# A New Martian Meteorite from Antarctica: Grove Mountains (GRV) 020090

MIAO Bingkui[1, 2], OUYANG Ziyuan[3], WANG Daode[4], JU Yitai[5], WANG Guiqin[4] and LIN Yangting[1]

1 *Institute of Geology and Geophysics, Chinese Academy of Sciences, Beijing 100029; E-mail: Linyt@mail.igcas.ac.cn*

2 *Department of Resources and Environmental Engineering, Guilin Institute of Technology, Guilin, Guangxi 541004*

3 *National Astronomical Observatories, Chinese Academy of Sciences, Beijing 100012*

4 *Guangzhou Institute of Geochemistry, Chinese Academy of Sciences, Guangzhou, Guangdong 510640*

5 *The Second Bureau of China Exploration & Engineering Bureau, Fuzhou, Fujian 350001*

**Abstract** Reported in this paper are the petrology and mineral chemistry of GRV 020090, the second Martian meteorite collected from the Grove Mountains, Antarctica. This meteorite, with a mass of 7.54 g, is completely covered by a black and glazy fusion crust. It has two distinct textural regions. The interstitial region is composed of euhedral grains of olivine, pigeonite, and anhedral interstitial maskelynite, with minor chromite, augite, phosphates and troilite. The poikilitic region consists of three clasts of pyroxenes, each of which has a pigeonite core and an augite rim. A few grains of subhedral to rounded olivine and euhedral chromite are enclosed in the pyroxene oikocrysts. GRV 020090 is classified as a new member of lherzolitic shergottites based on the modal composition and mineral chemistry. This work will shed light on the composition of Martian crust and magmatism on the Mars.

**Key words:** meteorite, lherzolite, shergottite, achondrite, Mars, Antarctica

## 1 Introduction

SNC meteorites (including shergottites–nakhlites–chassignites) have been widely believed to come from the red planet, the Mars, on the basis of many lines of evidence, e.g. (1) the relatively young crystallization ages (< 1.3 Ga) suggest that their parent body is not an asteroidal body (with ages of about 4.4–4.5 Ga), but rather likely an earth-like planet (Nyquist et al., 1979; Shih et al., 1982; Chen and Wasserburg, 1986); (2) the isotopic compositions and relative abundances of noble gases, N and $CO_2$ trapped in glass in these meteorites (e.g. EETA 79001) are a remarkable match for Martian atmospheric abundances determined by the Viking landers (Bogard and Johnson, 1983; Becker and Pepin, 1984; Carr et al., 1985; Wright et al., 1986); and (3) the bulk compositions of these meteorites are consistent with those of Martian soil measured by the Viking landers and Pathfinders (Laul et al., 1986; Rieder et al., 1997). Recently, ALH 84001, an orthopyroxenite, has been classified as the fourth group of Martian meteorites (Mittlefehldt, 1994, McKay et al., 1998); and the report of evidence for the presence of old Martian life in this meteorite (McKay et al., 1996) has ignited Mars exploration. Shergottites are the most abundant Martian meteorites, and they are further divided into basaltic, lherzolitic and olivine-phyric (McSween et al., 1979a; McSween et al., 1979b; Goodrich, 2003). Up to date, there are 29 Martian meteorites, so far collected and they are the only available samples from the Mars, hence discovery of new Martian meteorites will provide a unique probe to constrain the origin and evolutional history of the red planet.

A total of 4 and 28 meteorites were collected in the Grove Mountains during the 15th and 16th Chinese Antarctic Research Expedition (CHINARE) in 1998–1999 and 1999–2000 seasons, respectively (Chen et al., 2001; Ju and Liu, 2002; Miao et al., 2003). One of them has been classified as a lherzolitic shergottite (Lin et al., 2003). In 2002–2003, 4448 meteorites were successfully collected in the same Grove Mountains region during the 19th CHINARE. Fifty-one samples were selected from this new meteorite collection, and they were classified as 1 Martian meteorite, 3 ureilites, 7 carbonaceous chondrites and 40 ordinary chondrites. This paper presents the petrology and mineralogy data of GRV 020090, and discusses its classification as a new member of lherzolitic shergottites.

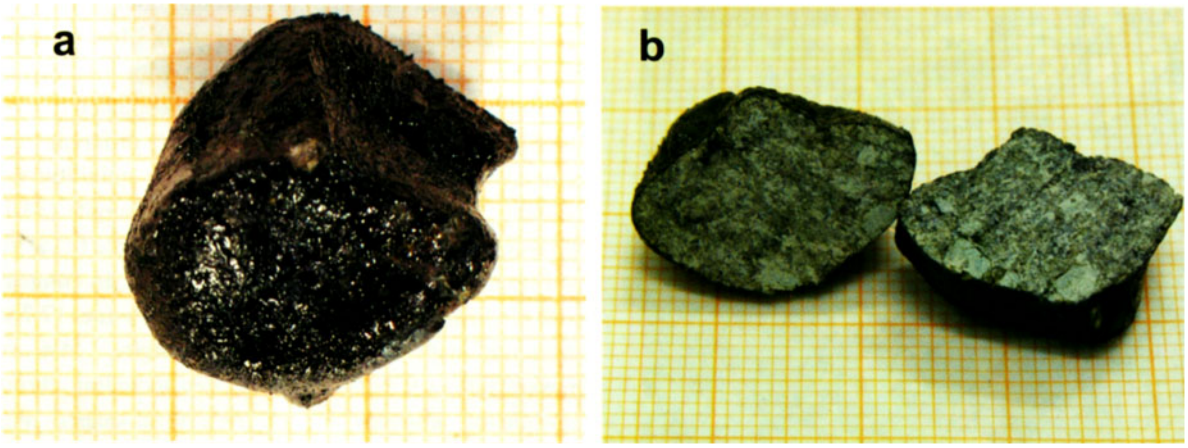


Fig. 1. (a) Photo of GRV 020090 completely covered by a black glazy fusion crust.
Small grids are 1.0 mm.
(b) Photo of the meteorite after cutting.
Note millimeter-sized light gray pyroxene clasts on the fresh surfaces.

