Chinese Journal of Polar Science, Vol. 20, No. 2, 166－171, December 2009

Petrography and mineral chemistry of 4 carbonaceous chondrites from the Grove Mountains, Antarctica

Dai Deqiu(戴德求)[1] and Wang Daode(王道德)[2]

1 Institute of Geology, Hunan University of Science and Technology, Xiangtan 411201, China

2 Guangzhou Institute of Geochemistry, Chinese Academy of Sciences, Guangzhou 510640, China

Received August 24, 2009

Abstract Petrography and mineral chemistry of four carbonaceous chondrites (GRV 020017, GRV 020025, GRV 021579, GRV 022459) collected from the Grove Mountains (GRV), Antarctica, were reported here. All four chondrites are unequilibrated, as indicated by well shaped chondrules and the chemical variations of olivine and low-Ca pyroxene. The modal abundance ratio of matrix/chondrule are 2 (GRV 020017), 2.8 (GRV 020025), 1.2 (GRV 021579), 1 (GRV 022459). GRV 022459 has the largest chondrules (0.6—2.0 mm). A total of 30 Ca-Al-rich inclusions were found in the four meteorites. Most inclusions were highly altered, with abundant phyllosilicates in the inclusions of GRV 020017 and GRV 020025. On the base of petrography and mineral chemistry, these chondrites are classified as CM2 (GRV 020017 and 020025), CO3 (GRV 021579) and CV3 (GRV 022459).

Keywords carbaonaceous chondrites; petrography and mineral chemistry; CAI; classification; Antarctica

1 Introduction

Carbonaceous chondrites are the primordial matter of the solar system. Although few in number, they have an important position in the models of meteorolite and planet. There are seven groups which range from CI, which 99 percent water-rich matrix, to CK and CH, which have none; CH is abnormally metal-rich. CM and CR groups have small and large chondrules, respectively, set in hydrous matrix. CO and CV groups have small and large chondrules, respectively, set in olivine-rich matrix. Ca; Al-rich inclusions (CAIs) are the most extensively studied components of carbonaceous chondrites, and they have various characters in various chemical groups.

Since the first discovery of 9 meteorites on blue ice in Antarctica by the Japanese Antarctic Research Expedition in 1969, Antarctica has become the most meteorite-rich region in the world[1－2]. Beside the large number, many new or rare types of meteorites have been found in Antarctica, i.e. martian meteorites[3－4], carbonaceous chondrites, iron meteorites, HED meteorite[5] *et al.* Grove Mountains consist of 64 nunataks, and locate at the eastern Antarctica[6]. After the first discovery of 32 meteorites from Grove Mountains region, Antarctica[7－8], another 4448 meteorites were collected from the same region by the 19th Chi-

nese Antarctic Research Expedition (CHINARE)[9]. In this paper, we report petrography and mineral chemistry of 4 carbonaceous chondrites come from these meteorites, and their chemical-petrographic types are assigned.

2 Samples and Experiments

One polished thin section was prepared for each of the 4 carbonaceous chondrites. The surface areas of the sections are 0.57 cm^2 (GRV 020017), 1.2 cm^2 (GRV 020025), 0.62 cm^2 (GRV 021579) and 0.29 cm^2 (GRV 022459), respectively.

Textural observations were carried out using an optical microscope and in back-scattered electron (BSE) image model of an electronic probe microanalyzer (EPMA) type JEOL 8800 in the Laboratory of Electron Microscopes, Zhongshan University and type CAMECA SX51 in the Institute of Geology and Geophysics, Chinese Academy of Sciences, Beijing. Quantitative analyses of minerals were conducted using the same EPMA. The operating conditions were 20 nA and 15 kV, and the standards were silicates and oxides. Peak overlapping of Kα lines by Kβ lines of some successive elements were corrected, such as V by Ti, and Mn by Cr. Analyses data were treated using the conventional ZAF method. Modal abundances of metal Fe-Ni, chondrule, matrix and CAI were calculated from surface areas of the phase in BSE images of the sections.

