Chinese Journal of Polar Science, Vol. 20, No. 2, 215 - 224, December 2009

Weathering, shock metamorphism and type distribution patterns of 98 ordinary chondrites from the Grove Mountains, Antarctica

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Received August 24, 2009

Abstract Petrography and mineral chemistry of ninety-eight ordinary chondrites from Grove Mountains (GRV), Antarctica, were presented and their Weathering effect, shock metamorphism and type distribution patterns were discussed in this study. Among them, six are unequilibrated ordinary chondrites, including 3 H3 and 3 L3; and 92 meteorites are equilibrated ordinary chondrites, including 24 H-group (13 H4, 10 H5, 1 H6), 64 L-group (2 L4, 44 L5, 18 L6) and 4 LL-group (3 LL4, 1 LL5). Most GRV chondrites (> 90%) displayed minor weathering effect (W1 and W2). About half of the meteorites experienced severe shock metamorphism. They commonly contain shock-induced melt veins and pockets. These heavily shocked meteorites provide us with natural samples for study of high-pressure polymorphs of minerals. In addition, the Grove Mountains collection seems to have more abundant unequilibrated and L group ordinary chondrites compared to the US Antarctic meteorite collection which were mainly found along the Transantarctic Mountains.

Key words ordinary chondrites, weathering, shock metamorphism, type distribution patterns, Antarctica

1 Introduction

Since the first discovery of 9 meteorites on blue ice in Antarctica by the Japanese Antarctic Research Expedition in 1969[1], Antarctica has become the most important meteorite-searching region in the world. Many new or rare types of meteorites have been found in Antarctica, including lunar meteorite, martian meteorite[2-3], stone-iron meteorite, HED meteorite[4] and carbonaceous chondrites *et al.*[5].

Grove Mountains consist of 64 nunataks, and locate at the eastern Antarctica[6]. During 1998-1999 season, the 15th Chinese Antarctic Research Expedition (CHINARE) collected 4 meteorites on blue ice in this area[7-8]. This is the first discovery of meteorites in Grove Mountains. Subsequently, another 28 meteorites were collected in the same site, suggestive of a new potential meteorite-rich region[8-10]. Another 4448 meteorites were collected from the same region by the 19th Chinese Antarctic Research Expedition (CHIN-

ARE)[11]. In this paper, we report petrography and mineral chemistry of 98 ordinary chondrites from these meteorites, and their chemical-petrographic types are assigned. Furthermore, we discuss weathering, shock metamorphism of them. In addition, our results are compared with other Antarctic meteorites, in order to characterize GRV meteorites and to have hints for meteorites concentrating processes and conditions in Grove Mountains region.

2 Samples and experiments

One polished thin section was prepared for each of the 98 ordinary chondrites. 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 K_α lines by K_β 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. Except for 6 unequilibrated ordinary chondrites, the numbers of analyzed grains of olivine and pyroxene are 20—30 random grains. Other 92 meteorites are equilibrated, so ~ 8 random grains of each olivine and low-Ca pyroxene in the individual meteorites were analyzed. Modal abundances of metal Fe-Ni, chondrule and matrix were calculated from surface areas of the phase in BSE images of the sections. Classification of chemical-petrographic types is mainly based on refs [12-14], degree of shock metamorphism on ref [15], and degree of weathering on ref [16].

3 Petrography and mineral chemistry

Mineral chemical compositions, petrographic features, shock metamorphism and degree of weathering of all 98 ordinary chondrites from the Grove Mountains are summarized in Table 1. 6 of these meteorites are unequilibrated ordinary chondrites, and the others are equilibrated chondrites, including 24 H-group, 64 L-group and 4 LL-group.

3.1 Unequilibrated ordinary chondrite

GRV 020016, 020162, 020166, 020106, 020164 and 020165 are unequilibrated ordinary chondrite, including 3 H3 (GRV 020016, 020162 and 020166) and 3 L3 (GRV 020106, 020164 and 020165). In all 6 unequilibrated chondrite, chondrules show very shape outlined and clear texture. Primary glass in chondrules is light brown in color and devitrified. Matrix of the chondrite is opaque in transmitted light, indicating little recrystallized. Fe-Ni metal and troilite occur as opaque mineral assemblages. Metallic Fe-Ni and troilite have three occurrences: (1) as rounded nodules, (2) small grains around chondrules, and (3) large individual grains or fragments. All of these features are typical of type 3 chondrites. It is noticed that small grains opaque minerals are predominant in H-group, however, nodules or large individual grains are predominant in L-group.

