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Meteorites from Grove Mountains, Antarctica: An overview

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Abstract Thirty-two meteorites were collected in Grove Mountains area, Antarctica, by the 15th and 16th Chinese Antarctic Research Expeditions (CHINARE). Petrography and mineral chemistry of these meteorites are reviewed, among which there are one Martian lherzolite, one eucrite, one ungrouped iron meteorite, and six unequilibrated and twenty-three equilibrated ordinary chondrites. An equilibrated ordinary chondrite GRV 98004 (H5) has an unusually low cosmic-ray exposure age. Meteorite concentrating processes in Grove Mountains area are discussed. In addition, future studies on Grove Mountains (GRV) meteorites are proposed.
Key words Antarctica, meteorite, Martian meteorite, basalt, cosmic ray exposure age.

1 Introduction

The 15th team of Chinese Antarctic Research Expedition collected first 4 meteorites on blue ice in Grove Moutains area, Antarctica. They are 3 ordinary chondrites and 1 iron meteorite, with a total weight of 526.9 g. Another 28 meteorites, including 2 achondrites and 26 chondrites with a total weight of 580.26 g (Ju and Liu 2000), were found by the 16th team in the same area. Searching for meteorites by the 19th team in the summer season of 2002/2003 turned out a big discovery of 4448 meteorites. This updates a total number of Grove Mountains (GRV) meteorites to 4480, and brings the Antarctic meteorite collection of China to be the third by number in the world (after Japan and USA). Furthermore, this discovery indicates that Grove Mountains region is one of the most meteorite-rich in Antarctica. Classification of the first 32 meteorites turned out 1 Martian meteorite (Lin *et al.* 2003; Liu *et al.* 2002; Wang *et al.* 2002), 1 eucrite (probably from 4-asteroid, Vesta), and 6 unequilibrated ordinary chondrites (L3.0-L3.6) (Miao *et al.* 2002a). In comparison, only 8 Martian meteorites (including the GRV one) were reported from 26000 Antarctic meteorites.

The 28 meteorites collected by the 16th team were classified by 4 working groups from Guangzhou Institute of Geochemistry, Institute of Geology and Geophysics, and National Astronomic Observatory, Chinese Academy of Sciences, and Department of Earth Sciences, Nanjing University, respectively. The results were published in journal of Antarctic Research, vol. 14, no. 4, 2002. Classification of the first 4 meteorites collected by the 15th team were reported by Chen *et al.* (2001). In addition, Lin *et al.* (2002) conducted a study on petrography and thermal metamorphism of two of them (GRV 98002 and 98004), and Wang *et al.* (2002) reported their cosmic ray exposure ages and gas retention ages. All available studies of the 32 GRV meteorites are summarized in this paper. Furthermore, possible meteorite concentrating mechanisms in Grove Mountains area, and cosmic ray exposure ages of certain meteorites are discussed. Finally, suggestion for the future studies on GRV meteorites is made.

2 Main results of the studies on GRV meteorites

2.1 *Chemical groups and petrographic types of ordinary chondrites*

Of the 32 GRV meteorites, there are 29 ordinary chondrites. Six of them are unequilibrated and classified as L3. Abundance proportion of the ordinary chondrites from Grove Mountains (90.6%) is similar to that from other areas in Antarctica, e.g. Alan Hills by Japan (94.7% of 3500) and Transantarctic Mountains by US (91.5% of 8941). However, abundance ratio of unequilibrated rocks of the ordinary chondrites seems unusually higher in Grove Mountains area (20.7%) than that in other areas (*e.g.* 3.3% in Transantarctic Mountains region). In China, 48 ordinary chondrites have been collected, but only the Boxian meteorite may be unequilibrated (Li *et al.* 2000). Tables 1 and 2 summarize major mineral chemistry of the 32 GRV meteorites.