3 Results and discussion

3.1 GRV 020017

Figure 1a is a back-scattered electron (BSE) image mosaic of GRV 020017, consisting mainly of phyllosilicates-bearing matrix (66 vol%) and small chondrules (33 vol%, 50—300 m). GRV 020017 has very shape outlined chondrules, common textural types of the chondrules are porphyritic olivine (PO), porphyritic olivine and pyroxene (POP), and granular olivine and pyroxene (GOP). Modal abundance of metallic Fe-Ni and sulfide is 1.8 vol%. 3 CAIs and some amoeboid olivine aggregates (AOAs) were found in the section. The total surface of three CAIs is 0.05 mm^2, giving a modal abundance of 0.1 vol% (Table 1). Two out of three CAIs are classified as Type A-like inclusions (Type A: melilite-spinel-rich CAI; Type A-like: alterred Type A). Both inclusions are irregular and loose assemblages that consist of cores of fine-grained spinel and needle-shaped phyllosilicates can be found in CAIs. The other CAI are classified as Spinel-pyroxene-rich inclusions.

Table 1. Petrography characters of four cabonaceous chondrites

Meteorites	Type	Diameter of chondrules (μm)	Type of chondrules	Modal abundance of chondrules (vol%)	Number of CAI	Modal abundance of CAI (vol%)	Modal abundance of martix (vol%)	Matrix / chondrule
GRV 020017	CM2	50-300	GOP PO POP	33	3	0.1	66%	2
GRV 020025	CM2	< 500, 100-300	GOP PO POP BO	26	11	0.29	72%	2.8
GRV 021579	CO3	30-100, 350-600	GOP PO POP BO	45	13	0.81	54%	1.2
GRV 022459	CV3	600-2000	GOP PO BO	50	3	0.18	50%	1

Olivine and low-Ca pyroxene in GRV 020017 show large variations in compositions (Table 2, 3). Fayalite (Fa) content of olivine ranges from 0.2 to 94 mol%, with an aver-

