AN OVERVIEW OF THE RESEARCH CONSORTIUM, "ANTARCTIC CARBONACEOUS CHONDRITES WITH CI AFFINITIES, YAMATO-86720, YAMATO-82162, AND BELGICA-7904"

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Abstract: Three Antarctic meteorites, Yamato(Y)-82162, Y-86720, and Belgica(B)-7904, are unusual carbonaceous chondrites having characteristics of both CI and CM chondrite groups. Therefore, a research consortium has been carried out in 1987–1990, and all the results are summarized here. Remarkable results are; (1) Several minerals that are rare or new in carbonaceous chondrites were found in the consortium chondrites. They are sodian talc, FeO-bearing periclase or magnesiowustite, an unknown Fe-Ca-O-S mineral, rhodochrosite, chalcopyrite, eskolaite, schreibersite, Co-rich metal, Ni-Co-free kamacite, and so on. (2) Phyllosilicate veins were firstly found in Y-82162, suggesting that the hydration took place in the parent body. (3) Detailed mineralogy and petrology of altered chondrules and clasts suggest that most of the phyllosilicates in chondrules and clasts were produced from anhydrous precursors in the solar nebula. (4) At the final stage of the chondrite formation, the three chondrites underwent intense impact-shock or metamorphic heating after the hydrous alteration on their parent body. (5) Mineralogical, chemical, and oxygen isotopic data indicate that the three chondrites have some characteristics of both CI and CM groups, and the genetical relationships between the two groups and the consortium chondrites have been suggested. In addition, a new carbonaceous chondrite group CY is proposed for the three unusual chondrites.

1. Introduction

Three Antarctic meteorites, Y-86720, Y-82162, and B-7904, are unusual carbonaceous chondrites having characteristics of both CI and CM groups or an intermediate nature between the two. Their oxygen isotopic compositions are similar to those of non-Antarctic CI chondrites (MAYEDA and CLAYTON, 1990). However, Y-86720 and B-7904 are similar in mineralogy and chemistry to normal CM chondrites. Y-82162 resembles normal CI chondrites, but it contains many clasts which are rare or not found in the latter. In order to study in detail the three unusual chondrites on wide grounds and to resolve the genetical relationships between CI and CM groups, a research consortium was organized by the author in the summer of 1987.

The consortium was approved by the Antarctic Meteorite Research Committee of National Institute of Polar Research (NIPR) in September 1987. The duration was three years from October 1987 to September 1990. The duty of the members was merely to submit at least one paper to the Proceedings of the NIPR Symposium

on Antarctic Meteorites by 1991. The organized members covered many branches of meteoritics, including mineralogy, petrology, trace element chemistry, rare gas research, isotopic chemistry, organic chemistry, reflectance, and so on.

The samples were prepared by NIPR and allotted to members from NIPR, according to their proposals which were approved by both the consortium leader and the Antarctic Meteorite Research Committee. However, the amounts of samples and the numbers of thin sections which were available for the consortium study were limited. Therefore, the consortium members must have studied under the severe sample constraint.

In spite of the constraint, many of the consortium members have completed their studies within the short duration, and many striking and fruitful results have been obtained. In this paper, all of the results concerning the three consortium chondrites are summarized, and the genetical relationships between the CI or CM group and the consortium chondrites will be discussed.

2.   Samples

B-7904 was originally 1234 g in weight. The stone has regmaglypts on the original surface and is wholly covered with a somewhat weathered black fusion crust except along edges. The uncovered part of the surface displays abundant white inclusions, about 1 mm across, as seen on the interior dark surface (Photographic Catalog, ed. by YANAI and KOJIMA, 1987). The specimen looks like a hard stone. Four thin sections, B-7904,92-1, ,92-2, ,92-3, and ,94-2, were available for the consortium. Three of them are in a very poor state, with large holes, a few to several millimeters across, occupying about half of the total area of the thin section.

Y-82162 consists of three fragmental pieces and was originally 41.73 g in weight. Most of the fusion crust has been lost, and the specimen is very friable and dark gray in color without any obvious inclusions or chondrules. It looks like a breccia. Some parts of the surface are coated with thin and powdery efflorescence-like material which is white to pale gray in color (YANAI and KOJIMA, 1987). Two thin sections, Y-82162,4-2 and ,4-3, and samples less than 5 g were available for the consortium. One thin section (4-2) was very poor; nearly half of the area was lost probably due to polishing during the sample preparation.

Y-86720 was originally 858.71 g in weight. The stone is partly covered with a weathered black fusion crust. The exposed interior surface is gray or slightly brownish in places, and does not show any obvious internal structure (YANAI and KOJIMA, 1987). Four thin sections were available for the consortium, and they are Y-86720,71-1, ,71-2, ,73-2, and ,74-2. However, two thin sections (,71-1 and ,74-2) were broken probably during the consortium studies.

The number of thin sections was not enough for the consortium members who needed them. Therefore, one set of two thin sections was alloted to each member from NIPR, on condition that it must be returned to NIPR after three months. Then, the set was to be sent to another member for the next three months. The order of rotation of five such sets was regulated according to the list shown in the

third circular (December 1987) of the consortium. It took about three years from January 1988 to March 1991 to circulate the sets to all members who needed thin sections.

The NIPR thin sections, which were available for the consortium, sometimes include small exotic objects and minerals. They are fragments of granitic rocks, zircon, SiC, Al_2O_3, a silica mineral, K-feldspar, hornblende, oscillatory-zoned plagioclase, etc., and may have been contaminated during the preparation of the thin sections.

3. Consortium Members and Sample Allotment

The original consortium members were 28 persons as of 1987, but the number has increased up to 41 during the consortium study. The consortium members and their subjects are summarized in Table 1. The samples allotted upon their request are also shown in Table 1. Exceptionally large samples of Y-86720 were alloted to Dr. GRAHAM group (7.6 g) and Dr. SHIMOYAMA (4.2 g), because they needed large amounts of samples for measurement of carbon and nitrogen isotopic compositions or organic materials. Four polished thin sections of B-7904, two of Y-82162, and four of Y-86720 were circulated among all members who needed them, although additional thin sections were used by some members who picked up some objects or minerals from the thin sections. The additional thin sections are indicated in Table 1 in parentheses.

4. Previous Works (Before 1987)

4.1. B-7904

B-7904 was firstly described in Meteorite News (YANAI and KOJIMA, 1982) as a C2 (CM) chondrite (Table 2). The major element chemical composition of B-7904 obtained by wet analyses was presented by HARAMURA et al. (1983), this meteorite being classified as a C3 because of the low water content (Table 3). KOJIMA et al. (1984a, b) studied the alteration of chondrules and matrix in B-7904, and concluded that it is an unusual CM2 chondrite and has suffered intense heating after alteration; the heating caused precipitation of numerous sulfide grains in it, escape of carbon-oxides, dehydration of hydrous minerals, and recrystallization of secondary olivine from hydrous minerals. It was also suggested that the intense heating may be due to shock-heating on or metamorphism in the parent body. AKAI (1984) found, using TEM, that crystal structures of the phyllosilicates are considerably decomposed and that submicron-sized grains of olivine and pyroxene are widely distributed in the matrix.

STEELE et al. (1984) noted higher Cr contents in magnesian and ferroan olivines in B-7904 and compared them with olivines in most other olivine-bearing meteorites. STEELE et al. (1985) and SKIRIUS et al. (1986) have carried out a work on cathodoluminescence of olivine in B-7904, and concluded that blue olivine containing high refractory elements (0.3 wt% of Al_2O_3, 0.06 wt% of TiO_2, and 0.5 wt% of CaO) represents relic olivines which formed from a high-temperature

Table 1. Consortium Members and Sample Allotment. PTS is polished thin section; four PTS's of B-7904 (92-1, 92-2, 92-3, 94-2), two PTS's of Y-82162 (4-2, 4-3), and four PTS's of Y-86720 (71-1, 71-2, 73-2, 74-2) were circulated except for additional PTS's.

Consortium Members (Affiliation): Subjects	B-7904	Y-82162	Y-86720
AKAI, J. (Niigata Univ.): Phyllosilicates by HRTEM		88 mg	223 mg
BISCHOFF, A. (Münster Univ.): Petrology & Mineralogy	3 PTS	2 PTS	4 PTS
CLAYTON, R. N. & MAYEDA, T. K. (Chicago Univ.): Oxygen Isotopes			
DANON Group: Mössbauer Spectroscopy		92 mg	94 mg
EL GORESY, A. & KIMURA, M. (Max Planck): Opaque Mineralogy	271 mg	88 mg	295 mg
EBIHARA, M. (Tokyo Metro. Univ.): REE		93 mg	202 mg
GRAHAM Group: Mineral., Petrol., Gas Contents, Isotopes	4 PTS	2 PTS, 192 mg	4 PTS, 7636 mg
IKEDA, Y. (Ibaraki Univ.): Mineralogy, Petrology, Review	4 PTS, 122 mg, 101 mg	2 PTS, 2 mg	4 PTS, 21 mg
KALLEMEYN, G. (UCLA): INAA		232 mg	583 mg
KITAMURA, M. (Kyoto Univ.): Mineralogy	4 PTS	2 PTS	4 PTS, 237 mg
LIPSCHUTZ, M. E. (Purdue Univ.): Trace Elements		172 mg	222 mg
MATUDA, J. (Osaka Univ.): Diamond, Rare Gas	102 mg		113 mg
MATSUNAMI Group (Naruto Univ.): Mineralogy, Petrology	3 PTS		4 PTS
MIYAMOTO, M. (Tokyo Univ.): Zoning of Ol, Reflectance	3 PTS, 245 mg	80 mg	268 mg, 21 mg
NAKAMURA, N. & YAMAMOTO, K. (Kobe Univ.): Trace Elements		92 mg	105 mg
NISHIIZUMI, K. (Cal. Univ.): Terrestrial Age	948 mg		202 mg
PALME, H. (Maintz): INAA		191 mg	193 mg
PIETERS, C. M. & BRITT, D. (Brown Univ.): Reflectance	362 mg	209 mg	400 mg
PRINZ, M. & ZOLENSKY, M. (Am. Mus., NASA): Mineral., Petrol.	4 PTS, 60 mg	2 PTS	4 PTS
SCHULTZ, K. (Maintz): Noble Gases		92 mg	106 mg
SHIMOYAMA, A. (Tsukuba Univ.): C, N, Organic Materials			4204 mg, 207 mg
TOMEOKA, K. (Tokyo Univ.): Mineralogy, Metamorphism	1 PTS (91-2)	1 PTS (4-4)	1 PTS (74-3)
WOOLUM, D. S. & BARNETT, D. (Cal. St. Univ.): PIXE	1 PTS (96-3), 245 mg	214 mg	1 PTS (71-3)
YABUKI, H. & OKADA, A. (IPCR): H & D Determination by ERDA		88 mg	59 mg
YANAI, K. & KOJIMA, H. (NIPR): Sample Preparation			

GRAHAM Group includes GRAHAM, A. L. (British Mus.), BARBER, D. J. (Essex Univ.), PILLINGER, C. T. (Open Univ.), GRADY, M. M (Open Univ.), EUGSTER, O. (Bern Univ.), and PALME, H. (Maintz). MATSUNAMI Group includes MATSUNAMI, S., NISHIMURA, H., and TAKESHI, H. DANON Group includes late DANON, J. (Observatorio Nacional), SCORZELLI, R. B. and SOUZA AZEVEDO, I. (Centro Brasileiro de Pesquisas Fisicas).

