Grove Mountains CM-Type Chondrites

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CM chondrite is the most important carbonaceous chondrite containing abundant Ca, Al-rich inclusions (CAIs) and other interesting objects, which probably experienced early condensation processes in the Solar Nebula environment and later alteration in parent body surroundings. Thus, it is a vital raw material to explore in the formation and evolution of the early Solar System. Grove Mountains (GRV) CM chondrites have been collected from Antarctica by Chinese Antarctic Research Expedition (CARE) for nearly 20 years.

CM chondrite | Grove Mountains | CAIs | GRV 020025

1. Introduction

Carbonaceous chondrites (CCs) are fragments of hydrated asteroids and among the oldest and most primitive objects that provide insights into the early protoplanetary disk, the formation of the planets and the origin of water and life [1][2][3]. The major chemical groups of CCs include the Ivuna-type (CI), Mighei-type (CM), Ornans-type (CO), Vigarano-type (CV), Karoonda-type (CK), Renazzo-type (CR), Bencubbin-type (CB), ALH 85085-type (CH) and Loongana-type (CL) [4][5]. The CM chondrites are of particular interest, as they are the most abundance group of CCs and are the material most frequently found as clasts within other types of meteorites [6][7]. This suggests that the CM parent asteroids are (or were) widespread in the asteroid belt, including the regions providing samples to Earth [8]. Up to date (1 February 2022), there are 715 pieces of CM chondrites according to Meteoritical Bulletin Database [9], accounting for about 25% of the total CCs and approximately 0.9% of all the officially named meteorites.

Antarctica is a cold and dry continent covered with ice and snow. Thus, it is a wonderful place to preserve and collect meteorites. Now, there are 1339 pieces of CCs found by Antarctic scientific expedition teams sent by various countries that occupied 47% of the total CCs. The proportion of CM chondrites is the highest, which is much higher than other types of CCs, reaching about 42% (564 pieces) out of the total Antarctic CCs. Thus, Antarctica is the most important enrichment site of CM-type meteorites.

In the last years, Grove Mountains was selected as an area of high meteorite concentration in Antarctica. Since the first expedition in 1998, 12,665 pieces of meteorites have been collected by CARE in this region and China has been one of the biggest owners of Antarctic meteorites [10].

2. Sample Description

The CM chondrite samples include GRV 020005, GRV 020017, GRV 020025, GRV 021536, GRV 021580, GRV 050179, GRV 050384 and GRV 13051 collected from Grove Mountains, Antarctica. Among these samples, GRV 020025 is the most intensively studied by several researchers (**Table 1**). All these samples are relatively small in weight with mass ranging from 0.4 to 5 g. The samples are black irregular fragments. They are relatively fresh. Some of them are almost completely covered by black fusion crust (**Figure 1**C,D) and others are only partially covered (**Figure 1**A,B).