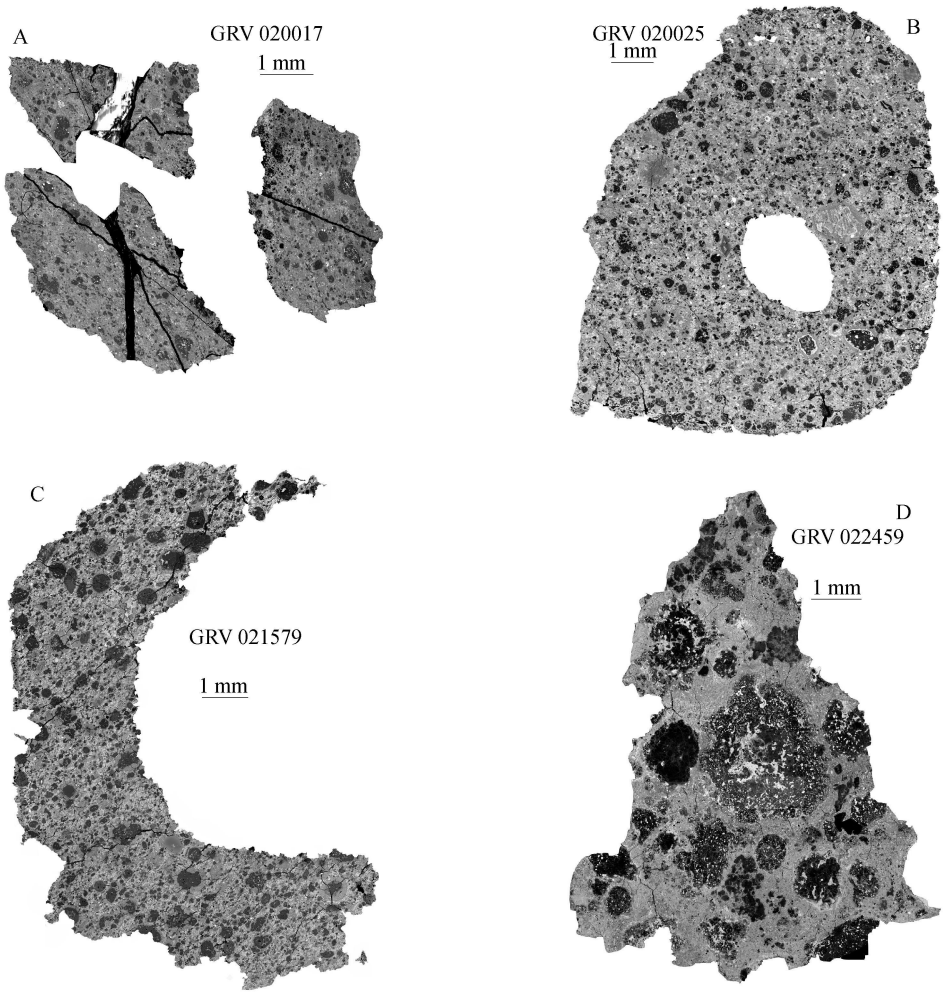

Fig 1 Back-scattered electron image mosaic of four carbonaceous chondrites. Note very shape-outlined chondrules. The scale bars are 1.0 mm. (a) GRV 020017, a CM2 chondrite. Note small chondrules and high abundance of matrix. (b) GRV 020025, a CM2 chondrite. Note small chondrules and high abundance of matrix. Accretionary rims on chondrules are common; (c) GRV 021579, a CO3 chondrite, shows two clusters of large and small chondrules, and higher abundance of chondrules than that in GRV 020017 and GRV 020025; (c) GRV 022459 has much larger chondrules and amoeboid olivine aggregates (AOAs) than that of the above three meteorites. It is a CV3 chondrite.

Table 2 Representative electron microprobe analyses of olivine (wt%)

Meteorites	Type	Analysis number	SiO_2	TiO_2	Al_2O_3	Cr_2O_3	FeO	NiO	MnO	MgO	CaO	Na_2O	K_2O	Fa (mol%)	PMD
GRV 020017	CM2	32	< 59* 41±10&	< 1.0 0.1±0.2	< 4.0 0.3±0.8	0.04-0.7 0.3±0.2	0.2-32 8±11	< 0.05 b.d	< 0.6 0.2±0.1	0.03-58 45±13	0.1-59 3±11	< 0.05 b.d.	b.d b.d	0.2-94 12#	163
GRV 020025	CM2	55	27-43 40±3	< 0.5 0.04±0.08	< 2.1 0.2±0.3	0.1-4.4 0.4±0.6	0.6-39 8±12	< 0.2 0.02-0.03	< 0.6 0.2±0.1	2.1-56 48±10	0.1-3.5 0.4±0.6	< 0.2 0.03±0.06	< 0.07 b.d	0.7-48.3 9	158
GRV 021579	CO3	27	28-42 39±4	< 0.08 b.d	< 0.6 0.1±0.1	0.2-0.6 0.4±0.1	0.6-46 16±17	b.d b.d	0.04-0.6 0.3±0.2	12-56 42±15	0.05-0.6 0.3±0.1	< 0.1 0.03±0.04	< 0.04 b.d	0.6-65 20	110
GRV 022459	CV3	26	37.0-42.0 40.5±1.0	< 0.1 1±0.1	< 1.2 0.1±0.04	< 1.0 49±4	2.1-19 8.2±4.6	< 0.3 0.02±0.05	0.05-0.3 0.1±0.04	39-53 49±4	0.09-0.3 0.2±0.05	< 0.07 0.04±0.02	< 0.05 b.d	2.2-22 8.7	59

