaltic clasts up to 5 mm across and a few areas of brecciated, granular crystals of pyroxene and plagioclase set in a fine-grained, fragmental matrix. The feldspars are clear and the pyroxenes lack exsolution lamellae. Two very fine-grained basaltic clasts are also present. Despite this variation in texture, the various clasts and the matrix have very similar mineral chemistries. The pyroxenes range from $Fs_{23}Wo_4$ to $Fs_{40}Wo_{20}$ with one analysis at $Fs_{29}Wo_{39}$ (see Fig. 2). The plagioclases range from Ab_7An_{93} to $Ab_{19}An_{79}$.

2.2.2. Howardite

Yamato-82052 is a partly crusted, angular fragment, comprising about two-thirds of an individual stone. It consists of pale, rounded and angular clasts up to 8 mm across and clastic fragments about 1 mm size set in a dark grey matrix. This stone is a polymict breccia, one clast showing basaltic texture, while another, of coarser grain is possibly of cumulate origin. In thin section the stone is composed of polymineralic clasts around 1 mm across and angular mineral fragments ranging in size from 1 to

0.1 mm across set in a fine-grained, semi-opaque matrix. Most of the clasts have a relatively coarse-grained, unbrecciated texture (Fig. 1f). A few isolated, angular to subrounded pyroxene crystals occur having the composition $Fs_{26}Wo_2$. Other orthopyroxene compositions range $Fs_{36-63}Wo_2$; also present are augites $Fs_{31-43}Wo_{43-17}$ and pigeonites $Fs_{63-39}Wo_{3-12}$, (see Fig. 3). Plagioclase ranges is An_{91-79}.

Yamato-82091 is a partly crusted fragment comprising about three-quarters of an individual. The interior consists of pale, often coarse-grained fragments set in a dark grey matrix. In thin section (Fig. 1g) the host material is made up of abundant fragmental pyroxene and plagioclase crystals. Clastic pyroxenes up to 2 mm across occur but the plagioclases are smaller ranging up to 0.6 mm across. The specimen also contains rounded coarse-grained eucritic clasts up to 1.5 cm across (section ,51–1). Metal and sulphide occur as rounded grains up to 0.04 mm in diameter and spinel is present as cracked grains up to 0.2 mm across. A single olivine grain was found (Fa_{85}) in one section examined. The pyroxene compositions span a wide range (see Fig. 3). Their dominant compositions are $Fs_{25}Wo_3$ (the diogenitic component), low-Ca pyroxene ranging $Fs_{43-70}Wo_2$, pigeonite $Fs_{54}Wo_{10}$, and augite $Fs_{30-41}Wo_{40}$. Plagioclase compositions range An_{96-89}.

2.2.3. Ureilite

Yamato-82100 is a complete, orientated individual with a shiny black fusion crust showing well developed flow lines. The anterior surface of the stone shows abundant cracks many of which meet at 120°, suggesting crystal grain boundaries. In thin section the stone consists of a granular assemblage of olivine and pigeonitic pyroxene whose size ranges from 0.5 to 5 mm. The minerals have been lightly shocked with the pyroxenes showing good cleavage and undulose extinction, while the olivines are cracked. The opaque phases are mainly graphite, with a little metal and sulphides, both troilite and niningerite. The silicates contain a little free metal, either as rounded grains 20 μm across or, more commonly, as very fine-grained dusty metal and veins less than 3 μm across. Most of the metal in the stone occurs between silicate crystals as discontinous veins about 30 μm across. Graphite is abundant as intercrystalline material but diamonds were not noticed during the preparation of the thin section. Some of the silicates are stained light brown by oxidation products.

2.2.4. Ungrouped achondrites

Yamato-8002 is a 2.27 g fragment which was embedded in epoxy resin to prepare a thin section. The section shows a coarse granular aggregate consisting of orthopyroxene with narrow exsolution lamellae, olivine and plagioclase. The grain size ranges from 0.5 to 1 mm, with very few crystals up to 2 mm across. Elongate, interstitial kamacite grains up to 1 mm in length occur. The modal proportions have been reported by Yanai *et al.* (1984) and are orthopyroxene 54%, olivine 26%, plagioclase 12%, kamacite 6% and minor clinopyroxene, chromite, troilite and schreibersite.

Yamato-82192 is an anorthositic breccia containing abundant clasts (1 mm to 1 cm across) of melted rock fragments and brecciated lithic fragments. It has been described by Yanai and Kojima (1985) and is only briefly referred to here. It is similar to Y-82193. The MnO/FeO ratio in olivines and pyroxenes corresponds to the lunar trend and is distinct from that of the basaltic achondrites. This specimen is considered to be of lunar origin.

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