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Grove Mountains (GRV) 024237: A new ureilite from Antarctica

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Abstract Ureilites share the characteristics of differentiated meteorites and of primary chondrites. GRV 024237 is a ureilite, which was found in the 19th Chinese National Antarctic Research Expedition (CHINARE), at the No. 4 moraine, Grove Mountains, Antarctica. GRV 024237 consists mainly of coarse-grained olivine (60 vol%), pigeonite (30 vol%) and opaque minerals (10 vol%). Tri-junction texture between olivine and pigeonite is common. Carbonaceous materials with minor amounts of troilite and nickel-iron metal were observed as interstitial phases. The *F*a value of olivine composition varies from 6.2 to 16.8 from rim to core, but pyroxene is homogeneous in composition, with *F*s 14.0 to 15.5. Both olivine and pyroxene have normal extinctions. Net-like iron or limonite veins filled in the fractures of olivine and pyroxene, and no diamond was observed. Based on petrographic and mineralogical features, GRV 024237 is a Type I and Group 2 monomict ureilite.

Keywords **Antarctic meteorite, ureilite, petrology, chemical composition, classification**

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0 Introduction

Ureilite is one of the most important types of achondrites. Thus far, more than 100 meteorites of ureilite have been found. Their origin is still a controversial issue. In the literature, two genetic models have been proposed[1]. The first is the igneous category, including the multi-stages igneous cumulate model[2], the partially-disruptive impact model[3], and the explosive volcanism model[4]. The second is the primitive category, including the planetesimal scale collision model[5], the nebular sedimentation model, the impact melt model[6], and the unified primitive meteorite model[7]. However, no model is complete enough to interpret the formation process of ureilite.

In recent years, many ureilites have been found in hot and cold deserts. These samples will provide more information on the formation and evolution of the solar system. In the Chinese collection of nearly 10 000 Antarctic meteorites, 9 ureilites have been identified, and all of them are monomict ureilites[8-12]. In this study, we report the petrologic and mineralogical features of a new ureilite, GRV 024237, found at the No. 4 moraine, Grove Mountains, Antarctica.

1 Sample and experiments

The GRV 024237 sample was supplied by the Polar Research Institute of China. Thin sections were made at the Guangzhou Institute of Geochemistry, Chinese Academy of Sciences and Guilin University of Technology. The apparent size was 5 mm × 7 mm in the section plane.

The petrography of the sample was observed with an optical microscope. The microstructure was observed using

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a FEI Quanta 400 secondary electron microscope (SEM). Chemical compositions of minerals were determined using a JEOL 8100 electron probe X-ray microanalyzer (EPMA) at Guangzhou Institute of Geochemistry. Quantitative analyses of silicates and oxides were conducted with a 15 keV accelerating voltage and a 20 nA beam current. The data were corrected by the ZAF procedure.

2 Results

2.1 Petrography

1.14 g specimen of GRV 024237 was spherical (Figure 1a), and 14 mm × 9 mm in size. No fusion crust was observed. This meteorite had a typical igneous granular structure, and no chondrules or chondrule fragments were observed. This meteorite consisted of coarse-grained olivine (60 vol%), pyroxene (30 vol%), and matrix (10 vol%). The olivine and pyroxene were subhedral in shape, with interstitial spaces filled with black carbonaceous material and trace amounts of nickel-iron metal, micro-silicate, and limonite (Figure 1b). The fractures in olivine and pyroxene were filled with limonite (Figure 1b). Most olivines and pyroxenes showed normal extinction. These characteristics indicate that this meteorite was not heavily shocked. Pyroxene in GRV 024237 showed perfect cleavages and twinning textures (Figure 1c). The sizes of olivine and pyroxene grains ranged from 0.5 mm to 1 mm, and 120° junctions among them were common (Figure 1d). Most carbonaceous particles were irregular and their diameters were less than 5 μm. Olivine grains were usually zoned, with the rim darker than the core in BSE images. It was estimated that the maximum width of the dark zone was about 100 μm.