Note: * - quantitative analyses range of minerals; & - average of quantitative analyses ± standard deviation; # - average of Fa; b.d - below detected.

age of 12 mol%. The percent mean deviation (PMD) of Fa values is 163%. Low-Ca pyroxene shows wider range of ferrosilite (Fs) content (0.4—14 mol%), with an average of

Table 3 Representative electron microprobe analyses of low-Ca pyroxene (wt%)

Meteorites	Type	Analysis number	SiO_2	TiO_2	Al_2O_3	Cr_2O_3	FeO	NiO	MnO	MgO	CaO	Na_2O	K_2O	Fs(mol%)	PMD
GRV 020017	CM2	13	41.60 53.8±8	<0.2 0.09±0.07	<1.3 0.5±0.4	0.1-0.9 0.5±0.2	0.5-9.0 2.1±2.5	<0.05 b.d	0.02-0.6 2±0.2	31.56 43.8±8	0.1-1.6 0.5±0.3	<0.05 h.d	<0.02 h.d	0.4-14 2.8	128
GRV 020025	CM2	6	33.42 40±3	<0.06 0.04±0.03	<0.9 0.2±0.3	0.2-0.4 0.3±0.08	0.6-13 3±4.6	<0.2 0.06±0.1	<0.14 0.1±0.05	38.55 51±6	0.2-0.4 0.3±0.1	<0.2 0.03±0.06	<0.05 h.d	0.6-16.4 3.8	150
GRV 021579	CO3	4	37.41 39±1.5	b.d b.d	<0.06 h.d.	0.3-0.7 0.4±0.2	6.0-30 20±9	<0.03 b.d	<0.4 b.d	32.52 40±7	0.1-0.3 2±0.07	<0.1 0.03±0.04	h.d h.d	6.0-34.4 22.3	46
GRV 022459	CV3	5	40.7-41.7 41.3±0.4	<0.1 0.07±0.04	<0.2 0.1±0.1	0.1-0.9 0.5±0.2	0.8-4.9 2.5±1.5	b.d b.d	<0.14 0.1±0.05	52.55 53±1	0.2-0.3 0.2±0.05	<0.07 0.04±0.02	<0.04 h.d	0.8-5.0 2.5	59.5

2.8 mol% and PMD of 128% (Table 2, 3). The highly heterogeneous mineral chemistry confirms that GRV 020017 is a typical unequilibrated chondrite. GRV 020017 contains small chondrules in phyllosilicate-bearing matrix. The sizes of chondrules (50-300 m) and modal abundance ratio of matrix/chondrule (2) are typical of CM2 chondrites, but distinguished from CO3, CV3 and other carbonaceous chondrites. Aqueous alteration is common for CAIs in CM2 chondrites[10-11]. The common occurrence of phyllosilicates in matrix and CAIs further confirms that GRV 020017 is a CM2 chondrite.

3.2 GRV 020025

Figure 1b is a back-scattered electron (BSE) image mosaic of GRV 020025, consisting mainly of phyllosilicates-bearing matrix (72 vol%) and small chondrules (26 vol%, < 500 m and most 100—300 m in diameter). Most chondrules have accretionary rims, and they are FeO-poor in chemical composition (Type I). Common textural types of the chondrules are barred olivine (BO), PO, POP, and GOP. Metallic Fe-Ni is rare (~ 0.12 vol%), and modal abundance of sulfide is 1.3 vol%. Eleven Ca-Al-rich inclusions (CAIs) were found in the section. The total surface of these CAIs is 0.35 mm^2, giving a modal abundance of 0.29 vol% (Table 1). Six out of 11 CAIs are classified as Type A-like inclusions, with a size range of 80—500 m. All of these inclusions are highly irregular and loose assemblages of concentrically zoned objects that consist of cores of fine-grained spinel and needle-shaped phyllosilicates and rims of Ca-pyroxene. Spinel-pyroxene-rich inclusions are the second most abundant CAIs in GRV 020025, with 4 inclusions found in the section. Only a spinel spherule was found in the section[12].

