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Type distribution pattern and pairing of ordinary chondrites from Grove Mountains, Antarctica

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Abstract **Twenty-eight meteorites were collected on blue ice in the Grove Mountains region, Antarctica, by the 16th Chinese Antarctic Research Expedition (CHINARE). 26 out of the stones are ordinary chondrites, and their chemical-petrographic types are assigned based on electron probe microanalyses, petrography and mineralogy. 6 of them are unequilibrated L-chondrites, and the other 20 chondrites are equilibrated, including 6 H-group (3 H4, 1 H5 and 2 H6), 9 L-group (3 L4, 1 L5 and 5 L6) and 5 LL-group (2 LL4 and 3 LL5). Detailed comparative study suggests that 10 of them (including other 2 chondrites collected by the 15th CHINARE) could be paired, and represent 5 individual fall events. Hence, all 32 meteorites collected from the Grove Mountains probably belong to 27 fall events, suggestive of meteorite transferring and concentrating processes. The Grove Mountains are likely a new meteorite-enriched region. Distribution patterns of chemical-petrographic type and mass of the Grove Mountains meteorites are significantly distinct from those found in other regions, indicative of their unique sources and/or concentration mechanism. However, more studies are required in order to clarify these differences.**

Keywords: meteorites, Antarctica, Grove Mountains, paired meteorites, classification.

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Since the discovery of 9 meteorites on blue ice in Antarctica by the Japanese Antarctic Research Expedition in 1969, the amount of Antarctic meteorites has much exceeded the total number of meteorites from other regions. Besides the large number, many unique types have been found from Antarctic meteorites, e.g. Lunar meteorites, Martian meteorites, and some rare types of iron meteorites and achondrites. Antarctica is the most meteorites-enriched region. The Grove Mountains consist of nunataks, and are located at the eastern Antarctica. This region was first explored by the Chinese team. After the discovery of 4 meteorites in the Grove Mountains icefield by the 15th CHINARE, other 28 pieces of meteorites were collected by the 16th team in the same region during 1999/2000 summer season [1, 2]. Except for a martian meteorite (GRV 99027) and a HED achondrite (GRV 99018)[3], other 26 are ordinary chondrites[4]. This discovery suggests that the Grove Mountains is a new meteorite-rich region, and it has a significant contribution to our meteorite collection, especially some rare types, such as martian meteorites, eucrites and primitive L-chondrites. In this report we analyze petrography and mineral chemistry of the 26 ordinary chondrites, clarify their type distribution patterns, possible pairing and enrichment of meteorite in the Grove Mountains region.

1 Samples and experiments

Samples of the meteorites were embedded in epoxy, and then cut into ~1-mm-thin chips. Polished thin sections were prepared from these chips without water. Features of chondrules, recrystallization degree of matrix, occurrences of major silicates and opaque minerals, size of plagioclase, shock metamorphism, and degree of weathering were observed under a microscope. Quantitative analyses of minerals were conducted using an electron probe micro-analyzer (EPMA) JEOL JXA-8800R in the Laboratory of Electron Microscopes, Zhongshan University. The operating conditions were 15 kV and 20 nA, and the standards were silicates and oxides. X-ray overlapping of K_α lines by K_β lines of some successive elements, such as V by Ti, and Mn by Cr, were corrected. Analyses data were treated using the Bence-Albee method. Modal contents of metallic Fe-Ni were calculated from areas of the phase in back-scattered electron (BSE) images of the sections. Classification of chemical-petrographic types is mainly based on refs. [5—8], degree of shock metamorphism on ref. [9], and degree of weathering on ref. [10].

2 Chemical-petrographic types

Mineral chemical compositions, petrographic features, shock metamorphism and degree of weathering of all 26 ordinary chondrites from the Grove Mountains are summarized in Table 1. Six of these meteorites are unequilibrated L-group, and the others are equilibrated chondrites, including 6 H-group, 9 L-group and 5 LL-group.