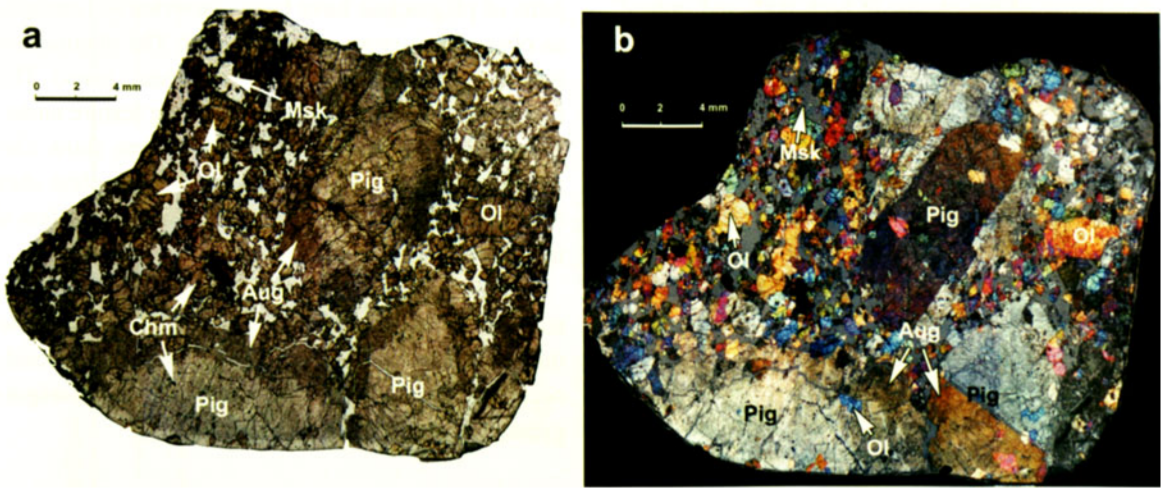


Fig. 2. Photo mosaics of the polished thin section GRV 020090-2.
(a) A view in plane polarized light, showing two different textural portions (interstitial and poikilitic). The poikilitic areas are composed of three pyroxene oikocrysts that have pigeonite (Pig) cores and augite (Aug) rims. The interstitial area is cumulated by euhedral olivine (Ol) and pigeonite with interstitial maskelynitic plagioclase (Msk). Euhedral chromites (Chm) are enclosed in the poikilitic pyroxene, the interstitial olivine and maskelynite. The field of view is 20 mm.
(b) A view in cross-polarized light, showing single or twin crystals of pyroxene oikocrysts.
The field of view is 20 mm.

## 2 Samples and Analytical Procedures

GRV 020090 weighs 7.54 g, and measures 24 mm × 22 mm × 20 mm in size. It has a strawberry-like shape, and is completely covered by a black and glazy fusion crust (Fig. 1a). The stone was cut into two halves with nearly similar sizes (Fig. 1b). One piece was embedded in epoxy, and two thin slices were cut from it. A polished thin section was made from one of the slices using oil for cooling. Petrographic and mineralogical observations were made under an optical microscope and in back-scattered electron (BSE) image mode of an electron microprobe analyzer (EPMA) Type JEOL JXA-8800R at the Sun Yat-sen University. Quantitative analyses of minerals were carried out using the same EPMA. The operating conditions were 15 kV of accelerating voltage and 20 nA of beam current. Both natural and synthetic minerals were used as standards. X-ray overlapping of $K_\alpha$ lines by $K_\beta$ lines of some successive elements, such as V by Ti, and Mn by Cr, were corrected. The analyses were treated using the Bence-Albee method. Modal abundances of minerals were calculated