These 6 meteorites show highly heterogeneous mineral chemistry, such as compositional zoning of olivine and pyroxene and wide compositional ranges of minerals in the same meteorites. Table 1 shows the summary of EPMA data. The average of fayalite (Fa) content of olivine varies from 15.6 to 24.3 mol%, with a large percent of mean standard deviation (PMD) of 21.4%—58%; that of ferrosilite (Fs) cotent of low-Ca pyroxene falls in a range of 13.1—20.1 mol%, with an even larger PMD up to 80.6%. PMD of low-Ca pyroxene in GRV 020165 is 2.4, fall in the range of equilibrated ordinary chondrite, because of these grains are so samll that reflect the analyzed data.

The average Fa content of olivine of GRV 020016, 020162 and 020166 (15.6—18.9 mol%) are within the range of H-group. In GRV 020106, 020164 and 020165, Fa of olivine varies from 22.3 to 24.3 mol%, fall in the range of L-group. Base on mineral chemical compositions and petrographic features, GRV 020016, 020162 and 020166 are classified as H3, and GRV 020106, 020164 and 020165 are classified as L3 (Fig. 1).

GRV 020106 and 020165 are rather fresh, with only few grains of metallic Fe-Ni and troilite slightly weathered. Their weathering degrees are classified as W1. GRV 020016, 020162, 020166 and 020164 are more significantly weathered, with metallic Fe-Ni and troilite close to the fusion crust and cracks nartially turned into oxides. Some silicates show stains in light brown. The amount of the weathered products is 20—40% of opaque phases, hence their weathering degrees are W2. In the 6 meteorites, only GRV 020016 show significant features of shock metamorphism (S2), such as intense fracturing and undulose extinction. Shock metamorphism of the other 5 meteorites is weak and referred to as S1 stage, based on the absence of undulose extinctim and less fracturing (Table 1).

Table 1. Chemical-petrographic types and major features of 98 GRV ordinary chondrites

Meteorite	Type	Fe-Ni (Vol%)	Troilite (Vol%)	Olivine		Low-Ca pyroxene		Chondrule Outline	Weathering phase	Shock degree
				Mean Fa (mol%)	PMD /%	Mean Fs (mol%)	PMD /%			
GRV 020016	H3	1	3.1	18.5	21.9	14.7	31.7	very clear	S2	W2
GRV 020162	H3	0.6	1.3	18.9	44.3	15	45		S1	W2
GRV 020166	H3	0.2	1	15.6	58	17.7	38.5		S1	W2
GRV 020106	L3	0.1	1.3	23.6	23.3	15.7	80.6		S1	W1
GRV 020164	L3	0.5	1.9	24.3	21.4	13.1	42		S1	W2
GRV 020165	L3	0.3	1.7	22.3	25.4	20.1	2.4		S1	W1
GRV 020007	H4	4.5	3.9	17	3.8	15.8	3.7	clear	S2	W2
GRV 020008	H4	2.8	1.7	18	1.1	16.1	1.6		S2	W1
GRV 020042	H4	1.6	2.6	18.2	1.6	16.2	2.6		S1	W2
GRV 020066	H4	0.7	2.6	17.4	4.1	16.5	4.7		S1	W3
GRV 020070	H4	2	4	18.4	0.8	16.4	1.6		S3	W0
GRV 020088	H4	2.1	3	18.6	1.7	17	1.3		S2	W1
GRV 020091	H4	300	3.1	18.2	1	16.4	0.6		S2	W2
GRV 020108	H4	1.3	0.1	18.5	1	16.5	1.6		S1	W2
GRV 020109	H4	2.3	3.1	18.6	0.6	16.5	1.6		S2	W2
GRV 020110	H4	2.6	4.7	18.7	1.5	16.6	1.1		S2	W2
GRV 020130	H4	1.8	1.5	18.6	0.8	16.6	1.7		S1	W2
GRV 021492	H4	3.6	6.4	18.1	1.3	16	0.7		S2	W1
GRV 021576	H4	1.5	1.9	18.7	1.1	16.9	0.9		S1	W0
GRV 020071	H5	0.8	1.9	18.2	1.7	16.6	0.8	easily-	S2	W3
GRV 020087	H5	1.2	1.2	18.4	1.8	16.6	1.4	distinguishable	S2	W2
GRV 020089	H5	3.5	5	18.7	1.3	16.9	1.1		S2	W3