Olivine and low-Ca pyroxene in GRV 020025 show large variations in compositions (Table 2, 3), too. Fa content of olivine ranges from 0.7 to 48.3 mol%, with an average of 9.0 mol%. PMD of Fa values is 158%. Fa content of olivine in chondrules ranges from 0.8 to 1.1 mol% (except for one analysis of 4.7 wt%). However, Fa content of olivine in matrix ranges from 0.7 to 48.3 mol%. Low-Ca pyroxene shows wider range of Fs content (0.6—16.4 mol%), with an average of 3.8 mol% and PMD of 150% (Table 2, 3).

GRV 020025 is similar with GRV 020017, contains small chondrules in phyllosilicate-bearing matrix. The sizes of chondrules (most 100—300 m) and modal abundance ratio of matrix/chondrule (2.8) are typical of CM2 chondrites. The common occurrence of phyllosilicates in matrix and CAIs further confirms that GRV 020025 is a CM2 chondrite, too.

3.3 GRV 021579

This chondrite contains much more abundant chondrules and less matrix than GRV

020017 and 020025 (Fig. 1c) with a modal abundance ratio of 1.2. Size distribution of chondrules appears bimodal with a peak at 350—600 m and another peak at 30-100 m. Common textural types of the chondrules are BO, PO, POP, and GOP. Metallic Fe-Ni and sulfides are rare (0.4 vol%). Thirteen CAIs were found in the section[12], including 4 Type A-like, 8 spinel-pyroxene-rich inclusions and 1 spinel spherule, and they have a total surface of 0.50 mm2, indicating a modal abundance of 0.81 vol% (Table 1).

Fa content of olivine in GRV 021579 ranges from 0.6 to 65 mol%, with an average of 20 mol%. PMD of Fa values is 110%. Low-Ca pyroxene shows wider range of Fs content (6.0—34.4 mol%), with an average of 22.3 mol% and PMD of 46% (Table 2, 3).

Chondrules in GRV 021579 show a bimodal pattern of size distribution with a peak at 350-600 m and another one at 30—100 m. The smaller size peak is within the range of CO3 chondrites, and the larger one is distinctly smaller than CV3 chondrules. The modal abundance ratio of matrix/chondrules (1.2) is within the ranges of CO3 and CV3, but much lower than that of CM2. Accordingly, GRV 021579 is classified as a CO3 chondrite, but with abundant large chondrules.

3.4 GRV 022459

Shown in Fig. 1d, chondrules and amoeboid olivine aggregates (AOAs) are much larger in GRV 022459 (0.6—2.0 mm) than in GRV 020017, 020025 and 021579. Common textural types of the chondrules are BO, PO and GOP. Abundance ratio of matrix/chondrules+AOAs is 1.0. Modal abundance of metallic Fe-Ni and sulfides is 6.0 vol%. Three CAIs, with a total surface of 0.053 mm2, were found in the section, suggesting a modal abundance of 0.18 vol% (Table 1). All of the three CAIs are Type A-like[12]. Another remarkable feature is the presence of abundant AOAs. A part of AOAs have refractory cores consisting of anorthite and/or Ca-pyroxene and/or spinel, referred to as refractory AOAs.

Fa content of olivine in GRV 022459 ranges from 2.2 to 22 mol%, with an average of 8.7 mol%. PMD of Fa values is 59%. Low-Ca pyroxene shows wider range of Fs content (0.8—5.0 mol%), with an average of 2.5 mol% and PMD of 59.5% (Table 2, 3). GRV 022459 and 021579 have the less PMD than GRV 020017 and 020025, indicate that they have the more homogeneous compositions of olivine and Low-Ca pyroxene than GRV 020017 and 020025.