**Table 1 Summary of EPMA mineral compositions (wt%)**

| | Olivine | | Pigeonite | | Augite | | Chromite | | Plagioclase |
|---|---|---|---|---|---|---|---|---|---|
| | 1* | 2 | 3* | 4 | 5* | 6 | 7* | 8 | 9* |
| $SiO_2$ | 35.8 ± 0.3 | 36.6 ± 0.5 | 52.3 ± 0.4 | 53.3 ± 0.7 | 51.5 | 52.1 ± 0.3 | 0.01 | 0.12 ± 0.07 | 56.5 ± 2.1 |
| | 35.0–36.4 | 35.8–37.9 | 51.6–53.0 | 51.1–54.1 | | 51.8–52.5 | <0.05 | 0.04–0.32 | 53.7–63.2 |
| $TiO_2$ | 0.02 | 0.01 | 0.28 ± 0.10 | 0.13 | 0.32 | 0.21 ± 0.02 | 13.5 ± 5.3 | 1.22 ± 0.17 | 0.05 |
| | <0.06 | <0.05 | 0.16 - 0.58 | 0.04–0.63 | | 0.19–0.25 | 2.13–16.7 | 0.88–1.46 | <0.14 |
| $Al_2O_3$ | 0.01 | 0.05 | 0.74 ± 0.17 | 0.77 ± 0.92 | 1.66 | 1.20 ± 0.19 | 3.69 ± 0.60 | 6.84 ± 0.67 | 27.0 ± 0.7 |
| | <0.04 | <0.62 | 0.53–1.05 | 0.40–5.07 | | 1.01–1.43 | 3.35–5.08 | 5.66–8.05 | 24.6–28.2 |
| $Cr_2O_3$ | 0.02 | 0.04 | 0.28 ± 0.09 | 0.38 ± 0.08 | 0.76 | 0.71 ± 0.09 | 21.5 ± 6.8 | 53.5 ± 2.8 | |
| | <0.06 | <0.14 | 0.17 - 0.49 | 0.13–0.54 | | 0.62–0.86 | 15.5–36.8 | 46.5–56.6 | |
| FeO | 34.5 ± 0.9 | 30.2 ± 2.2 | 19.0 ± 0.77 | 16.3 ± 0.6 | 11.3 | 10.7 ± 0.2 | 55.1 ± 4.6 | 30.5 ± 1.3 | 0.43 ± 0.07 |
| | 30.6–35.5 | 26.2–34.5 | 16.7–20.2 | 15.3–18.1 | | 10.5–11.0 | 45.6 - 60.4 | 27.7–32.7 | 0.25–0.61 |
| MnO | 0.74 ± 0.05 | 0.68 ± 0.05 | 0.70 ± 0.03 | 0.61 ± 0.05 | 0.48 | 0.46 ± 0.04 | 0.59 ± 0.08 | 0.24 ± 0.03 | |
| | 0.65–0.84 | 0.59–0.77 | 0.63–0.75 | 0.55–0.70 | | 0.41–0.51 | 0.44–0.65 | 0.17–0.31 | |
| MgO | 28.9 ± 0.7 | 32.4 ± 1.7 | 20.8 ■ 0.54 | 24.0 ± 1.53 | 16.8 | 17.3 ± 0.12 | 2.72 ± 0.42 | 5.04 ± 0.40 | 0.08±0.02 |
| | 27.6–31.3 | 28.7–34.5 | 19.7–21.6 | 20.2–26.2 | | 17.3–17.5 | 2.17–3.35 | 4.27–5.36 | 0.03–0.13 |
| CaO | 0.19 ± 0.05 | 0.17 ± 0.06 | 4.71 ± 0.68 | 3.40 ± 1.44 | 15.9 | 15.4 ± 0.3 | | | 9.77±1.14 |
| | 0.12–0.28 | 0.07–0.29 | 3.97–6.39 | 1.53 - 6.71 | | 14.9–15.7 | | | 5.86–11.1 |
| $Na_2O$ | | | 0.09 ± 0.02 | 0.07 ± 0.05 | 0.24 | 0.18 ± 0.06 | | | 4.92±0.43 |
| | | | 0.04–0.14 | <0.21 | | 0.11–0.27 | | | 4.41-6.50 |
| $K_2O$ | | | | | | | | | 0.41±0.15 |
| | | | | | | | | | 0.18–0.79 |
| Analysis points | 25 | 20 | 19 | 24 | 1 | 5 | 8 | 12 | 53 |

Note: Average ± σ; Numbers in italic: ranges; *Interstitial texture, the others are poikilitic; blank, not analyzed.

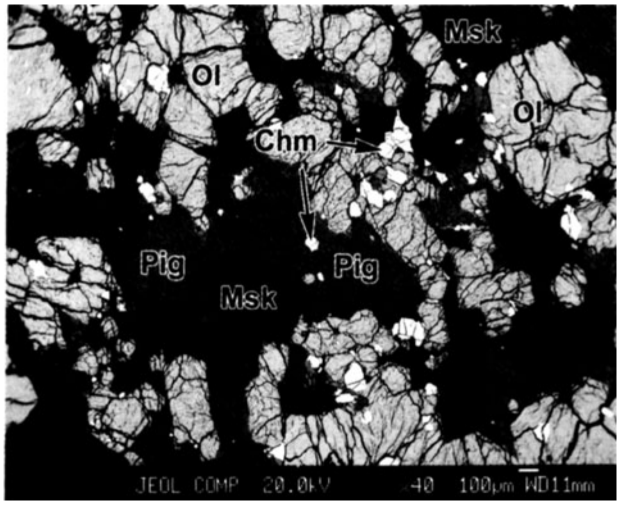


Fig. 3. Back-scattered electron image of the interstitial lithology of GRV 020090.
Note euhedral olivine (Ol) and pigeonite (Pig) grains with interstitial maskelynite (Msk). The field of view is 3 mm.

from surface areas of the phases in both BSE and optical photo mosaics.