Table 1. Chemical groups and petrographic types of 26 ordinary chondrites collected by the 16th team

meteorite	Miao *et al.* (2002)[1]	Tao *et al.* (2002)[2]	Wang *et al.* (2002)[3]	Liu *et al.* (2002)[4]
GRV 99001	L3.4	L3	H3	H3
GRV 99002	LL4-6	LL4-6	LL5	LL6
GRV 99003	L4	L4	L4	L4
GRV 99004	LL5	LL5	L4	LL5
GRV 99005	LL5	LL5-6	L5, LL5 *	LL5
GRV 99006	H4	H4	H4	H6
GRV 99007	L6	L6	L6, LL6 *	L6
GRV 99008	L4	L4-5	L4, LL4 *	L4
GRV 99009	H6	H6	H6	H6
GRV 99010	H6	H/L6-7	H6, L6 *	H6
GRV 99011	H4	H4-5	H4	H4
GRV 99012	L4	L/LL4	L4, LL4 *	L4
GRV 99013	LL5	LL6	L5, LL5 *	LL5
GRV 99014	L6	L/LL6	L6	L6
GRV 99015	LL4	LL4	LL4	LL4
GRV 99016	L6	L6	L6	L6
GRV 99017	L6	L5-6	L6	L6
GRV 99019	L3.6	L3		H3
GRV 99020	L3.5	L3		H3
GRV 99021	L3.5	L3	L3	L3
GRV 99022	L3.0-3.4	L3		H3
GRV 99023	L6	L5	L6	L6
GRV 99024	L5	LL4	L5, LL5 *	L5
GRV 99025	H5	H4-5	H4	H5
GRV 99026	L3.5	L3	L3, H3 *	H3
GRV 99028	H4	H4-5	LL3, H3 *	H4

Note: numbers of analyses of olivine and low-Ca pyroxene: 1) 474 of olivine, 350 of pyroxene; 2) 10-15 analyses for each of olivine and pyroxene; 3) 54 of olivine, 40 of pyroxene; 4) 263 of olivine, 231 of pyroxene.

* : Beside EPMA analyses of olivine and pyroxene, EDS data (81) were also used.

Table 2. Classification parameters for the 32 GRV meteorites

Meteorite	Type	Mean Fa (range) (mol%)	Fa PMD¥ (%)	Mean Fs (range) (mol%)	Fs PMD (%)
GRV 98001 *	Chondrite				
GRV 98002	L6	25.5 ±0.4 (24.3-26.2)	1.5	21.4 ±0.4 (20.6-22.2)	2.2
GRV 98003 §	Iron				
GRV 98004	H5	19.0 ±0.5 (17.9-20.4)	2.6	16.8 ±0.6 (15.6-19.8)	3.8
GRV 99001	L3.4	24.9(43) (2.6-38.8)	50	11.1(13) (2.6-27.5)	68
GRV 99002 $	LL4-6	28.9(24) (28.0-29.9)	2	23.7(16) (18.9-25.9)	11
GRV 99003	L4	25.5(27) (24.7-26.5)	2	19.7(21) (11.1-22.9)	15
GRV 99004	LL5	26.5(9) (26.2-28.5)	3	21.6(9) (20.3-22.9)	4
GRV 99005	LL5	27(10)	1	21.9(9)	4
GRV 99006	H4	17.3(10) (16.6-19.2)	4	15.3(10) (14.8-16.8)	4
GRV 99007	L6	22.6(11)	2	19.2(8)	1
GRV 99008	L4	21.5(10) (20.7-21.8)	2	18.1(10) (15.5-18.8)	5
GRV 99009	H6	18(9)	2	16(10)	1
GRV 99010	H6	18.4(10)	1	16(10)	2
GRV 99011	H4	17(10) (16.8-17.3)	1	15(10) (14.1-16.9)	5
GRV 99012	L4	25.2(10) (24.6-26.0)	2	17.7(11) (7.8-20.5)	22
GRV 99013	LL5	26.5(10)	3	21.1(9)	14
GRV 99014	L6	23.5(9)	1	20.2(10)	2
GRV 99015	LL4	28.4(30) (27.7-29.4)	1	21.8(20) (12.2-25.4)	17
GRV 99016	L6	22.7(10)	2	19(8)	1
GRV 99017	L6	23.4(9)	1	19.7(8)	1
GRV 99018	Eucrite		Detail seen achondrites		
GRV 99019	L3.6	26.3(30) (9.6-39.3)	35	8.7(28) (1.0-20.5)	60
GRV 99020	L3.5	22.3(32) (5.4-39.8)	45	9.8(17) (1.0-20.0)	71
GRV 99021	L3.5	27.2(44) (9.7-46.8)	40	12.9(21) (2.3-26.4)	59
GRV 99022	L3.0-3.4	21.9(37) (2.6-38.5)	54	7.6(27) (1.8-29.8)	89
GRV 99023	L6	22.6(11)	3	19.1(8)	1
GRV 99024	L5	25.9(11)	2	19.5(8)	20
GRV 99025	H5	15.6(9)	1	13.9(10)	2
GRV 99026	L3.5	23.8(26) (0.4-39.9)	44	11.4(15) (0.9-25.1)	81
GRV 99027	Martian meteorite		Detail seen achondrites		
GRV 99028	H4	17.9(23) (17.3-18.3)	2	15.6(24) (13.0-16.5)	5