Table 2. Classification of B-7904, Y-86720, and Y-82162.

	B-7904	Y-86720	Y-82162
Meteorites News (1982)	C2 (CM)		
HARAMURA et al. (1983)	C3		
KOJIMA et al. (1984a)	CM		
KOJIMA et al. (1984b)	Unusual CM2		
Meteorites News (1985)	C2		C
SKIRIUS et al. (1986)	Unusual C2		
KOJIMA and YANAI (1987)			C1
MAYEDA et al. (1987)	C1		C1
Catalog of Meteorites (1987)	CM2	C1	C1
KALLEMEYN (1988)	CM-anomal	Intermed	CI
TOMEOKA et al. (1988a)			CI
TOMEOKA et al. (1988b)		CM	
CLAYTON and MAYEDA (1989)	CI2	CI1	CI1
EBIHARA and SHINONAGA (1989)	C2	Intermed	C1
ZOLENSKY et al. (1989a, b)	CI2	CI	CI
PRINZ et al. (1989)	CB2	CB	CB
PAUL and LIPSCHUTZ (1989d)	C✳✳2	C✳✳2	C✳✳1
TOMEOKA (1990a)	CI2	CI2	CI1
MAYEDA et al. (1991)	C2	C2	C2
ZOLENSKY et al. (1991)	CM	CM	CM
This paper	CY3	CY2	CY2

cf. Classification of PAUL and LIPSCHUTZ (1989d) is a new scheme including four parameters, chemical type, oxygen isotopes, petrography, and labile trace element contents.

gas (probably, nebular gas) rich in the refractory elements.

GIBSON et al. (1984) measured the carbon (0.972 wt%) and sulfur (5.037 wt%) contents of B-7904, and found that it is depleted in carbon relative to other CM chondrites, and is closer to C3 chondrites, but the sulfur abundance resembles those in C1 chondrites. In addition, B-7904 does not have indigenous amino acid at the concentration (level less than 1 n mole/g). Therefore, GIBSON et al. (1984) suggested that B-7904 may be a subgroup of the CM type meteorites. SHIMOYAMA and HARADA (1984) also determined the C and amino acid contents of B-7904, and their results were similar to that obtained by GIBSON et al. (1984). SHIMOYAMA et al. (1986) found a linear relation between C and N contents in Antarctic carbonaceous chondrites and showed that B-7904 is the lowest in C and N contents among Antarctic and non-Antarctic CM chondrites. MURAE et al. (1985, 1986, 1987, 1989) did pyrolysis analysis for B-7904, and measured the total C content (0.96 wt%) and naphthalene (1.3 ppm), indicating that the naphthalene/total C of B-7904 is lower by one factor than those of Murchison and Allende. McGRAVIE et al. (1987) measured the C content and the isotopic ratios of B-7904 and other Antarctic C2 chondrites, and concluded that the carbon isotope profiles for Antarctic and non-Antarctic C2 meteorites are dissimilar.

NAGAO et al. (1984a, b, 1985) and MATSUBARA et al. (1987) reported rare gas (He, Ne, Ar, Kr, and Xe) contents of the B-7904 matrix and the isotopic compositions, concluding that primordial rare gases are dominant, and the cosmic-ray exposure

age of 0.7 Ma was obtained with the cosmogenic ^{21}Ne. Oxygen isotopic composition of B-7904 was measured by MAYEDA *et al.* (1987), showing that B-7904 is isotopically Cl.

4.2. Y-86720 and Y-82162

Y-86720 and Y-82162 were firstly described as Cl chondrites (YANAI and KOJIMA, 1987). The brief petrography of Y-82162 was presented by KOJIMA and YANAI (1987), who found some narrow veins in the matrix and that the volatile components (water and C) are obviously lower than those of non-Antarctic Cl chondrites. MAYEDA *et al.* (1987) reported the oxygen isotopic composition of Y-82162 and showed that Y-82162 is isotopically similar to B-7904.

5. Mineralogy and Petrology

5.1. General description

The three consortium chondrites consist of many kinds of components. They are chondrules, clasts, isolated minerals, matrices, and so on. The term chondrule is used in this paper for melt-droplet chondrules and their fragments. Clasts are defined here to be aggregates of minerals which have clear boundaries against the matrix, although other terms such as aggregate, inclusion, or cluster were used instead of clast by several consortium members. Isolated minerals are used for minerals or mineral fragments larger than a few microns across, which set directly in the matrix. Matrix is defined to be aggregates of tiny grains smaller than a few microns, which fill interstitial spaces between chondrules, clasts, and isolated minerals. The components and their mineral assemblages differ among the three consortium chondrites, and are summarized in Table 3 with references of non-Antarctic CI and CM chondrites.

Although all phyllosilicates in the consortium chondrites are more or less dehydrated by heating event (see Section 6), original phyllosilicates can be estimated from the chemical compositions, and they will be discussed in the following sections.

5.2. Matrices of the three consortium chondrites

Matrices of Y-82162, Y-86720, and B-7904 consist mainly of dehydrated phyllosilicates with minor amounts of opaque minerals, carbonates, and phosphates. The compositional ranges of each matrix, which were obtained by an electron-probe microanalyzer (EPMA) using a focussed beam to avoid isolated minerals such as troilite, magnetite, etc., are shown in Fig. 1 and Table 4. The compositional range of the Y-82162 matrix coincides with that of the Y-86720 matrix (Fig. 1), but the B-7904 matrix is wider in compositional range than the other two, although their average compositions may be similar to each other.

The average compositions of matrices in other carbonaceous chondrites were reported by McSWEEN and RICHARDSON (1977), and the compositional range of matrices in CI and CM chondrites are shown in Fig. 1 for reference, where the range for CI matrices is different from that for CM matrices. However, the difference may be only apparent, because McSWEEN and RICHARDSON (1977) obtained

Table 3. The petrological and mineralogical features characteristic of non-Antarctic CI, ordinary CM, and the new type of Antarctic carbonaceous chondrites (Y-82162, Y-86720, and B-7904).

	CI	Y-82162	Y-86720	B-7904	CM
H_2O (wt%) of whole rock	17-23	8.01 (11.95)	4.6 (6.1)	2.1 (2.6)	3-17
Chondrules	no	no	(+)	+	+
Phyllosilicate Clasts	+	+ (dehydrated)	+ (dehydrated)	+ (dehydrated)	+
Al_2O_3 contents	Low	Low	Low, High	Low, High	Low, High
Unusual Clasts	no	+	no	no	no
Anhy. Chond. Frag.	no	+	no	no	no
PCP	no	no	no	no	+
Accretional Dust Mantles	no	no	+	+	+
Primary Olivine	(+)	no	no	+	+
Secondary Olivine	no	+	+	+	no
Isolated Opaque Minerals	Pyr, Fer, Mt, Pen	Pyr, Mt, Awa, Pen, Ilm	Pyr, Ta, Ka, Ilm	Tr, Ta, Ka, Mt, Pen, Ilm, Chm	Toc, Mt, Pyr
Euheral FeS laths	(+)	+	+	no	no
Matrix Phyllosilicates	Smec, Serp	Dehydrated (Smec, Serp)	Dehydrated (Smec, Serp)	Dehydrated (Smec, Serp)	Serp
Framboidal Magnetites	+	+	no	no	no
Veins	Sulfate, Carbonate	Phyllosilicate	no	(Carbonate)	(Carbonate)