## 3 Results

### Textural features and modal compositions

The polished thin section (PTS) of GRV 020090 is 1.7 cm×1.9 cm in size, with a surface area of 2.01 $cm^2$. The fusion crust is 20–40 μm thick. GRV 020090 is composed of olivine (29.0 vol%), pigeonite (35.7 vol%), augite (15.7 vol%), plagioclase (18.1 vol%) and chromite (1.7 vol%) with acçessory minerals (e.g. phosphates, troilite, and ilmenite). Distribution of minerals is heterogeneous on a centimeter scale (Fig. 2a). There are three large pyroxene oikocrysts (5 mm×8 mm, 4 mm×8 mm, 6 mm×6 mm), accounting for ~45 vol% of the whole section. Each pyroxene oikocryst is concentrically zoned, with a large pigeonite core and augite rim (up to ~1 mm thick), and often shows twin bands (up to 5 mm wide) (Fig. 2b). Gradual variation is noticed from the pigeonite core to the augite rim. Subhedral to rounded olivine and euhedral chromite grains are embedded in the pyroxene oikocrysts (Fig. 2b). These oikocrysts are referred to as poikilitic lithology. Among the pyroxene oikocrysts, there are euhedral olivine and pigeonite with interstitial plagioclase (Fig. 3), referred to as interstitial lithology. The interstitial lithology accounts for ~55 vol% of the section. Except for a few large grains of olivine (up to 2.3 mm), most of olivine, pigeonite and plagioclase are within the range of 0.3–1 mm in size. Minor chromite (<1.9 vol%) occurs as small euhedral inclusions mainly in olivine and pyroxene.

In interstitial lithology, most pyroxene grains are pigeonite, except for a few grains of augite. Pigeonite in the poikilitic region (4–8 mm) is much bigger in grain size than that in the interstitial region (0.3–1 mm). Most phosphates, ilmenite and troilite occur in contact with maskelynite in the interstitial region. Most minerals show a heterogeneous distribution, as indicated by their different modal abundances in the two lithologies. The poikilitic region contains more pigeonite (54.9 vol%) and augite (34.1 vol %) with less olivine (4.4% vol%) and chromite (<1% vol%) and no plagioclase, phosphate and sulfides, in comparison with the interstitial lithology (46.2 vol% olivine, 17.7 vol% pigeonite with a few grains of augite, 34.4 vol% maskelynite, 1.9 vol% minor phases including chromite, phosphates, ilmenite and troilite). Oval-shaped magma inclusions (50–200 μm) are common in olivine and rarely in pyroxenes. Radial cracks are often observed in the host minerals around the magma inclusions.

Olivine, pigeonite and augite are heavily fractured and show undulatory extinction. In addition, the pyroxene oikocrysts show planar fractures and mosaic extinction. All laths of plagioclase have been converted to isotropic glass as observed in cross-polarized light. The plagioclase glass is referred to as maskelynite (diaplectic glass). They are colorless and do not exhibit any zoning feature under plane polarized light. But some laths of them show chemical zonation on BSE images. The plagioclase glass shows no flowing or recrystallized features. There are a few shock-induced thin veins and pockets.

Except for a few dark brown spots probably stained by terrestrial weathering products, several small nodules and thin veins (<10μm thick) of gypsum have been found. They occur in fractures. Extraterrestrial or terrestrial origin of the gypsum cannot yet be distinguished.

### Mineralogy

Analyses of most minerals show correlations with their occurrences, and the results are summarized in Table 1.

*Olivine*: The grains in the interstitial region (Fa 35.4–41.9 mol%, with an average of 40.1±1.2 mol%) are more ferroan than those in the poikilitic clasts (Fa 30.2–40.0 mol %, with an average of 34.3±2.8 mol%). The largest olivine grain in the interstitial region is zoned, with Fa increasing from 35.0 mol% to 39.7 mol% towards the rim. However, other individual grains in both poikilitic and interstitial regions are homogenous, regardless of significant variation among grains. Minor elements are CaO (0.07–0.29 wt%) and MnO (0.59–0.84 wt%), and they show no significant differences between the two textural occurrences. The FeO/MnO ratio of olivine is 45.3 ± 2.9.

*Pyroxenes*: Pigeonite shows a similar compositional trend as olivine, being more ferroan in the interstitial region (average $En_{59.7}Wo_{9.72}Fs_{30.6}$) than the pigeonite cores of pyroxene oikocrysts (average $En_{67.4}Wo_{6.88}Fs_{25.7}$). In