Note: According to Lin *et al.* (2002) and Miao *et al.* (2002a,b); Figures in brackets are analyzed grain numbers and ranges of Fa and Fs.

* Not classified; § very fine grained octahedral iron, ungrouped; $ brecciated, the classes are LL6 and host matrix is LL4 (Miao *et al.*, 2002b).

¥ Percent of mean standard deviation, PMD $= \frac{s}{\bar{x}} \times 100\%$, while $s = \sqrt{\frac{\sum(\bar{x}-x)^2}{n}}$; $\bar{x}$, mean value.

Among groups of ordinary chondrites there are significant variations, such as relative abundances of various components, sizes and types of chondrules and Ca-Al-rich inclusions (CAI), bulk chemical compositions, mineral chemistry, oxygen isotopic compositions, and redox state. These differences reflect heterogeneity in the solar nebula. For instance, abundance of chondrules decreases from 80% in ordinary and enstatite chondrites to lower than 1% in CI carbonaceous chondrites; CAIs were mainly reported in carbonaceous chondrites (especially, CM, CV, CO), but rarely found in ordinary (H, L, LL) (Kimura *et al.* 2002) or in enstatite chondrites (EH, EL) (Lin *et al.* 2003a). Abundance of metal increases in order of C, LL, L, H, EL and EH, and FeO contents of silicates are reverse, indicating variation of redox state among their forming locations in the solar nebula (Wang and Lin 1992). Classification of meteorites is a basic work, and it supplies with information about evolution of parent bodies of meteorites and chemical fractionation in the solar nebula. Beside the parameters mentioned above, classification of GRV 98002 and 98004 was also based on Co content of metallic Fe-Ni (Lin and Wang 2002), confirming that the Co content is critical for classification of ordinary chondrites (Rubin 1990).

In Table 1, it is noticed that classification of equilibrated ordinary chondrites (type 4-6) by different working groups is nearly the same. However, there are apparent differences as regarding to the 6 unequilibrated ordinary chondrites. This could be due to their high heterogeneity in mineral chemistry. The differences occur not only among grains but also in individual ones. A limited number of grains and/or different analysis positions (core or rim) may have different results. Hence, abundance of metallic Fe-Ni and sulfides is more critical to determine chemical groups of unequilibrated ordinary chondrites than mineral chemistry. In addition, Miao *et al.* (2002a) tried to determine subtypes of the unequilibrated ordinary chondrites, based on degree of heterogeneity of olivine and pyroxene. However, study of thermoluminescence (TL) is required in order to confirm their results.

Thermal metamorphism is an important event in parent bodies of meteorites, and it supplies with hints for and puts constraints on structural information of the asteroidal bodies. Temperatures of thermal metamorphism of GRV 98002 (L5) and 98004 (H5) were calculated by Lin and Wang (2002), using a two-pyroxene thermometer. The temperature is higher for GRV 98002 (800℃) than for GRV 98004 (700℃), and both are within the range of type 5 of ordinary chondrites (700℃-800℃). In addition, according to relationship between grain size and Ni content of the core of taenite coexisting with kamacite, cooling rates of GRV 98002 and 98004 were estimated to be 1-10℃/Ma and 0.1℃/Ma, respectively.

2.2 *Achondrites*

2.2.1 *Martian lherzolite*

Up to date, 18 shergottites have been reported. They are further classified into basaltic, lherzolitic and olivine-phyric types. Among them, lherzolites are the most rare, and only three have been reported (ALHA77005, Yamato 793605, and LEW 88516). Of the 32 GRV meteorites, GRV 99027 was found to be the fourth lherzolite (Lin *et al.* 2003b; Liu *et al.* 2002; Wang *et al.* 2002). Table 3 shows petrography and mineral chemistry of GRV

99027, in comparison with other Martian lherzolites. GRV 99027 is very similar to the others in texture, modal composition and mineral chemistry. Furthermore, bulk oxygen isotopic composition of GRV 99027 overlaps with that of the other Martian lherzolites, and plots within the Martian meteorite range (above and parallel to the terrestrial mass-dependent fractionation line, slightly poor in ^{16}O) (Lin *et al.* 2003). The oxygen data confirm GRV 99027 of Martian origin.