H_2O contents of the new type are H_2O (+), and those in parentheses include H_2O (+ and −) and carbondioxide.
Chondrules in Y-86720 are completely altered to aggregates of phyllosilicates shown here as (+).
Al_2O_3 contents are alumina of the phyllosilicates in phyllosilicate clasts (Low and High are 0–6.5 and 6.5–26 wt%, respectively). Unusual clasts consist mainly of FeO-bearing periclase and carbonate with a minor amount of unknown Fe-Ca-S-O mineral. Anhy. Chond. Frag. and PCP are anhydrous, chondritic, fragments, and aggregates of tochilinite and cronstedtite, respectively. Pyr, Fer, Mt, Pen, Awa, Tr, Ta, Ka, Ilm, Toc, Smec, and Serp are pyrrhotite, ferrihydrite, magnetite, pentlandite, awaruite, troilite, taenite, kamacite, ilmenite, tochilinite, smectite, and serpentine, respectively. In addition, B-7904 includes eskolaite and schreibersite in small amounts. Carbonate veins in B-7904 and CM's are network-like materials in the matrices, and not a typical vein. Data sources: TOMEOKA (1990a, b), IKEDA et al. (1991), IKEDA et al. (1992), and KIMURA and IKEDA (1992).
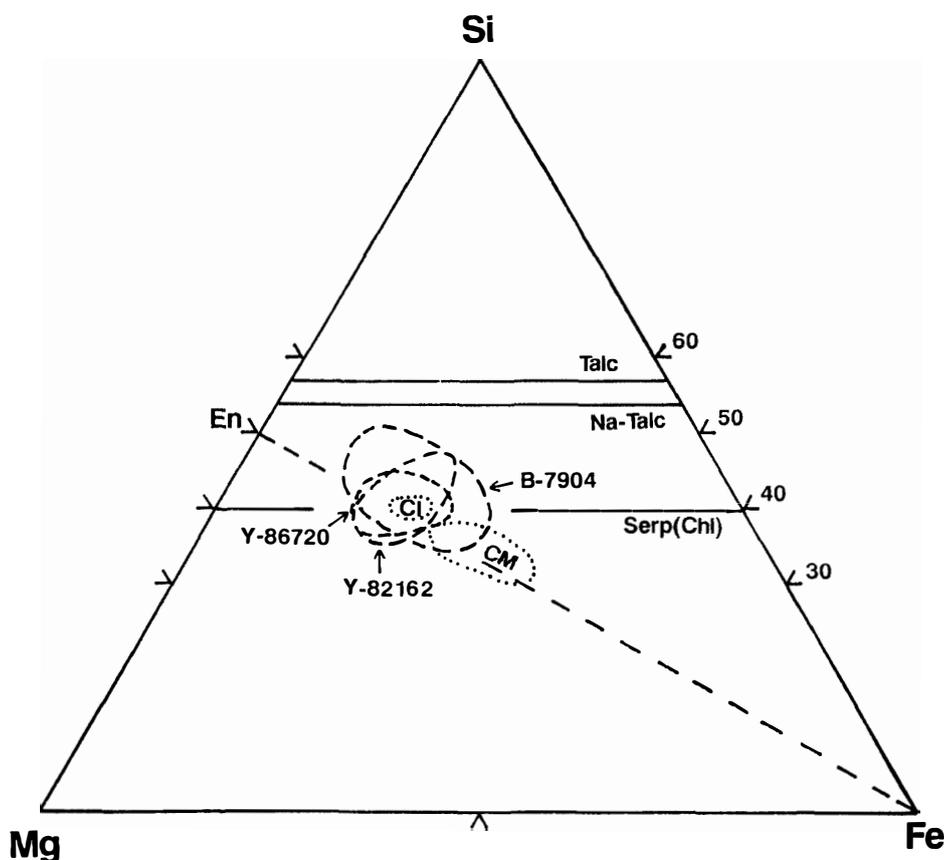
Fig. 1.   Compositional ranges (in atomic ratio) of matrices in Y-82162, Y-86720, and
          B-7904. They were obtained by EPMA analyses using a focussed beam to
          avoid opaque minerals in the matrix. The average chemical compositions of
          matrices in CI and CM chondrites, which were obtained by EPMA analyses
          using a broad beam of about 100 microns across (McSween and Richardson,
          1977), are plotted in the compositional ranges denoted by CI and CM,
          respectively. Stoichiometric compositions of enstatite (En), talc, Na-Al talc,
          and serpentine (or chlorite) are shown for reference. Data sources: Ikeda
          (1991) for Y-82162, Ikeda et al. (1992) for Y-86720, and Kimura and Ikeda
          (1992) for B-7904.

Table 4. Compositional ranges (wt%) of matrices in the Y-82162, Y-86720, and B-7904 chondrites.

	Y-82162	Y-86720	B-7904
Al_2O_3	1.5–3.0	1.8–3.0	2.0–7.5 (mainly 3–5)
$Na_2O + K_2O$	0.5–1.5	0.1–0.6	0.0–2.0
Cr_2O_3	0.4–0.8	0.4–0.7	0.1–1.5
CaO	0.2–1.3	0.1–0.3	0.0–18.5 (mainly 0–7)

Data sources; Ikeda (1991), Kimura and Ikeda (1992), and Ikeda et al. (1992).

the average matrix compositions using a defocussed electron beam of an EPMA,
about 100 microns across, probably including fine-grained Fe-phases occurring as
isolated minerals such as Fe-sulfides or Fe-oxides. Therefore, the "true" com-
positions of phyllosilicates in CM matrices may be similar to that of CI matrices.

The B-7904 matrix shows a wider range of composition (Table 4), and is richer in Al_2O_3 and CaO, while the Y-86720 matrix is depleted in alkalis and CaO. The high CaO content of the B-7904 matrix may be due to tiny grains of carbonates and phosphates in the matrix (KIMURA and IKEDA, 1992), because CaO was expelled from chondrules to the matrix as carbonates or phosphates during hydration (IKEDA et al., 1991; KIMURA and IKEDA, 1992). TOMEOKA (1990a) suggested that the high CaO content of the B-7904 matrix is due to the presence of narrow veins of Ca-rich materials in it. On the other hand, CaO was not expelled from chondrules during the hydration of Y-86720, resulting in low CaO contents of the Y-86720 matrix (IKEDA et al., 1992).

TOMEOKA et al. (1989a) noticed the difference in matrix mineralogy between Y-82162 and Orgueil; the Y-82162 matrix consists mainly of dehydrated phyllosilicate with minor amounts of pyrrhotite and Mg-Fe carbonates, whereas the Orgueil matrix consists of serpentine, smectite (saponite), and S-Ni-bearing ferrihydrite.

TOMEOKA et al. (1988b) reported that the composition of the Y-86720 matrix is similar to those of a highly altered CM chondrites, but the Fe content is particularly high in the area where the Fe-sulfides are concentrated, and Y-86720 has an unusually high abundance of euhedral and irregular troilite (about 10 vol%), which are commonly replaced by ferrihydrite-like material. In addition, the chondrules and clasts in Y-86720 were completely replaced by phyllosilicates. Therefore, TOMEOKA et al. (1988b) concluded that Y-86720 may be a highly altered CM chondrite, though it shows many mineralogical characters that differ from ordinary CM chondrites. TOMEOKA et al. (1989b) found that the Y-86720 matrix consists largely of submicroscopic olivine and amorphous material which were formed by thermal decomposition of phyllosilicates.

TOMEOKA (1990a) found that submicron particles of Fe-Ni metal are widespread in the B-7904 matrix, and revealed that the B-7904 matrix contains unusual clusters that apparently consist of intimate mixtures of Fe-sulfide particles and dehydrated phyllosilicates, and these clusters may be products of thermal alteration of Type II PCP.

ZOLENSKY et al. (1989a) showed that the Y-86720 matrix is compositionally similar to CI chondrite matrix although it is more Fe deficient. The deficiency was explained by the interpretation that coarse-grained pyrrhotite laths are abundant in Y-86720, and some parts of Fe were allotted to the pyrrhotite. ZOLENSKY et al. (1991) reported comprehensive mineralogy of the matrices in the three chondrites; the Y-82162 matrix was originally serpentine and saponite, but it now consists largely of olivine (Fo_{65-83}) and, to a lesser extent, pyroxene (enstatite and subcalcic pigeonite), the Y-86720 matrix consists largely of olivine (about Fo_{70}) and pyroxene (enstatite) produced by heating from serpentine and saponite, and the B-7904 matrix consists largely of olivine (Fo_{50-100}) with lesser amounts of poorly crystallized saponite and a phase apparently intermediate between serpentine and enstatite.

SCORZELLI and SOUZA AZEVEDO (1991) showed Mössbauer spectra of Y-86720 and Y-82162 (probably, matrices) at 300 K, which indicate (a) the presence of a magnetic spectrum that can be attributed to Fe-sulfides, (b) an Fe^{3+} doublet,

probably ferrihydrite, and (c) an Fe^{+2} doublet relative to olivine.

5.3. Clasts and isolated minerals in Y-82162

Y-82162 includes anhydrous chondritic fragments. They are a kind of clasts and are fragments of anhydrous chondritic materials similar to ordinary chondrites (TOMEOKA et al., 1989a; IKEDA, 1990, 1991). They were projectiles which were responsible for the regolith gardening to have produced the Y-82162 breccia (IKEDA, 1991). Clasts other than anhydrous chondritic fragments are grouped into six types on the basis of the predominant phase and the texture. They are phyllosilicate-rich clasts, matrix-like clasts, carbonate-rich clasts, unusual clasts including FeO-bearing periclase, magnetite-rich clasts, and composite clasts (IKEDA, 1991). The mineral assemblages and mineral compositions differ among the clast types.

Phyllosilicate-rich clasts are coarse-grained, and some clasts consist mainly of sodian talc and serpentine, and others mainly of chlorites (IKEDA, 1990, 1991). WATANABE et al. (1988) reported Na-rich glauconite and Na-analogue of phlogopite as the constituent minerals of coarse-grained phyllosilicate-rich clasts, but they may be sodian talc or sodian saponite.

Matrix-like clasts are fragments of a breccia, where some clasts and/or isolated minerals occur in fine-grained aggregates similar to the matrix. Thus, Y-82162 shows a breccia-in-breccia structure. The main phyllosilicates are chlorite and talc (or saponite). Some matrix-like clasts include phyllosilicate veins, which are described in the following section. Matrix-like clasts include various types of magnetite, which are framboidal aggregates, plaquettes, spherules, and polygonal to irregular grains (TOMEOKA et al., 1988a; IKEDA, 1990, 1991).

Carbonate-rich clasts consist mainly of ankerite and/or calcite with thin dolomite rims. Unusual clasts are fine-grained aggregates consisting mainly of carbonates and FeO-bearing periclase (or magnesiowüstite), and some unusual clasts are rich in Mn, rarely including rhodochrosite. Unusual clasts sometimes have carbonate-rich mantles which are similar in mineralogy and texture to the carbonate-rich clasts, suggesting that they have intimate genetical relationships with the carbonate-rich clasts (IKEDA, 1991).

Magnetite-rich clasts consist mainly of magnetite with variable amounts of phosphates and chlorite. The compositions of the minerals are similar to those in chlorite-rich clasts and matrix-like clasts, suggesting that the magnetite-rich clasts have an intimate genetical relationship with chlorite-rich clasts and matrix-like clasts (IKEDA, 1990, 1991).

Sulfides (about 10 vol%) are much more abundant than magnetite (about 0.5 vol%) (TOMEOKA et al., 1988a). Most abundant is pyrrhotite, which occurs as isolated fine grains and large, lath-like grains. Pentlandite also occurs in lesser amount. TOMEOKA et al. (1989a) stressed the difference in sulfide mineralogy between Y-82162 and Orgueil; pyrrhotite (about 11 vol%) is more abundant in Y-82162 than Orgueil, in which most Fe resides in ferrihydrite as ferric iron, and S also occurs in major amounts as Mg-, Ca-sulfates and elemental S in Orgueil, but no elemental S occurs in Y-82162.