**Table 2 Comparison of GRV 020090 with other lherzolitic shergottites**

| | | GRV 020090 | GRV 99027 | ALHA 77005 | LEW88516 | Yamato 793605 | NWA 1950 |
|---|---|---|---|---|---|---|---|
| Mass | | 7.54 g | 9.97 g | 482 g | 13 g | 16 g | 797 g |
| Found site | | Antarctica | Antarctica | Antarctica | Antarctica | Antarctica | Atlas Mountains in Morocco |
| Modal composition (in vol%) | | Ol 29.0, Pig 35.7, Aug 15.7, Pl 18.1, Chm 1.7 | Ol 32.3, Pig 55.7, Aug 5.1, Pl 5.9, Chm 1.1 | Ol 44–60, Py 35–43, Pl 8–12, opaque <2% | Ol 46–59, Py 22–37, Pl 7–16; minor phases <3 | Ol 35–40.4, Py 50–60, Pl 5–8, opaque <1.5 | Ol 55, Py 35, Pl 8, |
| Textural modal (interstitial/poikilitic) | | Nearly identical | Interstitial <<poikilitic | Interstitial>>poikilitic | Interstitial>>poikilitic | Interstitial<<poikilitic | Bimodal texture |
| Average Fa (ranges)(mol) | 1* | 40.1 (35–42) | 29.7 | 24 (23–29) | 36 (30–40) | 34 (30–35) | |
| | 2 | 34.3 (30–40) | 26.7 | | 31 | 31 (26–35) | |
| Low-Ca pyroxene | 3* | $En_{60}Fs_{31}Wo_{10}$ | $En_{61-70}Fs_{20-23}Wo_{7-16}$ | $En_{61-66}Fs_{23-27}Wo_{7-16}$ | $En_{65-77}Fs_{19-31}Wo_{4-15}$ | $En_{66-76}Fs_{21-23}Wo_{3-11}$ | $En_{78}Fs_{19}Wo_{2}$–$En_{60}Fs_{26}Wo_{14}$ |
| | 4 | $En_{67}Fs_{26}Wo_{7}$ | $En_{66-77}Fs_{20-23}Wo_{3-14}$; | $En_{65-77}Fs_{19-20}Wo_{4-15}$ | | | |
| High-Ca pyroxene | | $En_{50}Fs_{17}Wo_{32}$ | $En_{48-54}Fs_{13-19}Wo_{29-38}$ | $En_{48-55}Fs_{12-15}Wo_{32-38}$ | $En_{45-58}Fs_{12-21}Wo_{25-40}$ | $En_{49-52}Fs_{14-16}Wo_{14-32}$ | $En_{53}Fs_{16}Wo_{31}$–$En_{45}Fs_{14}Wo_{41}$ |
| Plagioclase | | Zoning; $An_{44.0-53.0}Ab_{44.8-52.7}Or_{2.3-3.3}$ | $An_{42-55}Ab_{45-57}Or_{<2}$ | Zoning; $An_{45-54}Ab_{45-53}Or_{1-2}$ | $An_{45-60}$ | $An_{45-55}Ab_{44-52}Or_{<3}$ | $An_{57}Ab_{41}Or_{1}$–$An_{40}Ab_{57}Or_{3}$ |
| Chromite | 5* | $Chm_{18-44}Sp_{12-18}Mt_{14-25}Usp_{24-46}$ | $Chm_{42-71}Sp_{11-22}Mt_{3-11}Usp_{5-36}$ | | Higher $TiO_2$ in interstitial parts than in poikilitic regions | | |
| | 6 | $Chm_{61-66}Sp_{23-28}Mt_{6-8}Usp_{2-4}$ | $Chm_{68-82}Sp_{13-22}Mt_{2-6}Usp_{2-4}$ | | | | |

Abbreviation: olivine - Ol; pigeonite - Pig; augite - Aug; pyroxenes - Py; plagioclase - Pl; chromite - Chm;

* In the interstitial lithology, and the other numbers in the poikilitic regions.

Data sources: GRV 020090, this work; GRV 99027 (Lin et al., 2003); ALHA 77005 (McSween et al., 1979b; Harvey et al., 1993; Mikouchi and Miyamoto, 1997); LEW88516 (Harvey et al., 1993; Gleason et al., 1997); Yamato 793605 (Mikouchi and Miyamoto, 1996, 1997; Ikeda, 1997); NWA 1950 (Russell et al., 2004).

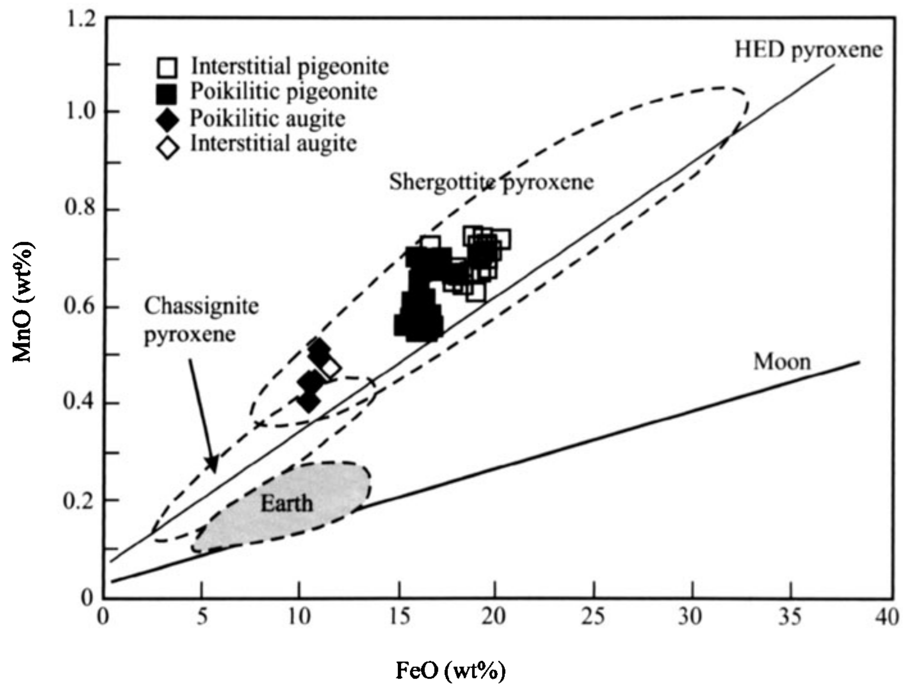


Fig. 4. Plot of MnO vs. FeO of pyroxenes in GRV 020090.
The MnO contents and the FeO/MnO ratios of pyroxenes in GRV 020090 are within the ranges of other lherzolitic shergottites, in comparison with the ranges of the Earth and the Moon. Literature: Lin and Wang, 1995.

addition, the interstitial pigeonite contains high CaO (3.97–6.39 wt%, average 4.71±0.68 wt%), $TiO_2$ (0.16–0.58 wt%, average 0.28±0.13 wt%), and MnO (0.63–0.75 wt%, average 0.70±0.03 wt%), in comparison with the pigeonite cores of pyroxene oikocrysts (CaO 1.53–6.71 wt%, average 3.40±1.44 wt%; $TiO_2$ 0.04–0.63 wt%, average 0.13±0.10 wt%; MnO 0.55–0.70 wt%, average 0.61±0.05 wt%). Detailed analyses conducted on the pyroxene oikocrysts revealed relatively constant contents of FeO in the pigeonite cores (average 16.3±0.6 wt%). However, the CaO contents increase from 1.53 wt% to 6.71 wt% towards the augite rims. FeO/MnO ratios of pigeonite are nearly the same for both textural occurrences (interstitial: 27.1±1.3; poikilitic: 26.6±2.0) (Fig. 4).