(ⅰ) Unequilibrated ordinary chondrites. In all 6 unequilibrated chondrites, chondrules show very sharp outlines and clear textures. Textural types of chondrules in GRV 99001, GRV 99019, GRV 99020 and GRV 99026 are cryptocrystalline, radial pyroxene, porphyritic olivine, porphyritic pyroxene, and barred olivine. In contrast, less textural types were observed in GRV 99021 and GRV 99022, and they are porphyritic olivine, porphyritic pyroxene and radial pyroxene. Glass is light brown in color and partially devitrified. It is commonly found in the barred olivine and porphyritic olivine chondrules. Except for GRV 99022, the other 5 meteorites contain dark inclusions that consist of a core of a porphyritic olivine chondrule and a fine-grained mantle of metallic Fe-Ni, troilite and silicates. Most of matrix of these meteorites are opaque, except for minor microcrystalline (1—5 μm).

Table 1 Chemical-petrographic types and major features of 26 ordinary chondrites from Grove Mountains

Meteorite	Type	Pairing	Found location	Outline of chondrules	Matrix	Fe-Ni (vol.%)	Troilite (vol.%)	Olivine mean Fa (mol%)	Olivine PMD (%)[b]	Low-Ca pyroxene mean Fs (mol%)	Low-Ca pyroxene PMD (%)	Shock[c]	Weathering[d]
GRV 99021	L3.5		S73°05′37.2″ E75°12′39.6″			6.5	2.8	27.3(44)[a]	40	12.9(21)[a]	59	S1	W1
GRV 99019	L3.6		S73°05′37.5″ E75°12′35.1″			4.5	1.9	26.3(30)	35	8.7(28)	60	S1	W1
GRV 99001	L3.4		S73°05′57.9″ E75°12′22.1″	very sharp	opaque	4.9	7.3	24.9(43)	50	11.1(13)	68	S1	W1
GRV 99026	L3.5	99026	S73°06′07.9″ E75°13′49.7″			5.7	7.0	23.8(26)	44	11.4(15)	81	S1	W1
GRV 99020	L3.5	99026	S73°05′38.4″ E75°12′33.0″			5.7	1.4	22.3(32)	45	9.8(17)	71	S1	W1
GRV 99022	L3.0-3.4		S73°05′36.4″ E75°12′38.3″			6.2	6.2	21.9(37)	54	7.6(27)	89	S1	W1
GRV 99006	H4	99006	S73°05′36.4″ E75°12′04.7″			8.7	1.0	17.3(10)	5	15.3(10)	4	S1	W1
GRV 99011	H4	99006	S73°06′05.4″ E75°11′23.7″	well defined	micro-crystalline	10.5	1.2	17.0(10)	1	15.0(10)	5	S1	W1
GRV 99028	H4		S73°06′02.3″ E75°14′13.1″			12.8	5.5	17.9(23)	2	15.6(24)	5	S1	W1
GRV 99025	H5		S73°06′04.3″ E75°12′19.6″	readily delineated		12.9	3.2	15.6(9)	1	13.9(10)	2	S1	W1
GRV 99009	H6	99009	S73°04′34.2″ E75°12′11.7″	poorly defined	recrystallized	10.4	1.1	18.0(9)	2	16.0(10)	1	S1	W1
GRV 99010	H6	99009	S73°05′18.6″ E75°12′21.5″			10.4	2.6	18.4(10)	1	16.0(10)	2	S1	W1
GRV 99003	L4		S73°05′12.6″ E75°12′43.3″			5.3	5.3	25.5(27)	2	19.7(21)	15	S1	W1
GRV 99008	L4		S73°05′10.3″ E75°13′01.4″	well defined	micro-crystalline	3.6	2.4	21.5(10)	2	18.1(10)	5	S1	W1
GRV 99012	L4		S73°05′59.0″ E75°11′44.2″			4.5	4.4	25.2(10)	2	17.7(11)	22	S1	W1
GRV 99024	L5		S73°06′03.8″ E75°11′26.9″	readily delineated		5.6	1.9	25.9(11)	2	19.5(8)	20	S2	W1
GRV 99016	L6		S73°05′49.5″ E75°12′33.1″			4.6	4.6	22.7(10)	2	19.0(8)	1	S1	W1
GRV 99007	L6	99007	S73°05′30.6″ E75°11′54.9″		recrystallized	5.6	5.7	22.6(11)	2	19.2(8)	1	S1	W1
GRV 99023	L6	99007	S73°06′02.0″ E75°11′45.7″	poorly defined		5.9	5.9	22.6(11)	3	19.1(8)	1	S1	W1
GRV 99014	L6	99014	S73°05′22.8″ E75°12′18.7″			5.9	1.9	23.5(9)	1	20.2(10)	2	S1	W1
GRV 99017	L6	99014	S73°05′47.3″ E75°12′32.5″			3.6	3.8	23.4(9)	1	19.7(8)	1	S1	W1
GRV 99015	LL4		S73°05′20.0″ E75°12′14.3″	well defined	micro-crystalline	2.4	3.5	28.4(30)	1	21.8(20)	17	S1	W1
GRV 99002	LL4-6		S73°05′57.8″ E75°11′21.3″			1.4-5.7	1.5-5.7	28.9(24)	2	23.7(16)	11	S1	W1
GRV 99004	LL5		S73°05′48.5″ E75°12′32.7″			3.6	5.7	26.5(9)	3	21.6(9)	4	S1	W1
GRV 99005	LL5		S73°05′23.9″ E75°12′24.8″	readily delineated	recrystallized	2.4	3.8	27.0(10)	1	21.9(9)	4	S2	W1
GRV 99013	LL5		S73°05′47.1″ E75°11′37.8″			3.6	5.6	26.5(10)	3	21.1(9)	14	S2	W1