Except for GRV 99027, the other three lherzolites share many petrographic, mineralogical and geochemical features (Harvey *et al.* 1993; Ikeda 1997; McSween *et al.* 1979; Mikouchi and Miyamoto 1997; Mikouchi and Miyamoto 2000; Treiman *et al.* 1994; Wadhwa *et al.* 1999; Warren and Kallemeyn 1997). Both ALHA77005 and LEW 88516 have identical Rb-Sr and Sm-Nd isochrones (183-185 Ma), initial $^{87}Sr/^{86}Sr$ ratios (0.71026-0.71056), and Nd value (8.2-11.1) within analysis errors (Borg *et al.* 2002). Nyquist *et al.* (2001) reported ejection times of the three meteorites (*i. e.* cosmic ray exposure age plus terrestrial age), and they are 3.06 ± 0.2 Ma (ALH), 4.7 ± 0.5 Ma (Yamato) and 3.94 ± 0.4 Ma (LEW), respectively. Eugster *et al.* (2002) recently re-estimated the ejection ages of ALH and LEW using ^{81}Kr-^{83}Kr method, and suggested the ejection ages of 3.8 ± 0.7 Ma (ALH) and 3.9 ± 0.4Ma (LEW). Hence, it is possible that all three lherzolites were ejected from a same igneous unit by an impact event. If this is true, these three meteorites sample only one site on the Martian surface. If GRV 99027 was ejected by a different impact event, it will sample rock of another area on the Martian surface. A comprehensive study of GRV 99027 is going on, in order to clarify its genetic linkage with the other Martian lherzolites.

Table 3. GRV 99027 in comparison with Martian lherzolites

	Lin *et al.* (2003)	Wang *et al.* (2002)	Tao *et al.* (2002)	Liu *et al.* (2002)	Martian lherzolites[1)]
Texture	Poikilitic and interstitial				Poikilitic and interstitial
Modal composition (vol%)					
Orthopyroxene	55.7	20			10-60
Clinopyroxene	5.1	2			<28
Olivine	32.3	70	35-60		
Plagioclase	5.9	5	5-15		
Chromite	1.1	<2	0.7-2.1		
Fa	26.7 ± 1.4 (poikilitic) 29.7 ± 0.4 (interstitial)	27	27.5	24.8-27.9	bimodal (22-40), higher Fa in interstitial than poikilitic
Orthopyroxene	$En_{61-78}Fs_{20-27}Wo_{2-16}$	$En_{74}Fs_{22}Wo_4$	$En_{76}Fs_{20.85}Wo_3$	$En_{81}Fs_{17}Wo_2$ $En_{66}Fs_{24}Wo_4$	$En_{57-78}Fs_{22-43}Wo_{2-18}$
Clinopyroxene	$En_{48-55}Fs_{13-19}Wo_{29-39}$	$En_{47}Fs_{22}Wo_{31}$			$En_{46-55}Fs_{12-18}Wo_{27-41}$
An	42-55	52	52.3		30-65
TiO_2 (wt%) of chromite	Poikilitic: <1.64 wt% Interstitial: 7.21 - 13.9 wt%				More TiO_2-rich in interstitial than in poikilitic
Oxygen isotopes	$\delta^{18}O = 3.97 \pm 0.07$‰ $\delta^{17}O = 2.34 \pm 0.07$‰ $\Delta^{17}O = 0.28$‰				$\delta^{18}O = 3.88$-4.14‰ $\delta^{17}O = 2.18$-2.39‰ $\Delta^{17}O = 0.16$-0.24‰

1) Data source: (Clayton and Mayeda 1996; Ikeda 1997; Mikouchi and Miyamoto 1997; Mikouchi and Miyamoto 2000; Treiman *et al.* 1994). $\Delta^{17}O = \delta^{17}O - 0.52\delta^{18}O$