Analyses of augite in the interstitial region and the rims of pyroxene oikocrysts show similar and homogeneous major element compositions (oikocryst rims: $En_{50.3}Wo_{32.2}Fs_{17.6}$; interstitial grains: $En_{48.5}Wo_{33.1}Fs_{18.3}$). But the interstitial augite is rich in minor elements $Al_2O_3$ (1.66 wt%) and $TiO_2$ (0.32 wt%), in comparison with the augite rim ($Al_2O_3$ 1.01–1.43 wt%; $TiO_2$ 0.19–0.25 wt%). The other minor elements are MnO (0.41–0.51 wt%) and $Na_2O$ (0.11–0.27 wt%) in both textural occurrences. The average FeO/MnO ratio is 23.3±1.8 (Fig. 4).

*Maskelynite*: It is $K_2O$-poor (0.40±0.15 wt%) with a chemical formula of $An_{36.6-57.3}Ab_{41.1-58.8}Or_{1.1-6.2}$. EPMA profiles conducted on several laths of maskelynite reveal a normal zoning feature, with CaO content decreasing from the cores ($An_{53.0}Ab_{44.8}Or_{2.3}$) to the rims ($An_{44.0}Ab_{52.7}Or_{3.3}$). Minor elements are FeO (0.25–0.61 wt%, average 0.43 ± 0.07 wt %), MgO (0.03–0.12 wt%, average 0.08 ± 0.02 wt%), and $TiO_2$ (<0.14 wt %, average 0.05 ± 0.03 wt%).

*Chromite*: The composition of chromite correlates with its occurrence as the olivine and pyroxene described above. The grains isolated in both pyroxene oikocrysts (average $Chm_{63}Sp_{27}Mt_7Usp_3$) and olivine ($Chm_{75}Sp_{16}Mt_7Usp_2$,) are $Al_2O_3$- and $Cr_2O_3$-rich. In contrast, other grains in contact with maskelynite in the interstitial region are $TiO_2$-rich (average $Chm_{25}Sp_{15}Mt_{19}Usp_{41}$), and some of them show pronounced zoning with $TiO_2$ and $Cr_2O_3$ contents increasing from the cores ($Chm_{44}Sp_{17}Mt_{14}Usp_{24}$) to the rims ($Chm_{26}Sp_{18}Mt_{17}Usp_{39}$).

## 4 Discussion

### A new lherzolitic shergottite

The main petrographic characteristics of GRV 020090, including two distinct lithologies (poikilitic and interstitial) and typical mineral modal abundances of olivine (29.0 vol %), pigeonite (35.7 vol%), augite (15.7 vol%), plagioclase (18.1 vol%) and other minor phases (1.7 vol%), obviously suggest that GRV 020090 is a lherzolite, although its olivine abundance is somewhat lower than the range of lherzolites. The poikilitic lithology is composed of pyroxene oikocrysts that enclose olivine and chromite and are zoned from the low-Ca cores (pigeonite) to the high-Ca rims (augite), whereas the interstitial lithology consists of olivine cumulus, pigeonite prisms and maskelynite. These overall textural relationships are obviously similar to those for other known lherzolitic shergottites, including ALH 77005 (McSween et al., 1979a), LEW 88516 (Harvey et al., 1993), Y-793605 (Mikouchi and Miyamoto, 1996, 1997) and GRV 99027 (Lin et al., 2003). Furthermore, olivine and pigeonite in GRV 020090 show bimodal patterns of FeO-contents, with the grains in the interstitial region being more ferroan than those in the poikilitic lithology, typical of lherzolitic shergottites (Lin et al., 2003). The composition of maskelynite in GRV 020090 ($An_{37-57}$) varies from andesine to labradorite, within the range of Martian meteorites (Lin and Wang, 1995), but distinguishes from much more calcic plagioclase in lunar mare basalts and plagioclase-pyroxene achondrites (i.e., eucrites, a kind of basalts probably from asteroid 4 Vesta, also see Lin et al., 2004). The FeO/MnO ratio of pyroxene is a critical parameter to distinguish various basalts from the Earth, Moon, Mars and HED (an achondrite clan consisting of eucrites, diogenites and howardites), as demonstrated in Fig. 4. Analyses of pigeonite and augite in GRV 020090 are plotted along the range of Martian meteorites, indicating an affinity with the Mars. The FeO/MnO ratio of olivine in GRV 020090 is also close to that of the GRV 99027 lherzolitic shergottite (Lin et al., 2003). Hence, we classify GRV 020090 as a new lherzolitic shergottite. In addition, the shock effects indicate that the shock stage of GRV 020090 is Stöffler's S5 (Stöffler et al., 1991). In comparison with common weathering degrees of Antarctic meteorites, GRV 020090 is very fresh as W1 (Wlotzka, 1993).