a) Analysis points; b) PMD: mean percent of standard deviation of Fa and Fs; c) shock phase[9]; d) degree of weathering[10].

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.

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 Fa content of olivine varies from 21.9 to 27.3 mol%, with a large percent of mean standard deviation (PMD) of 35%—54%; that of Fs content of low-Ca pyroxene falls in a range of 7.6—12.9 mol%, with an even larger PMD up to 59%—89%. The high heterogeneity of olivine and pyroxene indicates that these meteorites are unequilibrated, typical of type 3 ordinary chondrites. Based on the correlation between the PMD of Fa content of olivine and thermal luminescence (TL)[11,12], these meteorites can be further classified into subtypes below: 3.6 (GRV 99019), 3.5 (GRV 99020, 99021, 99026), 3.4 (GRV 99001) and 3.0—3.4 (GRV 99022)[13].

The content of metallic Fe-Ni of the unequilibrated chondrites is in a range of 4.5—6.5 vol%, similar to that of L-group. The average Fa contents of olivine of GRV 99001, 99020, 99022, and 99026 (21.9—24.9 mol%) are within the range of L-group too. GRV 99019 and 99021 show higher average Fa contents of olivine (26.3, 27.3 mol%, respectively), and fall in the range of LL-group (Fig. 1). However, the average Fa content can be used only for reference since mineral chemistry of unequilibrated chondrites is typical of highly heterogeneous. On the other hand, the content of metallic Fe-Ni can be referred to as a criterion of classification for unequilibrated ordinary chondrites. Although GRV 99019 and 99021 show higher average Fa contents, their metallic Fe-Ni contents are within the range of L-group. Accordingly, both meteorites are classified as L-group too. The average Fs contents of low-Ca pyroxene of all 6 unequilibrated meteorites vary between 7.6 and 12.9 mol%, significantly lower than that of equilibrated L-chondrites (Fig. 1). The low Fs contents are probably due to the absence of equilibrium between small FeO-rich silicates and coarse FeO-poor grains[14].

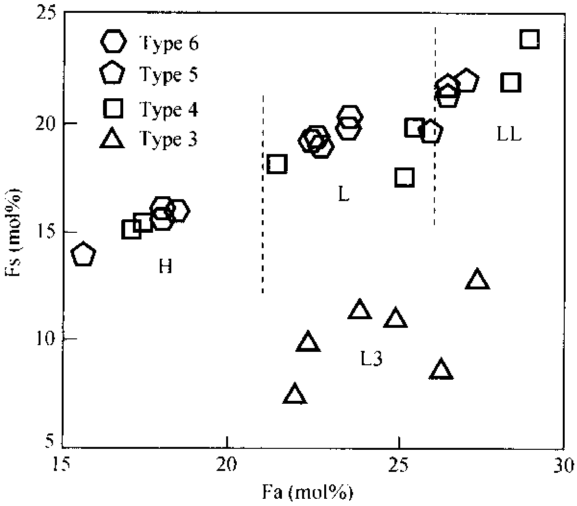

Fig. 1. Fa versus Fs of ordinary chondrites from Grove Mountains.