GRV 020092	H5	2.6	2.4	18.4	2.3	16.65	0.6		S4	W1
GRV 020123	H5	2.9	3.3	19.2	1.2	17.2	1.3		S1	W2
GRV 021517	H5	1.6	2.4	18.9	1.3	17	2		S2	W3
GRV 021518	H5	1.8	3.6	18.9	0.8	16.5	2.2		S2	W2
GRV 021611	H5	1.4	1.9	18	1.1	16	0.5		S2	W2
GRV 021715	H5	0.2	1	17.4	3.9	15.4	1.9		S4	W2
GRV 021795	H5	2.9	0.6	18.5	0.7	16.6	0.9		S2	W2
GRV 021522	H6	2.6	4.4	17.3	1.7	15.6	2.5	hard-distinguishable	S4	W1
GRV 020038	L4	1.6	1.5	25.7	0.8	22	0.8	clear	S2	W1
GRV 021643	L4	2	2.7	24	1.3	20.4	1.3		S2	W2
GRV 020040	L5	2.4	3.8	24.4	1.4	21	1.9	easily-	S2	W2
GRV 020068	L5	1.3	2.2	24.6	0.6	21.2	1.2	distinguishable	S4	W2
GRV 020069	L5	1.1	4	24.4	1.5	20.8	0.7		S2	W1
GRV 020107	L5	0.2	1.6	24.2	0.9	20.7	0.8		S4	W2
GRV 020125	L5	1.5	2.4	24.9	0.6	21.4	1.1		S4	W2
GRV 020127	L5	0.4	1.2	24.7	1.9	18.7	1.3		S1	W1
GRV 020163	L6	1.7	3.7	24.7	0.8	21	0.8		S4	W2
GRV 021495	L5	1.8	2.1	24.2	1.1	20.8	1.1		S4	W2
GRV 021499	L5	1.7	2.2	23.1	0.7	19.7	0.7		S2	W1
GRV 021500	L5	1.3	2.6	23.7	1.1	20.8	3		S4	W2
GRV 021501	L5	1.1	1.4	24	1.5	20.7	0.8		S3	W1
GRV 021548	L5	1.2	1.2	24.1	0.7	20.9	1.3		S2	W2
GRV 021582	L5	2.1	3.2	24.2	2.1	20.5	1.3		S4	W2
GRV 021586	L5	1.8	1.6	24.4	1.5	21	1.1		S2	W2
GRV 021587	L5	1.9	1.8	24.2	2.7	20.5	1		S2	W2
GRV 021614	L5	1.3	1.8	23.4	1.1	20.2	1		S4	W2
GRV 021724	L5	1.4	1.9	23.4	1.4	20.2	0.9		S4	W2
GRV 021794	L5	0.1	0.1	24.2	1.9	20.9	0.5		S3	W2
GRV 022024	L5	0.7	1.1	23.4	2.1	20.1	0.8		S2	W1
GRV 022026	L5	1.5	1.8	23.5	1.4	20.2	2		S2	W2
GRV 022027	L5	1.3	2	23.4	1.2	20.1	1.1		S4	W2
GRV 022028	L5	0.9	1.2	23.9	1.6	20.4	1.7		S2	W2
GRV 022126	L5	1.3	1.8	23.5	1	20.5	2.6		S2	W2
GRV 022127	L5	0.9	1.5	23.9	1.3	20.7	2.6		S4	W2
GRV 022128	L5	0.9	1.9	23.6	1.8	20.4	0.9		S4	W2
GRV 022141	L5	0.8	1.5	23.6	2.4	20.5	2.1		S4	W1
GRV 022142	L5	1.6	3.3	24	3.5	20.8	2.6		S4	W2
GRV 022143	L5	1.2	2.2	23.4	1.6	20.1	0.7		S4	W2
GRV 022146	L5	1	1.6	23.7	2.8	20.4	1		S4	W2
GRV 022159	L5	0.1	0.1	23.4	2.7	20	0.8		S4	W2
GRV 022160	L5	1.6	1.6	23.7	1.8	20.4	4.6		S4	W2
GRV 022161	L5	3.3	2.5	24	1.8	20.6	1		S4	W2
GRV 022177	L5	1.4	1.7	23.6	1.5	20.2	1.1		S4	W2
GRV 022185	L5	1.6	2.1	23.8	1.6	20.5	1.2		S2	W2
GRV 022186	L5	2.4	2.5	23.5	1.1	20.4	0.8		S2	W2
GRV 022190	L5	2.9	3.1	23.6	0.8	20.2	1.3		S2	W2
GRV 022206	L5	2.7	2	23.7	1.6	20.8	0.8		S2	W2
GRV 022207	L5	2.1	2.6	23.4	0.8	20	1.5		S4	W2
GRV 022210	L5	0.7	1.3	23.3	1	20.4	1.1		S4	W1