### Comparison with other lherzolitic shergottites

Up to date, 5 lherzolitic shergottites, i.e., ALHA 77005, LEW 88516, Yamato 793605, GRV 99027 and NWA 1950, have been reported (McSween et al., 1979a and b; Harvey et al., 1993; Ikeda, 1997; Mikouchi and Miyamoto, 1997; Lin et al., 2003). Compared with these meteorites (Table 2), GRV 020090 shares many similar petrologic and mineral chemical features as described above. However, we also notice significant differences between GRV 020090 and other lherzolitic shergottites. First, GRV 020090 contains the lowest olivine of lherzolitic shergottites (32–60 vol%, Lin et al., 2003). This could be due to the rareness of olivine inclusions in the pyroxene oikocrysts in this meteorite. In contrast, the modal abundances of olivine in both interstitial and poikilitic lithologies in GRV 99027 are almost the same (Lin et al., 2003). Second, augite in GRV 020090 occurs predominantly as the rims of the pyroxene oikocrysts, different from GRV 99027 and other lherzolitic shergottites, in which augite usually coexists with pigeonite and maskelynite in the interstitial regions (Gleason et al., 1997; Mikouchi and Miyamoto, 1997; Lin et al., 2003). Third, both olivine and pyroxenes contain significantly higher FeO in GRV 020090 than their counterparts in other lherzolites (Lin et al., 2003). Finally, maskelynite in GRV 020090 is a clear glass and has no evidence of flowing feature, suggesting a solid transformation without melting. This is different from plagioclase glass in Shergotty that probably solidified from dense melt (Chen and El Goresy, 2000). In addition, GRV 020090 shows no evidence of recrystallization, suggesting the lack of significant thermal metamorphism after the main impact event. This is also confirmed by preservation of the zoned maskelynite in GRV 020090.

GRV 020090 was collected in the same Grove Mountains region close to the site of GRV 99027 (10 km away), and both are lherzolites. The first issue is whether both meteorites are paired (pieces from the same meteorite fall). As described above, GRV 020090 shows significant differences from GRV 99027. These differences are too large to be accounted for by paired meteorites. A part of variation could be attributed to heterogeneous sampling, since GRV 020090 and other lherzolitic shergottites are composed of two different textural lithologies. However, the very low modal abundance of olivine in the pyroxene oikocrysts, the higher FeO-contents of olivine, augite and pigeonite in both textural lithologies in GRV 020090 exclude the possibility of pairing with GRV 99027. Furthermore, GRV 020090 could not be paired with other Martian meteorites. Hence, its differences in modal composition, mineral chemistry and maskelynite from other Martian meteorites suggest that GRV 020090 probably represents a sample from another igneous unit different from those from where other Martian meteorites were ejected, and then opens a new window of understanding the mechanism of formation and evolution of the Mars.

## Acknowledgements

The authors wish to thank all of the team members (e.g. Ju Yitai, Li Jinyan, Xu Xiaxing, Miao Bingkui, Qin Xiang, Yu Liangjun, Yan Li, and Zhang Shengkai) of the 19th CHINARE for collecting 4448 Antarctic meteorites. Allocation of the samples was done with help from Prof. Li Yuansheng, and analyses were carried out with help from Miss Chen Linli. Discussions with Profs. Zhou Xinhua, Liu Xiaohan, Tao Kejie and Zhang Hongfu are very helpful. The sample is provided by the Polar Research Institute of China. This work is supported by the National Natural Science Foundation of China (Grant No. 40232026) and the pilot project of knowledge innovation program of the Chinese Academy of Sciences (Grant No. KZCX3-SW-123).

Manuscript received July 2, 2004
accepted Sept. 11, 2004
edited by Xie Guanglian

### References

Becker, R.H., and Pepin, R.O., 1984. The case for a Martian origin of the shergottites—Nitrogen and noble gases in EETA 79001. *Earth Planet. Sci. Lett.*, 69: 225–242.

Bogard, D.D., and Johnson, P., 1983. Martian gases in an Antarctic meteorite? *Science*, 221: 651–654.

Carr, R.H., Grady, M.M., Wright, I.P., and Pillinger, C.T., 1985. Martian atmospheric carbon dioxide and weathering products in SNC meteorites. *Nature*, 314: 248–250.

Chen, J.H., and Wasserburg, G.J., 1986. Formation ages and evolution of Shergotty and its parent planet from U-Th-Pb systematics. *Geochim. Cosmochim. Acta*, 50: 955–968.

Chen Jing, Liu Xiaohan, Ju Yitai, Xu Jun and Yan Yongjie, 2001. Classification of four meteorites from Grove Mountains, Antarctica. *Acta Petrol. Sinica*, 17: 314–320 (in Chinese with English abstract).

Chen Ming and El Goresy, A., 2000. The nature of maskelynite in shocked meteorites: not diaplectic glass but a glass quenched from shock-induced dense melt at high pressures. *Earth Planet. Sci. Lett.*, 179: 489–502.

Gleason, J.D., Kring, D.A., Hill, D.H., and Boynton, W.V., 1997. Petrography and bulk chemistry of Martian lherzolite LEW 88516. *Geochim. Cosmochim. Acta*, 61: 4007–4014.

Goodrich, C.A., 2003. Petrogenesis of olivine-phyric shergottites Sayh al Uhaymir 005 and Elephant Moraine A79001 lithology A. *Geochim. Cosmochim. Acta*, 67: 3735–3772.

Harvey, R.P., Wadhwa, M., Mcsween, H.Y.Jr., and Crozaz, G., 1993. Petrography, mineral chemistry, and petrogenesis of Antarctic Shergottite LEW88516. *Geochim. Cosmochim. Acta*, 57: 4769.