GRV 99019, 99020 and 99026 are rather fresh, with only few grains of metallic Fe-Ni and troilite slightly weathered. Their weathering degrees are classified as W1. GRV 99001, 99021 and 99022 are more significantly weathered, with metallic Fe-Ni and troilite close to the fusion crust and cracks partially turned into oxides. Some silicates show stains in light brown. However, the amount of the weathered products is less than 20% of opaque phases, hence their weathering degrees are also W1. All L3 chondrites contain complete chondrules, and fracture of silicates is less common. The degree of shock metamorphism is referred to as S1.

(ii) Equilibrated ordinary chondrites. Except for the above 6 L3 chondrites, other 20 ordinary chondrites contain homogeneous olivine. PMD of the Fa content is ≤5%. Most low-Ca pyroxenes are homogeneous too, with PMD of the Fs content ≤5%. However, 6 meteorites (GRV 99002, 99003, 99012, 99013, 99015 and 99024) show larger PMD of the Fs content (11%—22%), significantly higher than that of the Fa content of olivine in the same meteorites. This may be due to a fact that low-Ca pyroxene is more difficult to be homogenized than olivine during thermal metamorphism in their parent bodies[15]. Fig. 1 shows a positive and linear correlation between average contents of Fa and Fs for the 20 equilibrated chondrites, 6 in H-group, 9 in L-group and 5 in LL-group ranges, respectively. In addition, types of these equilibrated chondrites are assigned based on their petrographic features[16].

H-group: This group has 6 meteorites, i.e. GRV 99006, 99009, 99010, 99011, 99025 and 99028. The average Fa contents of olivine are 15.6—18.4 mol%, and the average Fs contents of low-Ca pyroxene are 13.9—16.0 mol%, both within the ranges of H-group. Contents of metallic Fe-Ni are 9.7—13.0 vol%, consistent with H-group too. Modal compositions of the 6 H-chondrites are nearly similar, mainly consisting of olivine, low-Ca pyroxene, metallic Fe-Ni and troilite. Variation in petrographic features among these chondrites suggests different types. In GRV 99006, 99011 and 99028, outlines of chondrules are well defined. Matrix is only partially recrystallized, fine-grained (5—10 μm), and semi-transparent. In addition, brown glass is observed in some chondrules from GRV 99011 and 99028. These three meteorites are classified as type 4. Although many chondrules in GRV 99025 are fractured due to impact, their outlines are readily delineated. Most of matrix is recrystallized, with grain size of 10—40 μm. GRV 99025 is classified as type 5. Petrographic features of GRV 9909 and 99010 are similar to each other, both are intensely recrystallized. Grain size of matrix is ~150 μm. Chondrules are poorly defined, with only some fragments remaining. The major minerals are olivine, low-Ca pyroxene, plagioclase, metallic Fe-Ni and troilite. Both chondrites are type 6.

L-group: There are 9 meteorites of L-group. The average Fa contents are 21.5—25.9 mol%, and the average Fs contents are 17.7—20.2 mol%, consistent with L-group. Except for GRV 99017, other 8 meteorites contain metallic Fe-Ni within the range of L-group. Low content of metallic Fe-Ni in GRV 99017 is probably related to heterogeneous distribution of metal in this meteorite. In GRV 99003, 99008 and 99012, chondrules are well defined, and matrix is only partially recrystallized and shows semi-transparent. GRV 99003 and 99012 may be more intensely metamorphosed than GRV 99008, because matrix of the formers are coarser (10—20 μm, locally up to 40 μm) than the latter (5—10 μm). However, all three meteorites can be classified as type 4. In GRV 99024, most chondrules are fractured and occur as fragments, but they are readily recognized. Matrix is well recrystallized (20—40 μm), plagioclase is common. It is a type 5 chondrite. GRV 99007, 99014, 99016, 99017 and 99023 are classified as type 6. All of them are intensely recrystallized, with coarse-grained matrix (50—200 μm). Only a few chondrules and fragments can be recognized. The major minerals are olivine, low-Ca pyroxene, plagioclase, metallic Fe-Ni and troilite, with minor chromite and whitlockite.