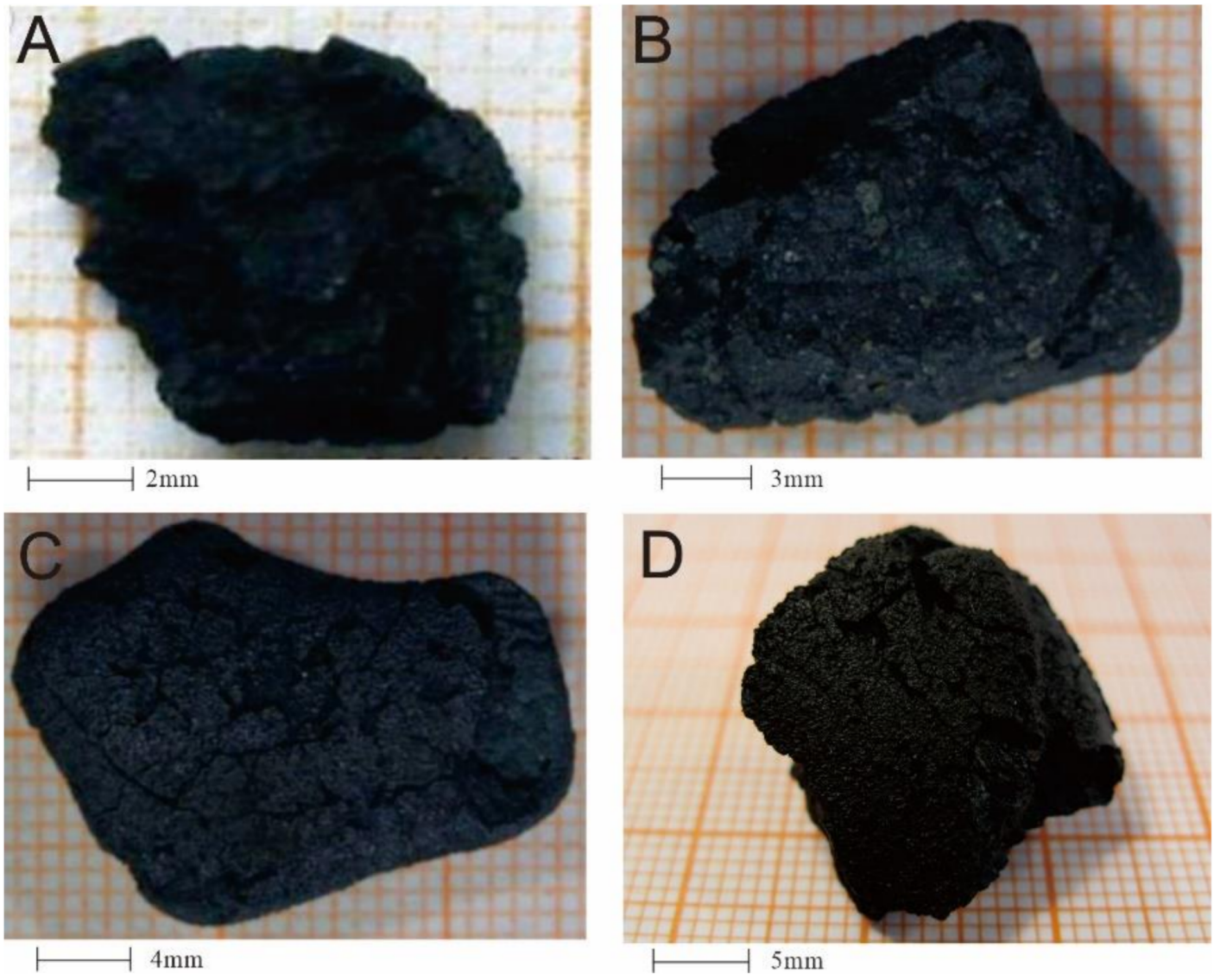

Figure 1. Typical specimens of CM chondrites in Grove Mountains, Antarctica: (**A**) GRV 020005; (**B**) GRV 020017; (**C**) GRV 020025; (**D**) GRV 050179.

Table 1. General information of CM chondrites found in Grove Mountains, Antarctica.

Number	Name	Status	Fall	Year	Type	Mass (g)	MetBul	Works
1	GRV 020005	Official	N	2002	CM2	0.4	89	[11]

Number	Name	Status	Fall	Year	Type	Mass (g)	MetBul	Works
2	GRV 020017	Official	N	2002	CM2	2.2	89	[11][12][13]
3	GRV 020025	Official	N	2002	CM2	3.55	89	[11][12][13][14][15][16]
4	GRV 021536	Official	N	2003	CM2	1.45	93	[17]
5	GRV 021580	Official	N	2003	CM2	0.48	96	
6	GRV 050179	Official	N	2006	CM2	5.03	93	[18]
7	GRV 050384	Official	N	2006	CM2	0.76	95	
8	GRV 13051	Official	N	2014	CM2	3.47	103	

3. Petrology and Mineralogy

3.1. General Description

In these GRV CM chondrites, four samples (GRV 020005, GRV 020017, GRV 020025 and GRV 050179) were studied in relative detail (**Table 1** and **Table 2**). Dai [14] first investigated the thin sections of GRV 020017 and GRV 020025. Several years later, Wang [15] observed new slices of these samples. In general, the GRV CM chondrites show similar petrographic properties of average CM chondrites [19] in chondrule/matrix abundance and size distribution (**Table 2**). The relative low CAI and AOA and high sulfide abundance probably resulted from the heterogeneous sampling on parent body and (or) selective alteration. Statistical error may sometimes be a possible factor leading to different results, especially in measuring the low content indicators (such as sulfide, metal and CAIs, **Table 2**). According to the published data by Shen et al. [20], GRV 020025 has a CAI content of up to 1.0%, which is much close to the average value of the CM chondrites (1.2%). The sample of GRV 020005 is quite different from other samples in chondrule size and content (low) and matrix content (high) which just shows the CM1 petrologic type [15].