5.4. Phyllosilicate veins in Y-82162

Veins in Y-82162 were first reported by KOJIMA and YANAI (1987), but the vein material was not identified. WATANABE et al. (1988) reported magnesite veins in Y-82162, but the veins have not been identified by later investigators. Phyllosilicate veins were firstly found by TOMEOKA (1989) in some matrix-like clasts in Y-82162. The phyllosilicate veins commonly terminate at the clast boundaries, indicating that the veins were produced before some of the brecciation events (TOMEOKA, 1990a, b; IKEDA, 1990, 1991). TOMEOKA (1990a, b) reported that veins in Y-82162 consist mainly of saponite and chlorite, which are similar in chemical composition to coarse-grained phyllosilicate in the host clasts, and concluded that the veins were produced by early-stage aqueous alteration in regolith regions. At the same time, TOMEOKA (1990a, b) noted that the coarse-grained phyllosilicates are more abundant in Y-82162 than in non-Antarctic CI chondrites; the coarse-grained phyllosilicates were early-stage products of hydration, and they have been degraded to finer-grained phyllosilicates and altered to the matrix by late-stage aqueous alteration that produced the sulfate veins in CI chondrites. Therefore, TOMEOKA (1990a, b) concluded that Y-82162 has not experienced the late aqueous alteration stage. IKEDA (1990, 1991) showed that there are two subtypes of coarse-grained phyllosilicates, sodian talc-rich and chlorite-rich, and the two subtypes were produced independently in different conditions, suggesting more complicated history of the coarse-grained phyllosilicates.

5.5. Clasts and isolated minerals in Y-86720

There are two types of clasts, phyllosilicate-rich and carbonate-rich. Completely altered chondrules, in which all of the original anhydrous minerals such as olivine, pyroxene, and plagioclase were replaced by hydrous minerals, are found in Y-86720, and they are classified as phyllosilicate-rich clasts.

Pseudomorphs of CAI's including high-Al silicates and ilmenite were reported by TOMEOKA et al. (1989b). However, the high-Al silicates may be high-Al chlorite or serpentine which were produced from plagioclase in original plagioclase-rich chondrules (IKEDA et al., 1992). Considering that Al_2O_3 is the most difficult component to move during the hydration (IKEDA et al., 1992), they may not have been CAI's, because the bulk Al_2O_3 content seems too low.

ZOLENSKY et al. (1989a) recognized antigorite and clinochlore as the main phyllosilicates in clasts, but TOMEOKA et al. (1988a, b) reported smectite and serpentine as the main phyllosilicates in clasts.

MATSUNAMI et al. (1989, 1990) discussed redistribution of CaO in altered chondrules and CAI's, but the redistribution of CaO in Y-86720 seems to differ from other CM chondrites; CaO was usually expelled from chondrules during the hydration in ordinary CM chondrites, whereas CaO remains as carbonate-rich inclusions in altered chondrules or clasts in Y-86720 (IKEDA et al., 1992).

BISCHOFF and METZLER (1990) measured the vol% of large objects in Y-86720; phyllosilicate-rich clasts larger than 100 microns amount to 9.42%, and euhedral sulfide laths 3.55%.

TOMEOKA et al. (1989b) reported that Y-86720 has an unusually high

abundance of troilite (about 9 vol%) and contains Ca-Mg-carbonates and Fe-Ni metal instead of magnetite and PCP which are common in ordinary CM chondrites. They suggested that fine-grained troilite and taenite were formed from tochilinite during thermal metamorphism under a reducing condition. In addition, Tomeoka et al. (1989b) found that troilite in Y-86720 was replaced by ferrihydrite-like material, and Fe diffused widely into the matrix, and suggested that the alteration is different from the early alteration and occurred after the thermal metamorphism was completed. Ikeda et al. (1992) found that taenite has Co/Ni ratios similar to that of the solar elemental abundances, although most kamacite is free from Ni and Co, and suggested that taenite is primary metal, but kamacite was produced from Fe sulfides or ferrihydrite during a heating event.

5.6. Chondrules, clasts, and isolated minerals in B-7904

Clasts in B-7904 are grouped into seven subtypes. They are phyllosilicate-rich clasts, sulfide-rich clasts, kamacite-rich clasts, etc. (Kimura and Ikeda, 1991, 1992).

Tomeoka (1989) studied this meteorite in detail; B-7904 is classified as a CM, and alteration products in B-7904 appear to be a mixture of serpentine and smectite, although those in ordinary CM's are predominantly Mg-Fe serpentine. Primary olivine ranges from Fo_{100} to Fo_{55}, and remains little altered. No laths of FeS are observed, but small irregular grains (<10 microns) and minor Fe-Ni metal set in the matrix. Tomeoka (1989) concluded that B-7904 is genetically related to Y-86720, and they were probably derived from similar precursors but experienced different degrees of aqueous alteration in a common environment.

Zolensky et al. (1989a) and Prinz et al. (1989) reported petrography of clasts and isolated minerals in B-7904. Phyllosilicates in clasts consist mainly of antigorite, ferroan antigorite, and clinochlore. Sulfides are pyrrhotite ($Fe_{0.98}S$) and pentlandite ($Fe_{6.24}Ni_{2.48}S_8$), and the Ni content of kamacite is less than 7.5 wt%. Primary olivine and orthopyroxene range in composition from Fo_{100-42} and En_{91-57}, respectively (Zolensky et al., 1989a). Chondrules in B-7904 are about 20 vol%, and includes type I (magnesian, $Fo_{99.5}$) and type II (ferroan, Fo_{88-34}), and magnesian chondrules contain forsterite condensed directly from a nebular gas (Prinz et al., 1989). In addition, they found chondrules containing a very fine-grained mixture of apatite and carbonate.

Bischoff and Metzler (1990, 1991) measured vol% of objects larger than 70 microns in B-7904; chondrules and their fragments are 7–8 vol%, olivine-bearing, fragment-like objects are 8–9 vol%, and CAI's are less than 0.2 vol%. They reported egg-shaped fine-grained particles rich in Cr_2O_3 (2–5 wt%) and Al_2O_3 (4–7 wt%), and found that a great number of chondrules in B-7904 are much larger than the mean diameter (0.3 mm) of chondrules from ordinary CM chondrites. Kimura and Ikeda (1992) presented a comprehensive mineralogy and petrology of B-7904; chondrules are grouped into two types, magnesian and ferroan, and the magnesian chondrules consist mainly of forsterite, enstatite, plagioclase, and/or dehydrated phyllosilicate with minor amounts of Mg-Al spinel, chromite, eskolaite, magnesiowüstite, magnetite, kamacite, taenite, schreibersite, troilite, and/or pentlandite. They were originally produced under a reducing condition and later

oxidized during the hydration. On the other hand, ferroan chondrules consist of ferroan olivine and dehydrated phyllosilicate with minor amounts of chromite, phosphate, taenite, troilite, and pentlandite. They were originally produced under an oxidizing condition and later hydrated.

6. Heating and Dehydration

Phyllosilicates in the three consortium chondrites have undergone a heating event or thermal metamorphism after the formation of the phyllosilicates. This heating did not take place in other CM and CI chondrites, making the consortium chondrites unique. KOJIMA et al. (1984a, b) firstly discussed the heating of B-7904. The lines of evidence are the low water content of bulk sample relative to normal CM's, high total wt% of major element oxides for phyllosilicates, and recrystallized tiny olivine grains occurring in the matrix.

AKAI (1988, 1989, 1990) gave stronger evidence for the heating; phyllosilicates in B-7904 have been almost completely transformed to olivine by heating, and the Y-82162 and Y-86720 matrices consist of olivine and Fe-rich almost-amorphous materials by transformation of matrix phyllosilicates. AKAI (1990) compared the matrices of B-7904, Y-86720, and Y-82162 with Murchison serpentine and terrestrial saponite, which were artificially heated in vacuo at different temperatures, and concluded that the degree of thermal metamorphism is estimated at the following order;

$$\text{Y-82162}(600\text{--}700°C) < \text{Y-86720}(700\text{--}750°C) \leq \text{B-7904}(\geq 750°C).$$

TOMEOKA et al. (1988a, b) also found by using TEM, that the Y-86720 and Y-82162 matrices consist of fibrous phyllosilicate-like material that is very poorly crystallized. Fine grains (<0.1 microns) of Mg-Fe silicates (pyroxene and/or olivine) occur in intimate association with the fibrous material, suggesting thermal metamorphism occurred after the formation of phyllosilicates. TOMEOKA (1989) interpreted that small grains of troilite in the B-7904 matrix have resulted presumably from thermal transformation of a thermally labile phase such as tochilinite or S-bearing ferrihydrite. He also suggested, based on the presence of Fe-Ni metal and the sparsity of magnetite and pentlandite in B-7904, that the thermal metamorphism occurred in a relatively reducing condition.

PAUL and LIPSCHUTZ (1989a, b, c, 1990) confirmed the thermal metamorphism for the three consortium chondrites by comparing the labile trace element contents with those in Murchison samples artificially heated in the laboratory. Their relative temperatures are;

$$\text{B-7904}(>600°C) < \text{Y-82162} < \text{Y-86720}(700°C \text{ or somewhat higher}).$$

The relative order of heating obtained by PAUL and LIPSCHUTZ (1989a, 1990) is different from that obtained by AKAI (1990). Similar heating experiments on Murchison were performed by ZOLENSKY et al. (1991), concluding that the three consortium chondrites did not locally experience temperatures higher than 600°C, and more likely 400 to 500°C. MIYAMOTO (1990, 1991) compared the mid-infrared

reflectance spectra of the three consortium chondrites with artificially-heated Murchison samples, and suggested that metamorphic temperature is higher than 500°C.

SHIMOYAMA et al. (1989) and KOMIYA et al. (1991) reported that a carbonaceous matter (purine) was not detected in B-7904, and that insoluble organic matters in B-7904 and Y-86720 are more graphitic than those in other normal Antarctic CM chondrites. The scarcity of organic compounds in the consortium chondrites likely reflects their thermal history on the parent body (SHIMOYAMA et al., 1991; MURAE et al., 1991).

The results obtained by the various heating experiments differ slightly from each other, but it seems to be reasonable to conclude that the three consortium chondrites were heated up to temperatures higher than 400°C. Then, a problem arises; Was the heating caused by impact-shock on the surface of their parent body or by thermal metamorphism in the interior?

MIYAMOTO (1991) presented an internal-heating model for the metamorphism. However, BISCHOFF and MEZTLER (1991) stated that in the case of metamorphism at temperature above 700°C the duration of heating must have been very short, because B-7904 contains primary olivine showing a wide compositional range of Fo_{100-40}. KIMURA and IKEDA (1992) also presented many mineralogical evidences against long-duration heating or metamorphism.