LL-group: GRV 99002, 99004, 99005, 99013 and 99015 belong to this group, based on their metal contents (1.4—3.6 vol%) and composition of olivine ($Fa_{26.5-28.9}$). In GRV 99015, chondrules are well defined; matrix is partially recrystallized and semi-transparent; size of the matrix is 30—50 μm; plagioclase is common, with grain size of 30—50 μm. All of these features indicate a classification of type 4. GRV 99002 is a breccia, with three lithic clasts (4 mm × 8 mm, 2 mm × 4 mm, 2 mm × 2 mm). Total area of the clasts is about 1/4 of the section. Metal content of the host meteorite is 1.4 vol%, consistent with typical LL-chondrites; but the clasts are significantly rich in metal (5.7 vol%). Chemical compositions of major phases are nearly identical between the host and clasts, and PMD of Fa content of olivine of the whole meteorite is only 2%. Hence, these clasts are referred to as LL-group materials. On the other hand, textures of the host and clasts are distinguishable. In the host, chondrules are well defined, and matrix is almost opaque. Whereas, the clasts are characterized by intense recrystallization, poorly defined chondrules, and occurrence of coarse- grained plagioclase (60—100 μm). The host is classified as type 4, and the clasts as type 6. Accordingly, GRV 99002 is referred to as LL4-6. GRV 99004, 99005 and 99013 are highly fractured, with most silicates as fine-grained fragments. Chondrules are still readily recognized. Most of matrix is recrystallized, with size of 10—20 μm. Secondary plagioclase is 30 μm in size. Although low-Ca pyroxene in GRV 99013 shows a wide range of composition (PMD of Fs: 14), composition of olivine and the above textural features are consistent with type 5. We classified these three meteorites as LL5.

GRV 99009 and 99010 are significantly weathered, and some silicates are colored in brown by the weathered products. However, degree of weathering of both meteorites is referred to as W1, because the products are less than 20% of total of metal and sulfide. The other equilibrated ordinary chondrites are more fresh than the above two. Only few grains of metal and sulfide have thin rims of oxides, and some silicates are colored in brown. All of these chondrites are referred to as W1 degree of weathering. In this study, only GRV 99005, 99013 and 99024 show significant features of shock metamorphism (S2), such as intense fracturing and undulose extinction. Shock metamorphism of the others is weak and referred to as S1 stage, based on the absence of undulose extinction and less common fracturing.

3 Discussion

(i) Paired meteorites. Because of transfer and concentration of meteorites by glacier and wind, meteorites collected from the same region in Antarctica have two possibilities: (1) each pieces belong to individual fall events, or (2) some of them may be pieces of the same meteorite fall (meteorite show, or paired meteorites). All 32 meteorites collected by the 15th and 16th CHINARE were located within two narrow and long regions at the southern segment and middle-northern one of Gale Escarpment, respectively[1,17]. Some of the ordinary chondrites share many petrographic and mineralogical features. It is necessary to determine if they are paired. Except for one iron, 2 achondrites and 1 unclassified stony meteorite, a comparative study is conducted on the other 28 ordinary chondrites. 7 sets of the chondrites could be paired, i.e. GRV 99003-GRV 99012 (L4), GRV 99004-GRV 99005 (LL5), GRV 99006-GRV 99011 (H4), GRV 99009-GRV 99010 (H6), GRV 99014-GRV 99017 (L6), GRV 99007-GRV 99023 (L6) and GRV 99020-GRV 99026 (L3.5). Petrographic types and average contents of Fa and Fs are almost identical to each other for the paired meteorites. Furthermore, 4 sets of the equilibrated chondrites show very similar concentrations of MnO in both olivine and low-Ca pyroxene (Figs. 2 and 3). They are GRV 99006-GRV 99011, GRV 99007-GRV 99023, GRV 99009-GRV 99010, and GRV 99014-GRV 99017. Other minor components (e.g. TiO_2, Al_2O_3, Cr_2O_3 and CaO) are very low (close to the detection limits), and their variations are consistent with the pairing. In addition, pairing of the four sets of meteorites is also confirmed by their identical petrographic textures, types of chondrules, occurrences of major phases, and shocked features. Hence, GRV 99006-GRV 99011, GRV 99007-GRV 99023, GRV 99009-GRV 99010 and GRV 99014-GRV 99017 are referred to as paired meteorites. Unequilibrated GRV 99020 and 99026 could be paired too, according to their similar petrographic subtype (3.5), type distribution pattern of chondrules, degree of recrystallization of matrix, compositional ranges and averages of Fa and Fs contents, and PMD data. However, further studies such as terrestrial ages and thermal luminescence are required in order to confirm the pairing, because of heterogeneity of unequilibrated chondrites.