GRV 022211	L5	1.7	2	23.5	1	20.2	1.2		S2	W2
GRV 022212	L5	0.8	1.4	23.9	3.5	20.4	2.7		S2	W1
GRV 022284	L5	1.5	1.7	24	1.2	20.7	1.3		S2	W2
GRV 022285	L5	1.8	2.3	23.8	0.8	20.4	0.9		S2	W2
GRV 022287	L5	1.2	1.9	23.4	2.9	20.2	1.1		S4	W2
GRV 021578	L6	2	2	24.3	0.8	21	1	hard-distinguishable	S2	W1
GRV 021649	L6	1.1	1.4	23	2.8	20.1	1.4		S4	W2
GRV 021714	L6	1.2	1.7	23.4	1.8	20.2	1.6		S4	W2
GRV 021722	L6	1.3	1.8	23.7	1.4	20.4	1		S4	W2
GRV 021723	L6	1	1.4	23.3	1.6	20.1	1.8		S4	W2
GRV 021796	L6	0.5	0.5	23.7	1.6	20.4	1.7		S4	W2
GRV 021797	L6	1.6	1.7	23.5	1.1	20.2	1.1		S3	W1
GRV 021799	L6	0.6	0.9	23.2	1.3	20.1	1.7		S4	W2
GRV 022025	L6	0.4	0.9	23.5	2.8	20.2	1.5		S2	W2
GRV 022114	L6	0.9	1	23.1	1.6	19.9	1.4		S4	W2
GRV 022129	L6	0.8	1	23.6	0.9	20.4	0.7		S4	W2
GRV 022145	L6	1.2	2.1	23.5	1	19.9	0.9		S2	W1
GRV 022158	L6	0.9	0.6	23.6	2	20.6	4.4		S4	W2
GRV 022162	L6	0.9	0.9	24.1	1.7	20.7	1		S3	W2
GRV 022178	L6	1.3	2.2	23.7	1.4	20.3	1		S4	W2
GRV 022237	L6	0.6	1.4	24.5	0.4	20.7	0.8		S4	W3
GRV 022282	L6	1.4	1.9	24.1	1.3	20.6	1.5		S2	W2
GRV 020021	LL4	0.5	1.7	27.5	3.4	23.7	4.2	clear	S1	W2
GRV 020037	LL4	0.8	2	28.4	1.2	23.8	4.6		S1	W0
GRV 020041	LL4	1.2	2.9	28.1	0.9	23.7	4		S1	W2
GRV 020019	LL5	0.1	0.5	31.6	2.3	27.2	3.6	easily-distinguishable	S2	W2

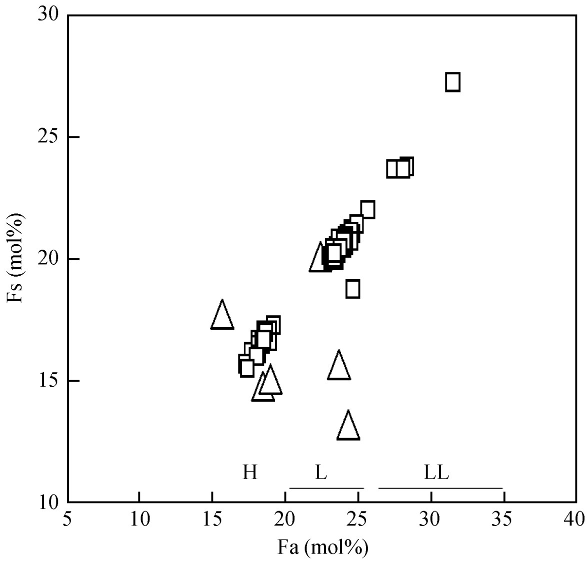

Fig 1 The correction of Fa of olivine and Fs of low-Ca pyroxene with chemical groups. Note: △- unequilibrated ordinary chondrite; □- equilibrated ordinary chondrite.