Strictly speaking, the term metamorphism means transformation from a stable or metastable mineral assemblage to another stable assemblage by changes in physical and chemical conditions. However, the heating event on the three consortium chondrites changed the phyllosilicates to an assemblage of secondary olivine (and pyroxene) and amorphous materials, and crystal structure of the original phyllosilicates remains as it was broken by the heating event, meaning that this assemblage is not stable in any condition. Therefore, the term metamorphism should not be used for the heating event on the consortium chondrites. Instead, impact-shock heating seems to be preferable, although the three consortium chondrites do not show any intense-shock texture. Probably, carbonaceous chondrites comprising a large amount of phyllosilicate may have been less brittle in comparison with other meteorites consisting of anhydrous silicate minerals, and the former may have absorbed the intense shock without a remarkable textural change. This idea is supported by shock experiments on hydrous minerals (LANGE et al., 1985). During the heating, extremely volatile components such as water, hydrocarbon, oxygen, and probably carbon dioxide, have been lost, but less-volatile components such as alkalis remained in the amorphous materials.

7. Chemistry

7.1. Major element chemical compositions

The major element compositions of the three consortium chondrites were obtained by wet analyses and presented by HARAMURA et al. (1983) for B-7904 and by TOMEOKA et al. (1989a, b) for Y-86720 and Y-82162; they are summarized in Table 5. Y-82162 contains 2.32 wt% of Fe_2O_3 and is free of metallic Fe (Table

Table 5.   Major element chemical compositions (wt%) of the consortium chondrites with reference of the solar system elementary abundances.

	B-7904	Y-86720	Y-82162	Solar
SiO_2	31.49	30.69	26.99	31.34
TiO_2	0.16	0.09	0.23	0.10
Al_2O_3	3.30	3.83	2.26	2.26
Cr_2O_3	0.50	0.45	0.48	0.53
Fe_2O_3	—	—	2.32	—
FeO	21.91	15.34	10.85	14.43
MnO	0.25	0.18	0.31	0.35
MgO	23.71	22.72	20.19	22.60
CaO	2.22	2.02	2.04	1.79
Na_2O	0.66	0.66	0.87	0.92
K_2O	0.04	0.04	0.13	•0.09
$H_2O(+)$	2.1*	4.6*	8.01*	—
$H_2O(-)$	0.5*	1.7*	3.94*	—
P_2O_5	0.37	0.19	0.36	0.39
FeS	11.45	13.22	20.08	23.62
Fe	—	2.84	—	—
Ni	—	—	—	1.51
NiO	1.21	1.16	1.28	—
Co	0.028	0.053	0.039	0.07
Total	99.89	99.78	100.37	100.00
Total Fe	24.3	23.16	22.81	26.23

* C content is included. Analyst: H. HARAMURA. Data; HARAMURA et al. (1983), TOMEOKA et al. (1989a, b), ANDERS and EBIHARA (1982).

5), although it includes a small amount of awaruite (IKEDA, 1990, 1991). Most of the ferric iron may reside in magnetite, ferrihydrite, and smectite (TOMEOKA et al., 1989a; IKEDA, 1991). The ferric iron contents of B-7904 and Y-86720 are zero in Table 1, although small mounts of magnetite and ferrihydrite are found in B-7904 and a negligible amount of ferrihydrite is found in Y-86720. B-7904 and Y-86720 contain all nickel as NiO (Table 5). However, taenite and minor kamacite commonly occur in B-7904 and Y-86720 (TOMEOKA et al., 1989b; KIMURA and IKEDA, 1992; IKEDA et al., 1992), and most of the Ni contents may be metallic Ni. Compared with the solar elemental abundance (Table 5), the siderophile elements (total Fe, Ni, and Co) of the consortium chondrites seem to be slightly depleted.

The water contents of the consortium chondrites (Table 5) are lower than those of normal CM or CI chondrites. VAN SCHMUS and WOOD (1967) defined the water contents of about 20 wt% for C1, 4–18 wt% for C2, and less than 2 wt% for C3. WASSON (1974) defined 18–22 wt% for C1, 2–16 wt% for C2, and 0.3–3 wt% for C3. The water content of Y-82162, which is classified as a CI, is far lower than that of the non-Antarctic CI chondrites. Especially in the case of B-7904, if the C content (0.972 wt%, GIBSON et al., 1984) exists as CO_2, the CO_2 content corresponds to 3.56 wt%, indicating that the apparent water content (2.6 wt% including CO_2) in Tables 3 and 5 is mainly CO_2, and the true water content of B-7904 is negligible. Therefore, the water content is exceptionally low

in comparison with the non-Antarctic and other Antarctic CM chondrites.

The consortium studies have resolved the reason why the water contents are low; the low water contents were caused by heating and dehydration, which took place at the final stage of the chondrite formation as already discussed.

7.2.   Trace element chemical compositions

Trace element and some major element compositions are shown in Fig. 2. KALLEMEYN (1988) firstly reported the trace element compositions of the three consortium chondrites, and concluded that Y-82162 is classified as a CI, B-7904 as a CM-anomalous, and Y-86720 is weakly grouped with CM chondrites, though it may be intermediate between CI and CM. EBIHARA and SHINONAGA (1989) determined some major and trace element contents in the three chondrites by INAA and RNAA, and gave a conclusion similar to that of KALLEMEYN (1988).
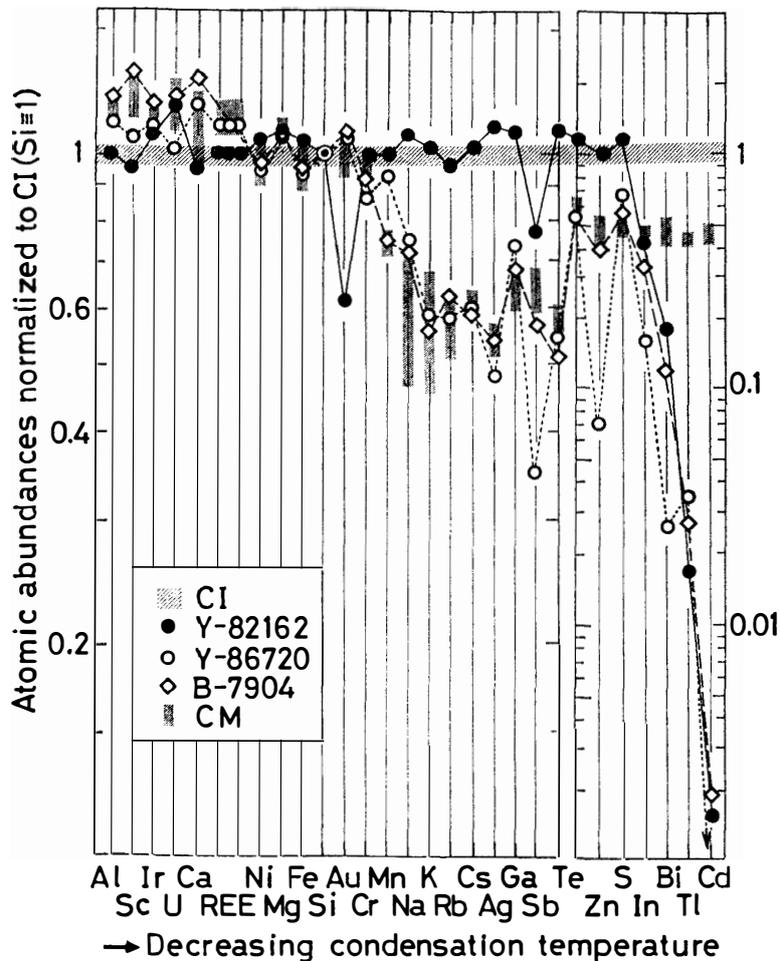

Fig. 2.   *Chemical compositions of Y-82162, Y-86720, and B-7904 with references of compositional ranges of CI and CM groups. Data sources are KALLEMEYN (1988), PAUL and LIPSCHUTZ (1990), and YAMAMOTO and NAKAMURA (1990), and data of CI and CM from ANDERS and GREVESSE (1989). This is quoted from IKEDA and NAKAMURA (1991).*

YAMAMOTO and NAKAMURA (1989, 1990) measured lithophile elements including REE of Y-86720 and Y-82162 by isotope dilution mass spectrometry. They concluded that Y-82162 is a CI but may contain small amounts of a high temperature component with a LREE/HREE fractionation caused by gas/solid reactions under moderately oxidizing conditions, and that Y-86720 is intermediate between CI and CM, showing a light positive Eu anomaly, which was explained by a mixture of high temperature components (inclusions and chondrules containing high REE abundances with negative Eu anomalies) and low temperature components (matrix including low REE with positive Eu anomaly).

PAUL and LIPSCHUTZ (1989c, 1990) measured many trace elements in the three chondrites by RNAA, and concluded that Y-82162 and the other two were originally C1 and C2, respectively. They stressed that the consortium chondrites are uniquely different from their non-Antarctic brethren, supporting the idea that Antarctic meteorites represent an extraterrestrial parent population different from a non-Antarctic meteorite population.

8. Oxygen Isotopic Compositions

MAYEDA et al. (1987) firstly reported the whole rock oxygen isotopic compositions of B-7904 and Y-82162, and concluded that the two meteorites are CI chondrites, because they are similar in oxygen isotopic composition to non-Antarctic CI (Fig. 3). The oxygen isotopic composition of Y-86720 was reported by CLAYTON and MAYEDA (1989) and MAYEDA and CLAYTON (1990), and was also classified as a CI. Oxygen isotopic compositions of several components (chondrules, clasts, olivine fragments, and matrix) separated from B-7904 were measured, and MAYEDA et al. (1991) found a new CM mixing line on which all CM chondrites including the three consortium chondrites and the components are plotted (Fig. 3), and concluded that B-7904 was formed from a precursor material similar to that of typical C2 chondrites, but that aqueous alteration occurred in an environment of higher water/rock ratio, and progressed to a considerably greater degree than in typical C2 meteorites. Thermal metamorphism had only a minor effect on the isotopic composition of the matrix and the bulk meteorite (MAYEDA et al., 1991). IKEDA et al. (1991) connected the petrography of the components with the oxygen isotopic compositions, and suggested that the hydration of chondrules and clasts took place in the solar nebula prior to the accretion onto their parent body, and that the newly-obtained CM mixing line means the oxygen isotope exchange between phyllosilicates and the nebular gas.