Summarily, the five sets of GRV chondrites could be paired, and all 32 meteorites probably represent 27 fall events.

(ii) Type and Mass distribution patterns of GRV meteorites. Fig. 4 shows type distribution patterns of-

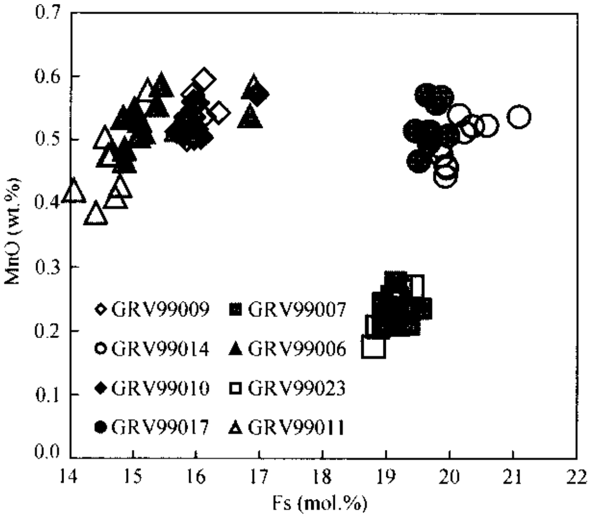

Fig. 2. Comparison of MnO concentration of low-Ca pyroxene between possible paired meteorites.

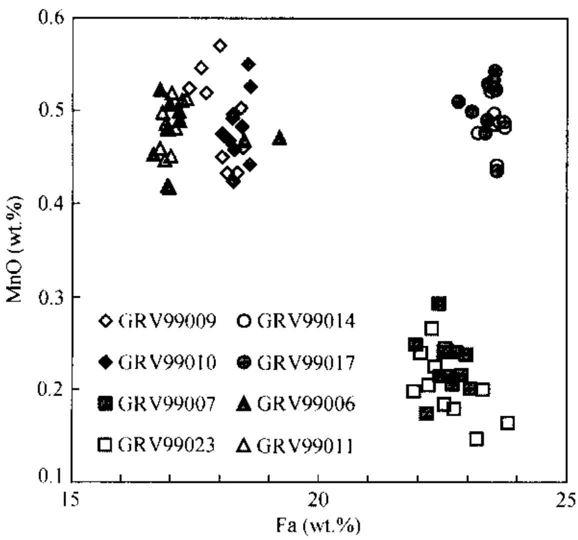

Fig. 3. Comparison of MnO concentration of olivine between possible paired meteorites.

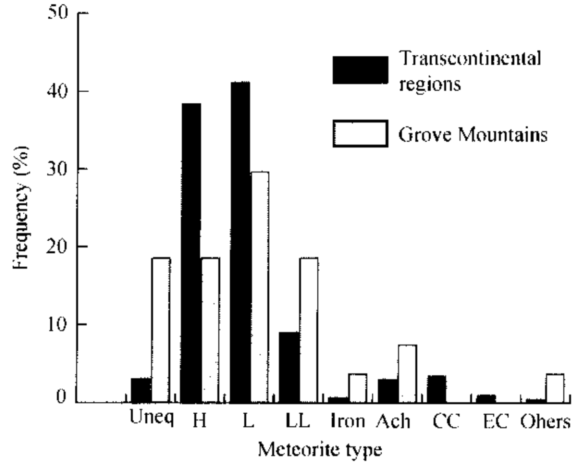

Fig. 4. Distribution patterns of meteorite groups from Grove Mountains and Transcontinental regions. Abbreviation: Uneq, Unequilibrated; EC, enstatite chondrites; Ach, achondrites; CC, carbonaceous chondrites. Data from Antarctic Meteorite Newsletters, Vol.19—25.