3.2 Equilibrated ordinary chondrites

The other 92 ordinary chondrites experienced significant thermal metamorphism in their parent bodies, which homogenized mineral chemistry, made matrix recrystallized and blurred outlines of chondrules. Both PMD of Fa content of olivine and PMD of Fs content of low-Ca pyroxene in these meteorites are < 5% (Table 1). Compositions of olivine and pyroxene of these equilibrated ordinary chondrites are plotted in Fig. 1, with 24 meteorites in H, 64 in L and 4 in LL ranges.

Group H: There are 24 meteorites of this group. Mean Fa values of olivine in these meteorites range 17.2—19.2 mol%, and mean Fs values of low-Ca pyroxene range 15.4—17.2 mol%. Both Fa and Fs values are within the ranges of group H. These 24 meteorites experienced significantly thermal metamorphism. Outlines of chondrules in both meteorites are clear, and the fine-grained matrix is only partly recrystallized, which appears locally transparent. Brown-colored glass has been found in a few chondrules. Low-Ca pyroxene is mainly monoclinic. Accordingly, 13 meteorites (GRV 020007 *et al.*) are classified as H4. Chondrules in 10 meteorites (GRV 020071 *et al.*) are ready to recognize, but the matrix is well recrystallized. Majority of low-Ca pyroxene is orthorhombic. These 10 meteorites are assigned as H5. GRV 021522 is highly metamorphosed. Only a few chondrules are remained with very blurred outlines. Their matrix is well recrystallized, and pyroxene is orthorhombic. GRV 021522 classified as H6.

Group L: There are 64 meteorites of L-group, and all of them are equilibrated. The mean Fa values of olivine range 23—25.7 mol%, and mean Fs values of low-Ca pyroxene range 18.7—22 mol%. Both Fa and Fs tally with the ranges of L-group. Of these L chondrites, GRV 020038 and 021643 experienced the lowest degree of thermal metamorphism, as indicated by the presence of well-outlined chondrules, the occurrence of primary glass in a few chondrules. GRV 020038 and 021643 are classified as L4. 40 meteorites are more strongly thermal metamorphosed, and all of them belong to L5. Most of their chondrules remain as fragments, but ready to recognize. Matrix is highly recrystallized, majority of low-Ca pyroxene are orthorhombic. In the other 18 meteorites, there are only a few chondrules and/or chondrule relics with highly blurred outlines. Low-Ca pyroxene is orthorhombic. The matrix is highly recrystallized. These 18 meteorites are classified as L6.

Group LL: Only 4 chondrites belong to this group, i.e. GRV 020019, 020021, 020037 and 020041. Compositions of olivine (mean Fa 27.5—31.6 mol%) and low-Ca pyroxene (mean Fs 23.7—27.2 mol%) indicate a LL-group of these meteorites. GRV 020019 experienced much stronger thermal metamorphism than the other 3 meteorites. In GRV 020019, there are only a few chondrule are ready to recognize. In contrast, in GRV 020021, 020037 and 020041, chondrules are clearly outlined, the matrix is only partly recrystallized. We classify GRV 020021, 020037 and 020041 as LL4, and GRV 020019 as LL5.

21 GRV meteorites are rather fresh, with only a few grains of metallic Fe-Ni and troilite slightly weathered. Their weathering degrees are classified as W1. GRV 020070, 021576 and 020037 are the most fresh, and their weathering degrees are classified as W0. 69 meteorites are more significantly weathered than above. The amount of the weath-

ered products is 20—40% of opaque phases, hence their weathering degrees are W2. In GRV 020066, 020071, 020089, 021517, and 022237, a mass of weathering veins scatter in all whole section, and most of metallic Fe-Ni and troilite are replaced by the weathered products. They is strongly weathered, and the weathering grade is W3.