9. Classification

The consortium chondrites have been classified differently by many authors (Table 2). Prior to this research consortium, all carbonaceous chondrites have been classified into five groups (CI, CM, CO, CV, and CR) on the basis of mineralogy, chemistry, and oxygen isotopic composition. However, the consortium chondrites cannot be classified by the traditional classification scheme, because they
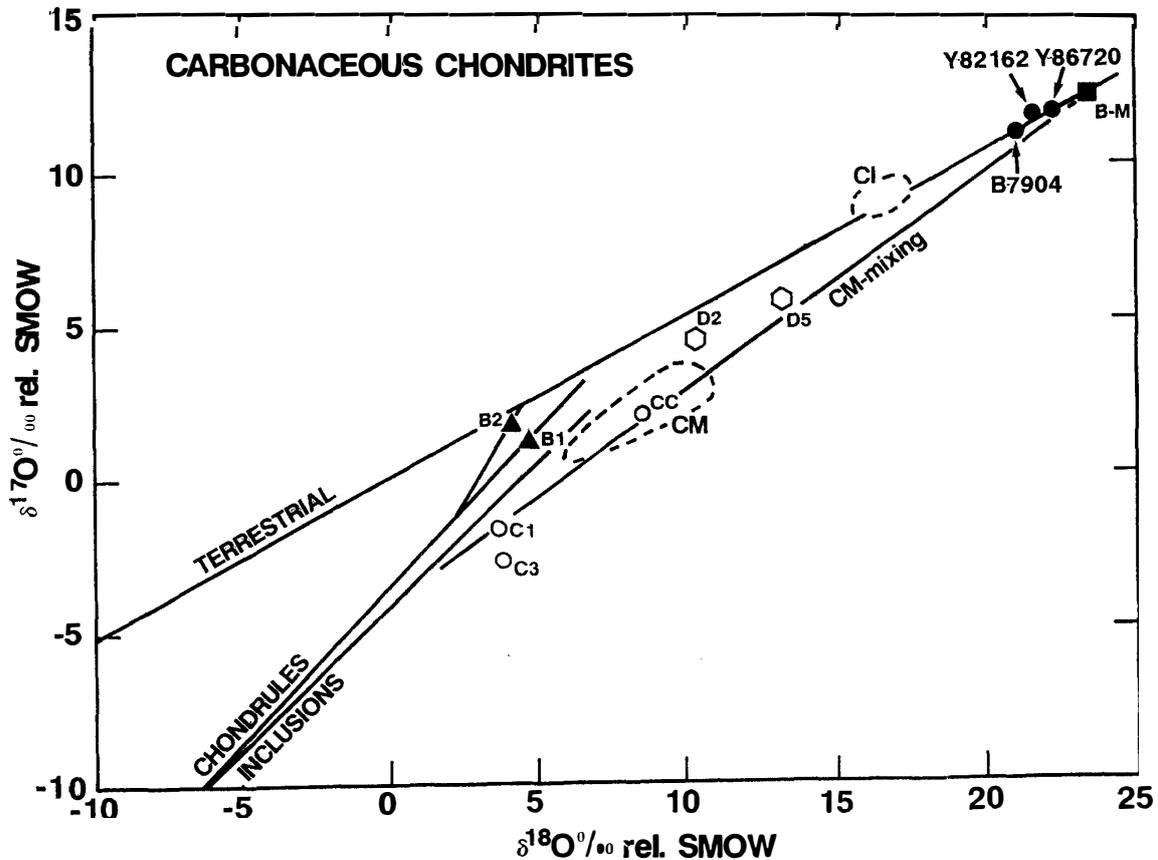
Fig. 3. Oxygen isotopic compositions of the Y-82162, Y-86720, and B-7904 whole rocks (solid circles) and components separated from B-7904. The components separated from B-7904 are; three chondrules (open circles, denoted by C1, C3, and CC), two phyllosilicate clasts (open hexagon, denoted by D2 and D5), two olivine fragments (solid triangles, denoted by B1 and B2), and the matrix (solid square, denoted by BM). Data sourses are MAYEDA and CLAYTON (1990), MAYEDA et al. (1991), IKEDA et al. (1991).

are isotopically CI, whereas mineralogically CI or CM, and chemically CI, CM, or intermediate between the two. Among the three chondrites, Y-82162 has been classified as a CI on the basis of mineralogy, chemistry, and oxygen isotopes, and seems to fit the traditional scheme. However, the whole rock water content is lower than the normal CI group (Table 3), meaning mismatch with the traditional scheme.

B-7904 has revealed more severe discrepancy in the traditional classification scheme; it is mineralogically and chemically CM, whereas oxygen-isotopically CI. Therefore, PRINZ et al. (1989) proposed a new group, CB, for the consortium chondrites. On the other hand, PAUL and LIPSCHUTZ (1989d, 1990) presented a new scheme for all carbonaceous chondrites; the new scheme expresses four parameters, chemical type, oxygen isotopes, petrography, and metamorphism (labile trace element contents). However, this conversion seems to be a little complicated. TOMEOKA (1990a) also proposed that carbonaceous chondrites should be divided into the separate groups on the basis of oxygen isotopes by using the previous designations of chemical groups, and then they should be subdivided on the basis of chemical, mineralogical and petrological characteristics in a conventional manner

by using numerics, *e.g.*, CI1, CI2, CM1, and CM2. He assigned Y-82162 as CI1 and Y-86720 and B-7904 as CI2. BISCHOFF and METZLER (1991) stated that they do not like to classify B-7904 as a CM chondrite, because of the great differences in mineralogical and petrological features between B-7904 and ordinary CM's.

As the consortium chondrites have mineralogical and chemical characteristics of both CI and CM, and the oxygen isotopic compositions form a cluster in the three isotope plots slightly different from the cluster of non-Antarctic CI, it seems to be better that a new group is established for the unusual consortium chondrites. As already mentioned, PRINZ *et al.* (1989) proposed a new group (CB) on the basis of mineralogy. However, the mineralogy is greatly different among the three chondrites. Therefore, the new group should not be established on the basis of the mineralogy. Therefore, I propose a new group, CY, on the basis of oxygen isotopic compositions.

The petrologic types of carbonaceous chondrites are also classified on the basis of several criteria. WIIK (1956) divided carbonaceous chondrites on the basis of the H_2O, C, SiO_2, and FeS contents into three subtypes, I, II, and III, mainly in order of the decreasing H_2O content. VAN SCHMUS and WOOD (1967) introduced five chemical groups (E, H, L, LL, and C) and six petrologic types from 1 to 6, where the subtypes of WIIK (1956) substituted by C1, C2, and C3, respectively. In addition, they put an emphasis on textural criteria for the classification between C1 and C2, and on mineral composition (average Ni content of sulfides) for the classification between C2 and C3. VAN SCHMUS (1969) divided the C3 chondrites into two subtypes, C3(O) and C3(V) on textural basis. WASSON (1974) called CI, CM, CO, and CV for C1, C2, C3(O), and C3(V), respectively, and stressed that each chemical group has an independent origin because of the different refractory element contents. In addition he slightly modified the sub-criteria (water and carbon contents) for the classification of petrologic types, 1, 2, and 3. KALLEMEYN and WASSON (1981) gave a chemical basis for the classification of the four chemical groups. DODD (1981) slightly modified the classification scheme for the petrologic types; he deleted the emphases on textural criteria for the classification between C1 and C2, and on mineral composition for the classification between C2 and C3. Taking the traditional classification scheme into consideration, the petrologic types (1, 2, and 3) should be classified on the basis of the water content; >17 wt% for petrologic type 1, 3–17 wt% for type 2, and <3 wt% for type 3. Thus, B-7903, Y-86720, and Y-82162 are CY3, CY2, and CY2, respectively.

10. Genetical Relationship between CI or CM Group and the Consortium Chondrites

The main constituent minerals of CI and CM chondrites are phyllosilicates, and the hydration to produce the phyllosilicates is the most important process for the origin of CI and CM chondrites. Two hypotheses, nebular process and parent body process, have been discussed for the hydration. Thermodynamic calculation for condensation of phyllosilicates from the solar nebular gas (LEWIS, 1972;

GROSSMAN and LARIMER, 1974) suggested the direct condensation of phyllosilicates from the solar nebular gas. On the other hand, parent body process has been supported by mineralogical and textural evidences, which are mainly the presence of carbonate and sulfate veins and framboidal magnetite in CI chondrites (DuFRESNE and ANDERS, 1962; KERRIDGE et al., 1979) and the colloform texture in CM chondrites (BUNCH and CHANG, 1980).

Y-82162 contains framboidal magnetite and phyllosilicate veins in some matrix-like clasts (TOMEOKA, 1990a, b; IKEDA, 1991). Therefore, it is sure that some phyllosilicates in Y-82162 were produced by reactions with liquid water in the parent body. However, Y-86720 and B-7904 do not contain such a direct evidence, and the ubiquitous occurrence of unaltered primary olivine in the B-7904 matrix (KIMURA and IKEDA, 1992) indicates that this meteorite has never undergone intense hydration after the final agglomeration of the meteorite. BISCHOFF and METZLER (1991) studied in detail accretional dust mantles surrounding coarse-grained components in B-7904 and Y-86720, and concluded that the dust mantles, which surround altered chondrules or clasts containing phyllosilicates, can only be explained by accretional processes in the solar nebula. IKEDA et al. (1991) studied some partially altered chondrules and clasts separated from B-7904; olivine in partially altered chondrules remains unaltered, whereas pyroxene and plagioclase altered. This alteration characteristic was fully explained by gas-solid reactions, because thermodynamic calculation indicates that hydrous reactions of pyroxene and plagioclase with a gas take place at temperatures higher than hydrous reactions of olivine. Therefore, IKEDA et al. (1991) concluded that the hydration of partially-altered chondrules was caused by reactions with the nebular gas at intermediate temperatures between hydrous alteration of pyroxene + plagioclase and olivine.

IKEDA et al. (1991) suggested that the newly obtained CM mixing line obtained by MAYEDA et al. (1991) means the oxygen-isotope exchange of chondrules and clasts with the nebular gas, not with liquid water, and that most phyllosilicates in CM chondrites were produced from anhydrous components such as chondrules and inclusions by reactions with the nebular gas.

The oxygen isotopic compositions of the three consortium chondrites are situated at a critical point connecting the terrestrial (and nearly CI chondrite) fractionation line with the newly obtained CM mixing line (Fig. 3), suggesting that the consortium chondrites are oxygen-isotopically midway between CM and CI groups. Namely, most of phyllosilicates in CM chondrites were produced by reactions with a nebula gas, resulting in the new CM mixing line, whereas most of phyllosilicates in CI chondrites were produced by reactions with liquid water in their parent bodies. The three consortium chondrites were produced under an intermediate condition connecting the two groups.

expresses his gratitude to all consortium members for their cooperation to the consortium, and hopes that several members, who do not yet present a paper, will discharge their duty in the near future. The author is very sorry that Dr. J. DANON, a powerful member of our consortium died in 1990. This study has been supported by a Grant-in-Aid for Scientific Research, from the Ministry of Education, Science and Culture.