Table 4. Mineral chemistry of GRV 99018 in comparison with eucrites

	Lin *et al.* (2002)	Tao *et al.* (2002)	Liu *et al.* (2002)	Eucrites[1)]
Low-Ca pyroxene	$En_{36-38}Fs_{55-62}Wo_{1-3}$	$En_{34.3}Fs_{59.6}Wo_{6}$	Fs_{55-62}	Fs_{44-63}
Ca-pyroxene	$En_{29-32}Fs_{25-31}Wo_{37-45}$	$En_{29.3}Fs_{25.4}Wo_{45.3}$	Fs_{25-31}	Fs_{15-34}
Pyroxene(FeO/MnO)	28 ± 2		28	30
Plagioclase An (mol%)	88-91	90.9		80-100

1) (Ruzicka *et al.* 1997)

2.2.2 *Eucruite*

Howardite, eucrite and diogenite are proposed from a same parent body, probably 4-asteroid (*i. e.* Vesta), and they are abbreviated as HED. Howardite is polymict breccia, consisting of components of eucrite and diogenite. Besides lunar and Martian meteorites, HED are the only known extra-terrestrial basalts, hence being probes to magmatism and volcano activity in the early solar system. Of the 32 GRV meteorites, GRV 99018 is a eucrite. It is classified as a monomict breccia, consisting of 50.5 vol% pigeonite, 32.7 vol% plagioclase, 5.2 vol% opaque minerals with accessory SiO_2. In GRV 99018, pyroxene is FeO-rich and with a high Mn/Fe ratio, and plagioclase is Ca-rich (An_{88-91}). All these characteristics are typical of eucrite. Analyses of GRV 99018 are given in Table 4, in comparison with typical eucrites.

Eucrites are divided into non-cumulate, cumulate and polymict subtypes. In addition, non-cumulate eucrites can further be identified as surface (S) and normal (O) (Takeda 1997). Based on studies of HED and spectrum of Vesta, a layered model of Vesta consisting of various types of HED meteorites was proposed (Takeda 1997). From the surface inwards, occurrence of the rocks are in an order of surface non-cumulate, normal non-cumulate, cumulate, diogenite, and howardite. GRV 99018 can be referred to as a normal non-cumulate eucrite.

2.3 *Iron meteorite*

Of the 32 GRV meteorites, there is only one iron meteorite (GRV 98003). INAA results (Wasson, per. com.) are: Cr 12 ppm, Co 6.89 mg/g, Ni 146.3 mg/g, Cu 370.7 ppm, Ga 6.96 ppm, As 21.8 ppm, Sb 404 ppb, W 0.6 ppm, Ir 0.068 ppm, Pt 5.9 ppm, Au 2.158 ppm. GRV 98003 contains high Ni and low Ir, different from any known iron meteorite. It is, hence, classified as ungrouped very fine-grained octahedral iron. A comprehensive study of GRV 98003 is required, in order to determine its chemical group, and to clarify melting fractionation of asteroids and formation of iron core.

2.4 *Cosmogenic nuclides*

By impact, meteorite was dug out from deep parts of parent body and ejected into the space. The meteoritic material will react with cosmic ray, producing cosmogenic nuclides that are radioactive or stable. Using the cosmogenic nuclides, it is possible to determine cosmic ray exposure ages (CRE) and terrestrial ages (time between a meteorite fell on surface of the Earth and it was found) of meteorites. Cosmogenic noble gas isotopic compositions of GRV 98002 and 98004 have been measured, and their CRE and gas retention ages have been calculated accordingly (Wang et al., 2002). The ^4He and ^{40}Ar retention ages are 1.6 ± 0.1 Ga and 4.63 ± 0.16 Ga for GRV 98002, and 3.6 ± 0.8 Ga and 4.53 ± 0.15 Ga for GRV 98004, respectively. CRE age of GRV 98002 is 17.0 ± 2.5 Ma, in the range of L chondrites. However, GRV 98004 has an unusually low CRE age of 0.052 Ma. This is the forth meteorites known to have such a low CRE age. Of 1600 chondrites with CRE ages determined, the other three with CRE ages <0.05 Ma are: Farmington (L5) 0.032 Ma, Galim (LL6) 0.033 Ma, and ALH 82100 (CM2) 0.04 Ma (Lorenzetti *et al.* 2003). These unusually low CRE ages are not due to diffusion loss of noble gases before breakup of their parent bodies, because these meteorites show consistent CRE ages based on ^3He, ^{21}Ne and ^{38}Ar. For instance, GRV 98004 has ^3He and ^{21}Ne CRE ages of 0.049 Ma and 0.056 Ma, respectively. Lorenzetti *et al.* (2003) suggested two possibilities for the unusually low CRE ages: (1) these meteorites were dug from their parent bodies in the asteroid belt, then fast ejected from the 3:1 resonant Kirkwood gap, or (2) they came from Apollo asteroids that are the closest to the orbit of the Earth.