15 meteorites have little impact effects, e. g. less common fracturing of silicates, and lack or rareness of undulose extinction of pyroxene and olivine. Their shock metamorphism degrees are classified as S1. 38 meteorites show significant features of shock metamorphism, such as intense fracturing and undulose extinction of silicates, suggesting shock metamorphism degrees of S2. 8 meteorites are more intensely shocked, classified as S3. In these meteorites, besides obvious undulose extinction and high degree of fracturing of silicates, thin shock-induced veins (< 30 μm) are observed. Another 37 meteorites are the most heavily shocked. They have shock-induced melt pockets and veins, and shock blacking is common especially along these pockets and veins. Degrees of shock metamorphism of these 4 meteorites are S4 (Table 1).

4 Discussion

4.1 Weathering and shock metamorphism

Weathering degrees of 98 GRV 02 ordinary chondrites are W0 (3 meteorites), W1 (21 meteorites), W2 (69 meteorites) and W3 (5 meteorites), respectively. All ordinary chondrites, consisting of predominant weathering degrees of W1 and W2 (> 90%), suggest a less weathered among GRV meteorites than its collected from desert. In comparison with GRV 98 and 99 meteorite collections, there are a higher proportion of significantly weathered samples in GRV 02 meteorites. Sixty-nine of 69 meteorites studied in this work have a weathering degree of W2, and 5 meteorites is more heavily weathered (W3). In contrast, all 27 ordinary chondrites of GRV 98 and 99 collections are little weathered, classified as W1[9, 17] except for one meteorite with a weathering grade of W3[9]. The significantly different weathering features of GRV 02 collection than GRV 98 and 99 meteorites could be due to their different meteorite-collecting sites. All GRV 98 and 99 meteorites were collected on blue ice, whereas more meteorites of GRV 02 collection were found in moraine than those on blue ice[18].

Shock metamorphism degrees 98 GRV 02 chondrites are S1 (15 meteorites), S2 (38 meteorites), S3 (8 meteorites) and S4 (37 meteorites), respectively. We found S2 is predominant in H-group chondrites, and S4 is predominant in L-group chondrites, however, S1 is predominant in LL-group chondrites. It meybe partly reflects parent bodies of various chemical groups have various shock metamorphism characrters. About half of the chondrites (45/98) experienced severe shock metamorphism, and degree of the shock metamorphism ranges from S3 to S4. In contrast, no GRV 98 or 99 meteorites have a shock metamorphism grade higher than S2[9, 19]. The heavily shocked meteorites provide us with natural samples to study high-pressure polymorphs of minerals and to clarify shock metamorphism on asteroidal bodies.

4.2 Type distribution patterns of GRV meteorites

Figure 2 shows distribution pattern of chemical-petrographic types of these 98 ordinary chondrites, compared with that from Transcontinental regions, Antarctica. The relative abundance of unequilibrated ordinary chondrites (i.e. type 3) from Grove Mountains is usually high (6.1%), whereas it accounts for only 3.3% of more than 8200 ordinary chondrites collected from Transcontinental regions by American teams. Abundance ratio between H: L: LL is 27.6: 68.4: 4 for Grove Mountains, different from that of Transcontinental regions (42: 48: 10). It is obvious that the GRV meteorites have more L-group and less H-group and LL-group in comparison with Transcontinental regions meteorites.

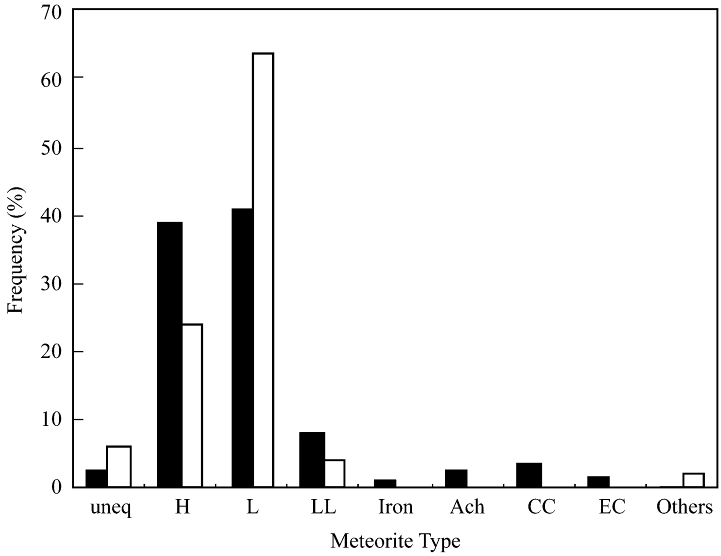

Fig. 2 Distribution patterns of meteorite groups from Grove Mountains and Transcontinental regions. Note: ■ - Grove Mountains meteorites; □ - Transcontinental regions meteorites. Abbreviation: uneq-unequilibrated, Ach-achondrites, CC-carbonaceous chondrites, EC-enstatite chondrites. Data from Antarctic Meteorite Newsletters, Vol. 19-25.