Ikeda, Y., 1997. Petrology and mineralogy of the Y-793605 Martian meteorite. *Antarctic Meteorites*, 22: 64–65.

Ju Yitai and Liu Xiaohan, 2002. Meteorites Collection in the Grove Mountains: Retrospect and Prospect. *Chinese Journal of Polar Research*, 14: 248–251 (in Chinese with English abstract).

Laul, J.C., Smith, M.R., Wanke, H., Jagoutz, E., Dreibus, G., Palme, H., Spettel, B., Burghele, A., Lipschutz, M.E., and Verkouteren, R.M., 1986. Chemical systematics of the Shergotty meteorite and the composition of its parent body (Mars). *Geochim. Cosmochim. Acta*, 50: 909–926.

Lin Yangting, Wang Daode, Miao Bingkui, Ouyang Ziyuan, Liu Xiaohan and Ju Yitai, 2003. Grove Mountains (GRV) 99027: A new Martian meteorite. *Chinese Sci. Bull.*, 48: 1771–1774.

Lin Yangting and Wang Daode, 1995. Inspiration from study on Antarctic meteorites IV: Investigations of Martian meteorites and implications for cosmochemistry. *Chinese Journal of Antarctic Research*, 7: 35–52 (in Chinese with English abstract).

Lin Yangting, Wang Daode and Wang Guiqing, 2004. A Tiny Piece of Basalt Probably from Asteroid 4 Vesta. Acta Geologica Sinica (English edition), 78(5): 1025–1033.

Mckay, A.G., Schwandt, S.C., and Mikouchi, T., 1998. Additional petrographic features of Martian meteorite ALH84001. *Antarctic Meteorites*, 23: 75–76.

Mckay, D.S., Gibson, E.K., Thomas-Keprta, K.L., Vali, H., Romanek, C.S., Clemett, S.J., Chiller, X.D.F., Maechling, C. R., and Zare, R.N., 1996. Search for past life on Mars: Possible relic biogenic activity in Martian meteorite ALH84001. *Science*, 273: 924–930.

Mcsween, H.Y., Stolper, E., Taylor, L.A., Muntean, R.A., O'Kelley, G.D., Eldridge, J.S., Biswas, S., Ngo, H.T., and Lipschutz, M.E., 1979a. Petrogenetic relationship between Allan Hills 77005 and other achondrites. *Earth Planet. Sci. Lett.*, 45: 275–284.

McSween, H.Y., Stolper, E., Taylor, L.A., Muntean, R.A., O'Kelley, G.D., Eldridge, J.S., Biswas, S., Ngo, H.T., and Lipschutz, M.E, 1979b. Allan Hills 77005—A new meteorite type found in Antarctica. *Science*, 204: 1201–1203.

Miao Bingkui, Lin Yangting and Zhou Xinhua, 2003. Type distribution pattern and pairing of ordinary chondrites from Grove Mountains, Antarctica. *Chinese Sci. Bull.*, 48: 908–913.

Mikouchi, T., and Miyamoto, M., 1996. A new member of lherzolitic Shergottite from Japanese Antarctic Meteorite Collection: Mineralogy and petrology of Yamato-793605. *Antarctic Meteorites*, 21: 104–106.

Mikouchi, T., and Miyamoto, M., 1997. Major and minor element distributions in pyroxene and maskelynite from Martian meteorite Y-793605 and other lherzolitic shergottites: Clues to their crystallization histories. *Antarctic Meteorites*, 22: 109–112.

Mittlefehldt, D.W., 1994. ALH84001, A cumulate orthopyroxenite member of the Martian meteorite clan. *Meteoritics*, 29: 214–221.

Nyquist, L.E., Wooden, J., Bansal, B., Wiesmann, H., Mckay, G., and Bogard, D.D., 1979. Rb-Sr age of the Shergotty achondrite and implications for metamorphic resetting of isochron ages. *Geochim. Cosmochim. Acta*, 43: 1057–1074.

Rieder, R., Economou, T., Wanke, H., Turkevich, A., Crisp, J., Bruckner, J., Dreibus, G., and Mcsween, H.Y., 1997. The chemical composition of Martian soil and rocks returned by the mobile alpha proton X-ray spectrometer: Preliminary results in X-ray mode. *Science*, 278: 1771–1774.

Russell, S.S., Folco, L., Zolensky, M.E., Grady, M.M., Jones, R., Righter, K., Zepfel, J., and Grossman, J.N., 2004. The Meteoritical Bulletin, No. 88, 2004 JULY. *Meteoritics and Planetary Science*, 39(Suppl.): Axxx–Axxx (Provisional).

Shih, C.-Y., Wooden, J.L., Bansal, B.M., Wiesmann, H., Nyquist, L.E., Bogard, D.D., and Mckay, G.A., 1982. Chronology and petrogenesis of young achondrites, Shergotty, Zagami, and ALHA77005—Late magmatism on a geologically active planet. *Geochim. Cosmochim. Acta*, 46: 2323–2344.

Stöffler, D., Keil, K.S., and Scott, E.R.D., 1991. Shock metamorphism of ordinary chondrites. *Geochim. Cosmochim. Acta*, 55: 3845–3867.

Wlotzka F., 1993. A weathering scale for the ordinary chondrites. *Meteoritics*, 28: 460.

Wright, I.P., Carr, R.H., and Pillinger, C.T., 1986. Carbon abundance and isotopic studies of Shergotty and other shergottite meteorites. *Geochim. Cosmochim. Acta*, 50: 983–991.