2.5 Meteorite Concentrating processes in Grove Mountains area

Discovery of the first 32 meteorites from the ice fields in Grove Mountains area by the 15th and 16th teams of CHINARE, and classification of the various groups of meteorites indicate concentration of meteorites in this area. Miao *et al.* (2003) tried to determine if some of the meteorites are paired, and they suggested that all 32 meteorites represent at least 27 falls. On the other hand, distribution pattern of chemical groups of the GRV meteorites appears distinct from other Antarctic meteorites. The discovery of a Martian meteorite and high relative abundance of unequilibrated chondrites could be due to heterogeneity for a small collection of meteorites, implying a large number of meteorites undiscovered in this area.

Grove Mountains locate 450 km north to Zhongshan station in eastern Antarctica. Relative altitude in the region is up to 1200 m, and this area is 3200 km^2. Sixty-four nunataks range along NNE-SSW direction as chains of islands, with a landscape of ridges and valleys (Ju and Liu 2002; Liu and Ju 2002). The nunataks play a role of barriers to glaciers. After fall, meteorites were buried by snow, and then transferred with glaciers. At sites where the glaciers were slowed down by ranges or barriers under ice surface, meteorites were grounded as the blue ice was ablated by descending wind which is common in Antarctica. This makes meteorites enriched in a small area. Recent discovery of 4448 meteorites from Grove Mountains by the 19th team of CHINARE confirms that this area is one of the most meteorite-rich in Antarctica.

3 Summary and future study

Except for GRV 98001, other 31 GRV meteorites have been classified, including 1 Martian meteorite, 1 eucrite, 1 iron, 6 unequilibrated L chondrites, and 23 equilibrated ordinary chondrites. Classification of the newly found 4448 meteorites is one of the major routine works in the future. Rare types of meteorites are expected.

GRV 99027 has a similar petrographic texture, modal composition and mineral chemistry as other known Martian lherzolites, hence it has been classified as the forth of this type. The Martian origin of GRV 99027 is further confirmed by its oxygen isotopic composition. The other three Martian lherzolites, *i. e.* ALHA77005, Yamato 793605, LEW 88516, have very similar petrographic, mineralogical and geochemical features, and their ejection ages are the same within analysis errors. Hence, it is possible that all three lherzolites were ejected from same site on the surface of Mars by a same impact event. It is important to clarify genetic relationship of GRV 99027 with the other lherzolites. For this purpose, it is required to determine crystallization, cosmic ray exposure and terrestrial ages of GRV 99027.

Based on the petrography and mineralogy, GRV 99018 is classified as a eucrite. It may be an oldest (*i. e.* 45Ga) basalt in the solar system, according to study of other HED meteorites. On the other hand, HED meteorites were proposed from 4-Asteroid, Vesta, based on comparison of reflection spectrums of HED and Vesta. Study of HED meteorites, including GRV 99018, will open a window to understand structure, chemical and mineral compositions, formation and evolution of Vesta. In addition, it will also supply with important hints for early magmatism in terrestrial planets, such as the Earth and Mars. A comprehensive study of petrography, mineralogy and isochronology of GRV 99018 is going on.

Cosmic ray exposure histories, CRE and terrestrial ages of meteorites can be achieved by study of cosmogenic nuclides. The analyses of two GRV meteorites found an unusually low CRE age of GRV 98004 (0.052 Ma). The asteroidal body of this meteorite probably has a special orbit. On the other hand, CRE and terrestrial ages are critical to determine if meteorites are paired. Hence, they are important in order to clarify genetic relationship between GRV 99027 and other Martian lherzolites.

A total number of meteorites collected from Grove Mountains area has been up to 4480, indicating one of the most meteorite-rich regions in Antarctica. Based on meteorite concentrating processes, more meteorites are expected to emerge along with ablation of ice. A long-term meteorite-searching program is required in order to collect most of the valuable scientific samples.

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