We compared type distribution pattern of these GRV 02 chondrites with previous results based on the GRV 98 and 99 collections[19], too. The relative abundance of unequilibrated ordinary chondrites is much lower in GRV 02 collection (6.1%) than in GRV 98 and 99 collections (21.7%), suggesting that the unusually high abundance of unequilibrated ordinary chondrites in GRV 98 and 99 collections is mainly a result of statistics because of a small number of samples. However, statistics error can't be excluded because of the large deviation between GRV 02 collection and GRV 98 and 99 meteorites.

5 Conclusions

Petrography and mineral chemistry of 98 ordinary chondrites selected from Grove Mountains were studied, and their chemical-petrographic types were assigned. They are H-chondrites (3 H3, 13 H4, 10 H5 and 1 H6), 67 L-chondrites (3L3, 2L4, 44 L5 and 18

L6) and 4 LL-chondrites (3 LL4 and 1 LL5).

All ordinary chondrites, consisting of predominant weathering degrees of W1 and W2 (> 90%), suggest a little weathered among GRV meteorites. The proportion of weathering grade of W2 is higher in these meteorites than that of GRV 98 and 99 collections. This is probably due to a very high proportion of GRV 02 meteorites found in moraines. In contrast, all GRV 98 and 99 meteorites were collected on blue ice.

Shock metamorphism degrees are various in various chemical groups in these meteorites. It meybe partly reflects parent bodies of various chemical groups have various shock metamorphism characrters. About half of the chondrites (45/98) experienced severe shock metamorphism (S3—S4).

The GRV meteorites have more unequilibrated ordinary chondrites, L-group and less H-group, LL-group in comparison with Transcontinental regions meteorites.

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

[3] 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.

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

[5] Dai DQ, Lin YT, Miao BK *et al* (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.

[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] Lin YT, Wang DD, Kimura K (2002): Thermal metamorphism of GRV 98002 (L5) and GRV 98004 (H5) ordinary chondrites. Chinese Journal of Polar Research (in Chinese), 14(4): 266-275.

[10] Wang DD, Lin YT (2002): Overview of classification of Antarctic meteorites, collected by 15th and 16th Chinese Antarctic Research Expedition in Grove Mountains. Chinese Journal of Polar Research (in Chinese), 14(4): 252-265.

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

[12] Van Schmus WR, Wood JA (1967): A chemical-petrologic classification for the chondritic meteorites. Geochim. Cosmochim. Acta, 31: 747-765.

[13] Ouyang ZY (1988): Cosmochemistry (in Chinese). Beijing: Science Press, 1-386.

[14] Wang DD, Liu J, Li Z *et al* (1993): Huang W. and Dai C. Introduction of Chinese Meteorites (in Chinese). Beijing: Science Press, 1-505.

[15] Stöffler D, Keil K, Scott ERD (1991): Shock metamorphism of ordinary chondrites. Geochim. Cosmochim. Acta, 55: 3845−3867.
[16] Wlotzka FA (1993): Weathering Scale for the Ordinary Chondrites. Meteoritics, 28: 460.
[17] Miao BK, Lin YT, Ouyang ZY, Zhou X (2002): Petrology of Grove Mountains meteorites-II: equilibrated ordinary condrites. Chinese Journal of Polar Research (in Chinese), 14(4): 288−299.
[18] Ju Y, Liu X (2000): Meteorite collection in the Grove Mountains. Chinese Journal of Polar Research (in Chinese), 12: 137−142.
[19] Miao BK, Lin YT, Zhou X (2003): Type distribution pattern and pairing of ordinary chondrites from Grove Mountains, Antarctica. Chinese Science Bulletin, 48(9): 908−913.