Table 2. Summary of average petrographic properties of the GRV CM chondrites.

Name	Type	Chd	Chd Dia	CAIs	Matrix	Sulfide/Metal	Matrix/Chd
GRV 020005	CM1	14 *	0.2 (0.1–0.6) *	-	83 *, 86 **	~3.0/0 *	6.0 *
GRV 020017	CM2	30–40 $, 20 *, 25 &	0.05–0.3 $, 0.3 (0.1–1.3) *	0.1 $	60–70 $, 80 *, 81 **, 70 &	1.8 $, 5.0/0.1 *, 1 &	2.0 $, 4.0 *, 2.8 &
GRV 020025	CM2	26 $, 20 *, 25 &	0.1–0.3 $, 0.3 (0.1–1.0) *	0.29 $, 1.0 #	72 $, 79 *, 80 **, 70 &	1.4 $, 1.0/0.1 *, 0.1 &	2.8 $, 4.0 *, 2.8 &
GRV 050179 $$	CM2	25	most <0.5	0.29	74	1.5/0.4	3.0
GRV 021579	CO3/CM2?	45 $, 22 *	(0.35–0.6; 0.03–0.1) $; 0.2 (0.1–0.8) *	0.81 $	54 $, 76 *, 78 **	0.4 $, 2 *, 2 &	1.2
Average CM ##	-	20	0.3	1.2	70	0.1	3.5

*: data from [11]; **: data acquired by backscatter image from [11]; $: data from [12]; #: data from [20]; $$: data from [18]; ##: data from [19]; &: data from [13]. Chd: chondrule; Chd Dia: chondrule diameter; CAIs: calcium, aluminum-rich inclusions.

The petrological and mineralogical characteristics of GRV 020017and GRV 020025 are similar, mainly composed of opaque matrix and a small amount of high-temperature components (including chondrule, CAIs and crystal clast) with fine-grained rims. Electron microprobe analysis on olivine and pyroxene in the chondrule and matrix of GRV 020017 and GRV 020025 shows that they have similar mineral composition patterns. The values of olivine Fa, low-Ca pyroxene Fs, En and Wo are summed up in **Table 3**. The chemical composition of olivine and pyroxene is very heterogeneous as indicated by the high PMD value (>>5, **Table 3**) [11][12][13][16]. It is noteworthy that the chemical composition of olivine in the chondrules of GRV 020025 is relatively uniform (Fa: 0.8–1.1 with one exception of 4.7) [12] while it varies largely in the olivine clasts (Fa: 0.6–48.3) [13].

Table 3. Mineral composition of olivine and pyroxene in GRV 020017 and GRV 020025.

Samples	GRV 020017			GRV 020025		
Reference	[11] *	[12]	[13]	[11] *	[12]	[13]
Fa	27 (1.0–44.3)	12 (0.2–94)	0.24–34.4	28 (1.2–68.6)	9 (0.7–48.3)	0.57–48.3
PMD	58	163	145	87	158	173
Fs	3.6 (1.6–4.6)	2.8 (0.4–14)	0.57–13.6	11 (4.3–14.5)	3.8 (0.6–16.4)	0.68–4.76
PMD	32	128	169	53	150	63
En	91.4–95.6		60–98.6	76.2–94.6		93.8–97.7
Wo	0.6–4.6		0.73–4.19	1.2–9.3		0.45–4.67

*: data of matrix olivine and pyroxene. Fa: fayalite. PMD: percent mean deviations. Fs: ferrosilite. En: enstatite. Wo: wollastonite.

3.2. Matrix

Matrix material is best defined as the optically opaque mixture of mineral grains 10 nm to 5 mm in size distinguishing from fragments of chondrules, CAIs and other components by their distinctive sizes, shapes and textures [19]. So far, Professor Miao Bingkui's team [11][13] has carefully studied the matrix of three GRV CM chondrites (GRV 02005, GRV 020017 and GRV 020025). The matrix is mainly divided into three types of interstitial matrix, fine-grained rim (FGR) and dark inclusions (DIs).

3.3. CAIs

CAIs were found in almost all GRV CM chondrites when they were reported to the International Society for Meteoritics and Planetary Science [9]. However, in-depth researches on CAIs (petrology and mineral chemistry) were only carried out in the samples of GRV 020025 and GRV 050179 [12][14][15][16][18][20].

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