GRV 022459 appears as a typical CV3 chondrite. It has the largest chondrules of the four meteorites, and the sizes of chondrules (0.6—2.0 mm) are within the range of CV3 (~1 mm). The observed abundance ratio of matrix/chondrules+AOAs (1.0) is consistent with the classification of CV3. In addition, the intense alteration of CAIs and the FeO-enrichment of spinel in GRV 022459[12] are similar to CAIs in oxidized CV3[13], but distinct from those in other reduced subtype. This is supported by the rareness of metallic Fe-Ni in the meteorite. We classify GRV 022459 as an oxidized CV3 chondrite.

4 Conclusions

The highly heterogeneous mineral chemistry and very shape-outlined chondrules confirms that all four chondrites are typical unequilibrated chondrite. However, GRV 021579 and 022459 have the more homogeneous compositions of olivine and Low-Ca pyroxene than GRV 020017 and 020025.

According to the petrography and mineral chemistry of the four cabonaceous chondrites, chemical-petrographic types were assigned. GRV 020017 and 020025 are CM 2, GRV 021579 is CO 3, GRV 022459 is CV 3.

Acknowledgements The samples were supplied by the China Polar Research Center. This work was supported by the Doctor's Foundation of Hunan University of Science and Technology (Grant No. E50806).

References

[1] Yoshia M, Ando H, Omato K *et al* (1971): Discovery of meteorites near Yamato Mountains, East Antarctica. Antarctica Record, 39: 62–65.

[2] Yanai K (1993): Proceedings of the 17th NIPR Symposium on Antarctic Meteorites. Antarctic Meteorite Research, 6.

[3] Lin YT, Ouyang ZY, Wang DD *et al.* (2002): Grove Mountains (GRV) 99027: A new martian lherzolite. MAPS, 37(7): A87.

[4] Miao BK, Ouyang ZY, Wang DD *et al* (2004): A new Martian meteorite from Antarctica: Grove Mountains (GRV) 020090. Acta Geologica Sinica, 78(5): 1034–1041.

[5] Lin YT, Wang DD, Wang G (2004): A tiny piece of basalt probably from Asteroid 4 Vesta. Acta Geologica Sinica, 78(5): 1025–1033.

[6] Liu X, Zhao Y, Liu X, Yu L (2002): Geological characteristics of Grove Mountains, East Antarctica: new proof of final suture of Gondwana. Chinese Science(D), 32(6): 457–468.

[7] Chen J, Liu X, Ju Y *et al.* (2001): Classification of four meteorites from Grove Mountains, Antarctica. Acta Petrologica Sinica, 17: 314–320.

[8] Ju Y, Liu X (2000): Meteorite collection in the Grove Mountains. Chinese Journal of Polar Research (in Chinese), 12: 137–142.

[9] Wang DD, Lin YT (2003): Overview of meteorite collections from Grove Mountains, Antarctica. Chinese Journal of Polar Research (in Chinese), 15(3): 161–170.

[10] Greenwood RC, Lee MR, Hutchison R, Barber DJ (1994): Formation and alteration of CAIs in Cold Bokkeveld (CM2). Geochimica et Cosmochimica Acta, 58: 1913.

[11] Lee MR, Greenwood RC (1994): Alteration of calcium-and aluminium-rich inclusions in the Murray (CM2) carbonaceous chondrite. Meteoritics, 29: 780–790.

[12] Dai DQ, Lin YT, Miao BK, Shen W, Wang DD (2004): Ca-, Al-rich inclusions in three new carbonaceous chondrites from the Grove Mountains, Antarctica: New evidence for a similar origin of the objects in various groups of chondrites. Acta Geologica Sinica, 78(5): 1042–1051.

[13] MacPherson GJ, Grossman L (1984): "Fluffy" Type A Ca-, Al-rich inclusions in the Allende meteorite. Geochimica et Cosmochimica Acta, 48: 29–46.