meteorites collected from Grove Mountains, compared with that from Transcontinental Ridges, Antarctica. Proportion of unequilibrated ordinary chondrites (i.e. type 3) from Grove Mountains is unusually high (21.7%, corrected for pairing of meteorites), whereas it accounts for only 3.3% of more than 8200 ordinary chondrites collected from Transcontinental Ridges by American teams. Abundance ratio between H∶L∶LL is 21.7∶56.5∶21.7 for Grove Mountains, different from that of Transcontinental Ridges (42∶48∶10). It is obvious that the Grove Mountains have more LL-chondrites and less H-chondrites in comparison with Transcontinental Ridges. The unique type distribution pattern of meteorites from the Grove Mountains is confirmed by discovery of a martian meteorite (abundance ratio of 1/32). For comparison, only 8 martian meteorites were reported from a total of more than 28000 Antarctic meteorites. On the other hand, the mass distribution pattern of meteorites from Grove Mountains is nearly the same of meteorites from Transcontinental Ridges (Fig. 5). Abundance of meteorites decreases exponentially with the increase of the mass. However, tiny meteorites with mass less than 5 g are much more abundant in Grove Mountains (53%) than in Transcontinental Ridges (21%). In addition, average mass of GRV meteorites is 34.8 g, much less than that of Transcontinental Ridges (261.3 g) too. Hence, GRV meteorites are typical of small ones.

(iii) Collection of meteorites from Grove Mountains. Thirty-two GRV meteorites were mainly collected from 2 regions: the northern of Gale Escarpment (3) and the southern (28)[1,17]. Mass and type distributions of meteorites from these two regions are significantly different. Meteorites in the northern region are larger (av. 171 g) than those in the southern (av. 21 g). In addition, the iron meteorite is found in the northern region. In comparison

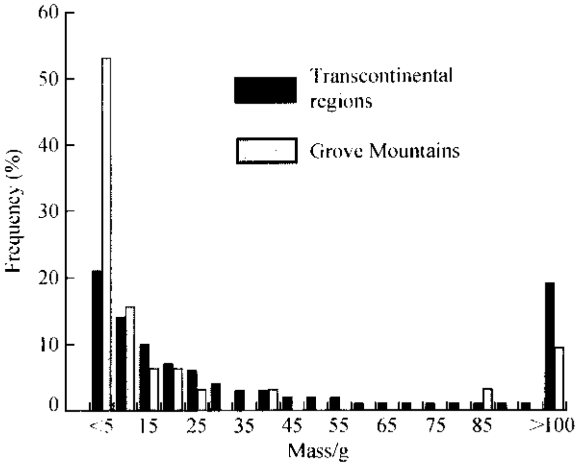

Fig. 5. Mass distribution patterns of meteorites from Grove Mountains and Transcontinental regions. Data from Antarctic Meteorite Newsletters, Vol.19—25.

with Transcontinental Ridges, the type and mass distribution patterns of meteorites from the Grove Mountains probably suggest incomplete collection of meteorites during the explorations. The collected meteorites could be only a very small part of GRV meteorites. Two possibilities may explain the small size and abundant fragments of these meteorites: (1) the summer season of 1999/2000 is colder than normal and there were lots of snow on the icefields, this made meteorites found difficult; and (2) lack of experience of searching for meteorites in Antarctica. However, another reasonable scenario is that these meteorites were transferred and concentrated below the escarpments by wind[1,17]. Most of the meteorites are smaller than 20 g, within power of wind to move stones (<100 g). In this case, these two regions below the escarpments may not be the primary meteorite-enriched areas. In addition, as discussed above, all 32 GRV meteorites probably represent 27 fall events, suggestive of effective processes of concentrating meteorites in the Grove Mountains.

Summarily, a larger meteorite collection is expected in Grove Mountains. In order to clarify the processes of concentrating meteorites in this region, more studies such as climate (especially direction of wind), relief, movement and evaporation of glacier are required. The primary meteorite-enriched areas will be determined based on these detailed researches and previous work by J. Sun et al. In order to find and collect more meteorites, we propose to send another meteorite-hunting team to Grove Mountains as soon as possible.

4 Conclusions

Based on EPMA data and petrography, chemical group-petrographic type of 26 ordinary meteorites were assigned, including 6 unequilibrated L-chondrites (L3) and 20 equilibrated chondrites. The equilibrated chondrite are 6 H-chondrites (3 H4, 1 H5, and 2 H6), 9 L-chondrites (3 L4, 1 L5, and 5 L6), and 5 LL-chondrites (2 LL4 and 3 LL5).

Based on petrography and mineral chemistry, five sets of meteorites could be paired, such as GRV 99006-GRV 99011, GRV 99009-GRV 99010, GRV 99007-GRV 99023, GRV 99014-GRV 99017 and GRV 99020-GRV 99026.

The Grove Mountains are likely a new meteorite-enriched region, based on determination of 27 fall events, type and mass distribution patterns of GRV meteorites.

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