References

AKAI, J. (1984): Mineralogical characterization of matrix materials in carbonaceous chondrites Yamato-793321 and Belgica-7904 by HREM. Papers Presented to the 9th Symposium on Antarctic Meteorites, March 22–24, 1984. Tokyo, Natl Inst. Polar Res., 59–61.

AKAI, J. (1988): Incompletely transformed serpentine-type phyllosilicates in the matrix of Antarctic CM chondrites. Geochim. Cosmochim. Acta, **52**, 1593–1599.

AKAI, J. (1989): Mineralogical evidence of heating events in carbonaceous chondrites, Y-82162 and Y-86720. Papers Presented to the 14th Symposium on Antarctic Meteorites, June 6–8, 1989. Tokyo, Natl Inst. Polar Res., 22–23.

AKAI, J. (1990): Mineralogical evidence of heating events in Antarctic carbonaceous chondrites, Y-86720 and Y-82162. Proc. NIPR Symp. Antarct. Meteorites, **3**, 55–68.

ANDERS, E. and EBIHARA, M. (1982): Solar-system abundances of the elements. Geochim. Cosmochim. Acta, **46**, 2363–2380.

ANDERS, E. and GREVESSE, N. (1989): Abundances of the elements: Meteoritic and solar. Geochim. Cosmochim. Acta, **53**, 197–214.

BISCHOFF, A. and METZLER, K. (1990): Petrography and chemistry of the three carbonaceous chondrites Y-86720, Y-82162, and B-7904. Papers Presented to the 15th Symposium on Antarctic Meteorites. Tokyo, Natl Inst. Polar Res., 185–187.

BISCHOFF, A. and METZLER, K. (1991): Mineralogy and petrography of the anomalous carbonaceous chondrites Yamato-86720, Yamato-82162, and Belgica-7904. Proc. NIPR Symp. Antarct. Meteorites, **4**, 226–246.

BUNCH, T. E. and CHANG, S. (1980): Carbonaceous chondrites-II. Carbonaceous chondrite phyllosilicates and light element geochemistry as indicators of parent body processes and surface conditions. Geochim. Cosmochim. Acta, **44**, 1543–1577.

CLAYTON, R. N. and MAYEDA, T. K. (1989): Oxygen isotope classification of carbonaceous chondrites. Lunar and Planetary Science XX. Houston, Lunar Planet. Inst., 169–170.

DODD, R. T. (1981): Meteorites. Cambridge, Cambridge University Press, 368 p.

DuFRESNE, E. R. and ANDERS, E. (1962): On the chemical evolution of the carbonaceous chondrites. Geochim. Cosmochim. Acta, **26**, 1085–1114.

EBIHARA, M. and SHINONAGA, T. (1989): Chemical compositions of some primitive carbonaceous chondrites from Antarctica. Papers Presented to the 14th Symposium on Antarctic Meteorites, June 6–8, 1989. Tokyo, Natl Inst. Polar Res., 35.

GIBSON, E. K., JR., CRONIN, J. R., KOTRA, R. K., PRIMAS, T. R. and MOOR, C. B. (1984): Amino acids, carbon, and sulfur abundances in Antarctic carbonaceous chondrites. Papers Presented to the 9th Symposium on Antarctic Meteorites, March 22–24, 1984. Tokyo, Natl Inst. Polar Res., 78–80.

GROSSMAN, L. and LARIMER, J. W. (1974): Early chemical history of the solar system. Rev. Geophys. Space Phys., **12**, 71–101.

HARAMURA, H., KUSHIRO, I. and YANAI, K. (1983): Chemical compositions of Antarctic meteorites I. Mem. Natl Inst. Polar Res., Spec. Issue, **30**, 109–121.

IKEDA, Y. (1990): Mineralogy of clasts in the Y-82162 chondrite (CI). Papers Presented to the 15th Symposium on Antarctic Meteorites, May 30–June 1, 1990. Tokyo, Natl Inst. Polar Res., 81–82.

IKEDA, Y. (1991): Petrology and mineralogy of the Yamato-82162 chondrite (CI). Proc. NIPR Symp. Antarct. Meteorites, **4**, 187–225.

IKEDA, Y. and NAKAMURA, N. (1991): A new type of Antarctic carbonaceous chondrites with

CI affinites. Episodes, **14**, 252–257.

IKEDA, Y., MAYEDA, T. K., CLAYTON, R. N. and PRINZ, M. (1991): Petrography and oxygen isotopic compositions of chondrules, clasts, and matrix separated from B-7904 and Yamato-86720 carbonaceous chondrites. Papers Presented to the 16th Symposium on Antarctic Meteorites, June 5–7, 1991. Tokyo, Natl Inst. Polar Res., 82–84.

IKEDA, Y., NOGUCHI, T. and KIMURA, M. (1992): Petrology and mineralogy of the Yamato-86720 carbonaceous chondrite. Proc. NIPR Symp. Antarct. Meteorites, **5**, 136–154.

KALLEMEYN, G. W. (1988): Compositional study of carbonaceous chondrites with CI-CM affinites. Papers Presented to the 13th Symposium on Antarctic Meteorites, June 7–9, 1988. Tokyo, Natl Inst. Polar Res., 132–134.

KALLEMEYN, G. W. and WASSON, J. (1981): The compositional classification of chondrites-I. The carbonaceous chondrites. Geochim. Cosmochim. Acta, **45**, 1217–1230.

KERRIDGE, J. F., MACKAY, A. L. and BOYTON, W. V. (1979): Magnetite in CI carbonaceous meteorites: Origin by aqueous activity on a planetesimal surface. Science, **205**, 395–397.

KIMURA, M. and IKEDA, Y. (1991): Mineralogical and petrological study of anomalous Belgica-7904 carbonaceous chondrite. Papers Presented to the 16th Symposium on Antarctic Meteorites, June 5–7, 1991. Tokyo, Natl Inst. Polar Res., 79–81.

KIMURA, M. and IKEDA, Y. (1992): Mineralogy and petrology of an unusual Belgica-7904 carbonaceous chondrite: Genetic relationships among the components. Proc. NIPR Symp. Antarct. Meteorites, **5**, 74–119.

KOJIMA, H. and YANAI, K. (1987): Yamato-82162: Possible first CI carbonaceous chondrite from Antarctica. Papers Presented to the 12th Symposium on Antarctic Meteorites, June 8–10, 1987. Tokyo, Natl Inst. Polar Res., 15.

KOJIMA, H., IKEDA, Y. and YANAI, K. (1984a): Classification of the Yamato carbonaceous chondrites. Papers Presented to the 9th Symposium on Antarctic Meteorites, March 22–24, 1984. Tokyo, Natl Inst. Polar Res., 22.

KOJIMA, H., IKEDA, Y. and YANAI, K. (1984b): The alteration of chondrules and matrices in new Antarctic carbonaceous chondrites. Mem. Natl Inst. Polar Res., Spec. Issue, **35**, 184–199.

KOMIYA, M., SHIMOYAMA, A. and HARADA, K. (1991): Thermal release of insoluble organic matter isolated from Antarctic CI and CM chondrites. Papers Presented to the 12th Symposium on Antarctic Meteorites, June 8–10, 1987. Tokyo, Natl Inst. Polar Res., 45–47.

LANGE, M. A., LAMBERT, P. and AHRENS, T. J. (1985): Shock effects on hydrous minerals and implications for carbonaceous meteorites. Geochim. Cosmochim. Acta, **49**, 1715–1726.

LEWIS, J. S. (1972): Metal/silicate fractionation in the solar system. Earth Plant. Sci. Lett., **15**, 286–290.

MATSUBARA, K., NAGAO, K. and MATSUDA, J. (1987): Noble gases in Belgica-7904 carbonaceous chondrite. Papers Presented to the 12th Symposium on Antarctic Meteorites, June 8–10, 1987. Tokyo, Natl Inst. Polar Res., 108–109.

MATSUNAMI, S., NISHIMURA, H. and TAKESHI, H. (1989): Compositional heterogeneity of alteration products in B-7904 chondrite. Papers Presented to the 14th Symposium on Antarctic Meteorites, June 6–8, 1989. 1991. Tokyo, Natl Inst. Polar Res., 21.

MATSUNAMI, S., NISHIMURA, H. and TAKESHI, H. (1990): Compositional heterogeneity of alteration products in Yamato-86720 chondrite. Papers Presented to the 15th Symposium on Antarctic Meteorites, May 30–June 1, 1991. Tokyo, Natl Inst. Polar Res., 88.

MAYEDA, T. K. and CLAYTON, R. N. (1990): Oxygen isotopic compositions of B-7904, Y-82162, and Y-86720. Papers Presented to the 15th Symposium on Antarctic Meteorites, May 30–June 1, 1991. Tokyo, Natl Inst. Polar Res., 196–197.

MAYEDA, K., CLAYTON, R. N. and YANAI, K. (1987): Oxygen isotopic compositions of several Antarctic meteorites. Mem. Natl Inst. Polar Res., Spec. Issue, **46**, 144–150.

MAYEDA, T. K., CLAYTON, R. N. and IKEDA, Y. (1991): Oxygen isotopic studies of carbonaceous chondrite Belgica-7904. Lunar Planetary Science XXII. Houston, Lunar Planet. Inst., 865–866.

MCGRAVIE, D. W., WRIGHT, I. P., GRADY, M. M., PILLINGER, C. T. and GIBSON, E. K. (1987): A stable carbon isotopic study of types 1 and 2 carbonaceous chondrites. Mem. Natl Inst. Polar Res., Spec. Issue, **46**, 179–195.

McSween, H. Y., Jr. and Richardson, S. M. (1977): The composition of carbonaceous chondrite matrix. Geochim. Cosmochim. Acta, 41, 1145–1161.

Miyamoto, M. (1990): Midindrared diffuse reflectance spectra of some Antarctic carbonaceous chondrites. Papers Presented to the 15th Symposium on Antarctic Meteorites, May 30–June 1, 1991. Tokyo, Natl Inst. Polar Res., 89–91.

Miyamoto, M. (1991): Thermal metamorphism of CI and CM carbonaceous chondrites: An internal heating model. Meteoritics, 26, 111–115.

Murae, T., Masuda, A. and Takahashi, T. (1985): Possibility of characterization of carbonaceous chondrites based on carbonaceous matter. Papers Presented to the 10th Symposium on Antarctic Meteorites, March 25–27, 1985. Tokyo, Natl Inst. Polar Res., 50–51.

Murae, T., Masuda, T. and Takahashi, T. (1986): Pyrolytic studies on major carbonaceous matter in carbonaceous chondrites Y-791198, Y-791717, Y-793321 and B-7904. Papers Presented to the 11th Symposium on Antarctic Meteorites, March 25–27, 1986. Tokyo, Natl Inst. Polar Res., 12–14.

Murae, T., Masuda, A. and Takahashi, T. (1987): Pyrolytic studies of carbonaceous matter in Antarctic carbonaceous chondrites. Mem. Natl Inst. Polar Res., Spec. Issue, 46, 196–204.

Murae, T., Masuda, A. and Takahashi, T. (1989): Studies of carbonaceous residues obtained from carbonaceous chondrites by acid treatments. Papers Presented to the 14th Symposium on Antarctic Meteorites, June 6–8, 1989. Tokyo, Natl Inst. Polar Res., 48–50.

Murae, T., Kitajima, F. and Masuda, A. (1991): Pyrolytic nature of carbonaceous matter in carbonaceous chondrites and secondary metamorphism. Proc. NIPR Symp. Antarct. Meteorites, 4, 384–389.

Nagao, K., Inoue, K. and Ogata, K. (1984a): Rare gas studies of the Antarctic meteorites: Belgica-7904 C2 chondrite. Papers Presented to the 9th Symposium on Antarctic Meteorites, March 22–24, 1984. Tokyo, Natl Inst. Polar Res., 99–100.

Nagao, K., Inoue, K. and Takahashi, T. (1984b): Primordial rare gases in Belgica-7904 (C2) carbonaceous chondrite. Mem. Natl Inst. Polar Res., Spec. Issue, 35, 257–266.

Nagao, K., Matsuda, J. and Inoue, K. (1985): Primordial rare gases in carbonaceous chondrites. Papers Presented to the 10th Symposium on Antarctic Meteorites, March 25–27, 1985. Tokyo, Natl Inst. Polar Res., 149.

Paul, R. L. and Lipschutz, M. E. (1989a): Consortium report on carbonaceous chondrites from Queen Maud Land, Antarctica: Glimpses of new parents. Papers Presented to the 14th Symposium on Antarctic Meteorites, June 6–8, 1989. Tokyo, Natl Inst. Polar Res., 32–33.

Paul, R. L. and Lipschutz, M. E. (1989b): Carbonaceous chondrites from Queen Maud Land, Antarctica: Glimpses of new parents. Lunar and Planetary Science XX. Houston, Lunar Planet. Inst., 830–831.

Paul, R. L. and Lipschutz, M. E. (1989c): Labile trace elements in some Antarctic carbonaceous chondrites: Antarctic and non-Antarctic meteorite comparisons. Z. Naturf., A44, 979–987.

Paul, R. L. and Lipschutz, M. E. (1989d): A modest proposal for carbonaceous chondrite classification in light of the Antarctic samples. Abstract of 52th Meeting of the Meteoritical Society, 313–314.

Paul, R. L. and Lipschutz, M. E. (1990): Consortium study of labile trace elements in some Antarctic carbonaceous chondrites: Antarctic and non-Antarctic meteorite comparisons. Proc. NIPR Symp. Antarct. Meteorites, 3, 80–95.

Prinz, M., Weisberg, M. K., Han, R. and Zolensky, M. E. (1989): Type I and II chondrules in the B-7904 carbonaceous chondrite. Abstract of 52th Meeting of the Meteoritical Society, 317–318.

Scorzelli, R. B. and Souza Azevedo, I. (1991): Mossbauer spectroscopy studies in Antarctic carbonaceous chondrites Y-86720 and Y-82162. Papers Presented to the 16th Symposium on Antarctic Meteorites, June 5–7, 1991. Tokyo, Natl Inst. Polar Res., 66.

Shimoyama, A. and Harada, K. (1984): Search for amino acids indigenous to the Yamato-793321 and Belgica-7904 carbonaceous chondrites. Papers Presented to the 9th Symposium on Antarctic Meteorites, March 22–24, 1984. Tokyo, Natl Inst. Polar Res., 81.

SHIMOYAMA, A., HARADA, K., YANAI, K. and KOJIMA, H. (1986): Carbon and nitrogen contents of carbonaceous chondrites from Antarctica, and their implication. Papers Presented to the 11th Symposium on Antarctic Meteorites, March 25–27, 1986. Tokyo, Natl Inst. Polar Res., 7–8.

SHIMOYAMA, A., HAGISHITA, S. and HARADA, K. (1989): Purines in Antarctic carbonaceous chondrites. Papers Presented to the 14th Symposium on Antarctic Meteorites, June 6–8, 1989. Tokyo, Natl Inst. Polar Res., 43–44.

SHIMOYAMA, A., KOMIYA, M. and HARADA, K. (1991): Release of organic compounds from some Antarctic CI and CM chondrites by laboratory heating. Proc. NIPR Symp. Antarct. Meteorites, 4, 247–262.

SKIRIUS, C., STEELE, I. M. and SMITH, J. V. (1986): Belgica-7904: A new carbonaceous chondrite from Antarctica: Minor-element chemistry of olivine. Mem. Natl Inst. Polar Res., Spec. Issue, 41, 243–258.

STEELE, I. M., COX, R. T., JR. and SMITH, J. V. (1984): Belgica 7904, an extreme C2 from Antarctica: Petrology and mineral chemistry. Lunar Planetary Science XV. Houston, Lunar Planet. Inst., 820–821.

STEELE, I. M., SKIRIUS, C. M. and SMITH, J. V. (1985): Olivine in Belgica 7904 and other chondrites: Evidence for relic olivine with unique chemical and textural features. Papers Presented to the 10th Symposium on Antarctic Meteorites, March 25–27, 1985. Tokyo, Natl Inst. Polar Res., 218–220.

TOMEOKA, K. (1989): Belgica-7904: A new kind of carbonaceous chondrite from Antarctica; mineralogy and petrology. Papers Presented to the 14th Symposium on Antarctic Meteorites, June 6–8, 1989. Tokyo, Natl Inst. Polar Res., 18–20.

TOMEOKA, K. (1990a): Mineralogy and petrology of Belgica-7904: A new kind of carbonaceous chondrite from Antarctica. Proc. NIPR Symp. Antarct. Meteorite, 3, 40–54.

TOMEOKA, K. (1990b): Phyllosilicate veins in a CI meteorite: Evidence for aqueous alteration on the parent body. Nature, 345, 138–140.

TOMEOKA, K., KOJIMA, H. and YANAI, K. (1988a): Yamato-82162: A new kind of CI carbonaceous chondrite found in Antarctica. Papers Presented to the 13th Symposium on Antarctic Meteorites, June 7–9, 1988. Tokyo, Natl Inst. Polar Res., 126–127.

TOMEOKA, K., KOJIMA, H. and YANAI, K. (1988b): Yamato-86720: An extensively altered and thermally metamorphosed CM carbonaceous chondrite? Papers Presented to the 13th Symposium on Antarctic Meteorties, June 7–9, 1988. Tokyo, Natl Inst. Polar Res., 130–131.

TOMEOKA, K., KOJIMA, H. and YANAI, K. (1989a): Yamato-82162: A new kind of CI carbonaceous chondrite found in Antarctica. Proc. NIPR Symp. Antarct. Meteorites, 2, 36–54.

TOMEOKA, K., KOJIMA, H. and YANAI, K. (1989b): Yamato-86720: A CM carbonaceous chondrite having experienced extensive aqueous alteration and thermal metamorphism. Proc. NIPR Symp. Antarct. Meteorites, 2, 55–74.

VAN SCHMUS, W. R. (1969): Mineralogy and petrology of chondritic materials. Earth Planet. Sci. Lett., 5, 145–184.

VAN SCHMUS, W. R. and WOOD, J. (1967): A chemical-petrological classification for the chondritic materials. Geochim. Cosmochim. Acta, 31, 747–765.

WASSON, J. T. (1974): Meteorites. New York, Spring, 316 p.

WATANABE, S., TSUCHIYAMA, A. and KITAMURA, M. (1988): A preliminary report of mineralogy of Y-82162 (CI). Papers Presented to the 13th Symposium on Antarctic Meteorites, June 7–9, 1988. Tokyo, Natl Inst. Polar Res., 128–129.

WIIK, H. B. (1956): The chemical composition of some stony meteorites. Geochim. Cosmochim. Acta, 9, 279–289.

YAMAMOTO, K. and NAKAMURA, N. (1989): Chemical characteristics and their inference to classification of Yamato-82162 and -86720 meteorites. Papers Presented to the 14th Symposium on Antarctic Meteorites, June 6–8, 1989. Tokyo, Natl Inst. Polar Res., 27–29.

YAMAMOTO, K. and NAKAMURA, N. (1990): REE characteristics of Yamato-82162 and -86720 meteorites and their inference to classification. Proc. NIPR Symp. Antarct. Meteorites,

3, 69–79.

YANAI, K. and KOJIMA, H. (1982): Meteorites News (NIPR), 1, 26.

YANAI, K. and KOJIMA, H., comp. (1987): Photographic Catalog of the Antarctic Meteorites. Tokyo, Natl Inst. Polar Res., 298 p.

ZOLENSKY, M., BARRETT, R. and PRINZ, M. (1989a): Mineralogy and petrology of Yamato-86720 and Belgica-7904. Papers Presented to the 14th Symposium on Antarctic Meteorites, June 6–8, 1989. Tokyo, Natl Inst. Polar Res., 24–26.

ZOLENSKY, M. E., BARRETT, R. A. and PRINZ, M. (1989b): Petrography, mineralogy and matrix composition of Yamato-82162, A new CI2 chondrite. Lunar and Planetary Science XX. Houston, Lunar Planet. Inst., 1253–1254.

ZOLENSKY, M., PRINZ, M. and LIPSCHUTZ, M. (1991): Mineralogy and thermal history of Y-82162, Y-86720, and B-7904. Papers Presented to the 16th Symposium on Antarctic Meteorites, June 5–7, 1991. Tokyo, Natl Inst. Polar Res., 195–196.