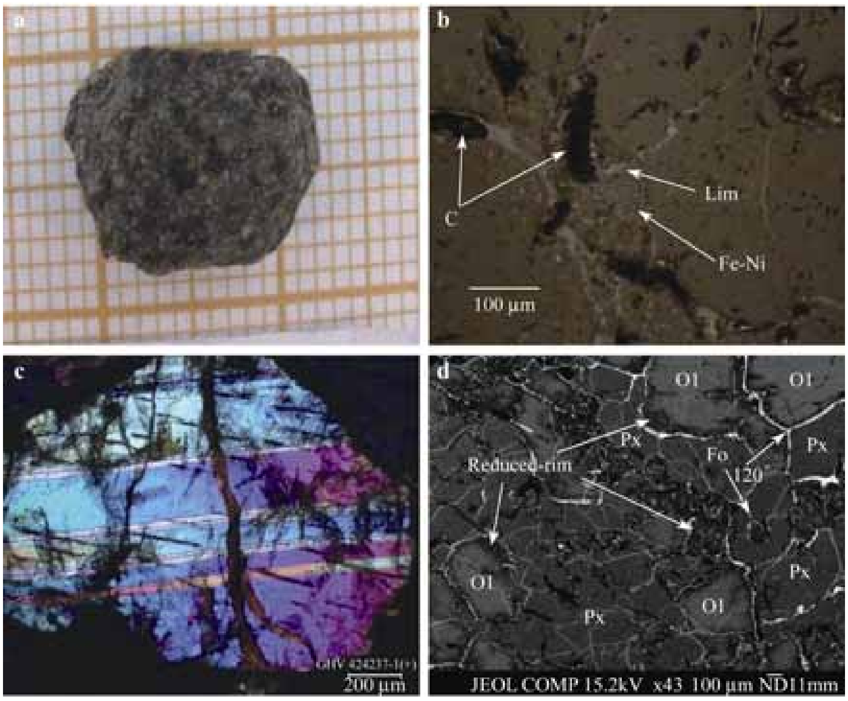

Figure 1 Petrology image of GRV 024237. **a,** The specimen is spherical in shape, and without fusion crust. **b,** Optical image in SEM. Opaque phases in thin section. **c,** Cross-polarized microphotograph of pyroxene showing polysynthetic twins. **d,** BSE image of GRV 024237. 120° junctions were common. Olivine grains had reverse zonation, with dark zones in olivine grains comprising Mg-rich reduced-rims. Ol—olivine; Px—pyroxene; Fo—forsterite; C—carbonaceous material; Fe-Ni—Fe-Ni metal; Lm—limonite.

2.2 Mineral chemistry

Table 1 lists compositions of olivine and pyroxene in GRV 024237. Olivine showed concentric zoning from core to rim, with the *F*a component varying from 16.8 to 6.2. The average value of *F*a component in olivine was 12.0. Olivine had high contents of Cr_2O_3 (<0.9 wt%) and CaO (~0.4 wt%). Pyroxene in GRV 024237 was pigeonite and homogeneous in chemical composition ($En_{73.9-77.4}$ $Fs_{14.0-15.5}$ $Wo_{8.6-10.6}$).

The matrix consisted mainly of carbonaceous material and minor Fe-Ni metal, limonite, and silicate. The carbonaceous particles could be graphite, based on their shapes. The matrix silicate was fine-grained olivine and pyroxene, which had high Fe content compared to coarse grains. The fine-grained pyroxenes included pigeonite and augite.

3 Discussion

3.1 Classification

The FeO content in olivine decreased from core to rim, and the CaO content in the core was slightly lower than that at the rim (Figure 2a). Cr_2O_3 and MnO were homogeneous. The component plots of Fe/Mg-Fe/Mn and Fe/Mg-Fe/Cr (Figure 3) showed good linear trends. The variation in FeO

Table 1 Compositions of olivine and pyroxene in GRV 024237, analyzed by EMPA

Element	Olivine(average) /(wt%)					Pigeonite(average) /(wt%)
	No.1	No.2	No.3	No.4	No.5	
SiO_2	40.4±0.5	40.3±0.2	40.5±0.7	40.4±0.5	40.1±0.6	54.8±0.5
TiO_2	bdl.	bdl.	bdl.	bdl.	bdl.	0.08
Al_2O_3	⩽0.06	⩽0.03	⩽0.04	⩽0.03	⩽0.04	0.65±0.01
Cr_2O_3	0.65±0.07	0.70±0.06	0.62±0.07	0.65±0.05	0.71±0.08	1.1±0.1
FeO	12.3±2.8	10.0±1.7	10.7±3.1	11.5±3.3	12.3±2.9	9.7±0.4
MnO	0.43±0.04	0.49±0.03	0.44±0.04	0.47±0.04	0.45±0.05	0.40±0.05
MgO	45.9±2.2	47.4±1.3	47.2±2.7	46.4±2.5	45.9±2.2	27.7±0.2
CaO	0.31±0.06	0.36±0.05	0.33±0.06	0.33±0.06	0.36±0.02	4.5±0.1
Na_2O	⩽0.06	⩽0.04	⩽0.07	⩽0.04	⩽0.05	0.09
K_2O	bdl.	⩽0.04	⩽0.03	⩽0.03	⩽0.04	bdl.
NiO	⩽0.04	⩽0.04	⩽0.06	⩽0.03	⩽0.04	0.06
Total	100.1	99.3	99.9	99.8	99.9	99.1
Fa/*Fs*	7.8-16.0	8.2-12.9	6.2-14.9	6.4-16.5	9.3-16.8	14.9±0.5

Notes: Five olivine grains (No.1-5) were analyzed; oxide contents are average values, and the data for *F*a constitute the ranges from core to rim. The notation 'bdl' indicates below detection limit.

is related to the amount of carbon reduction at the rims of olivine or pigeonite grains with interstitial material[13].

$$Fe_2SiO_4+Mg_2SiO_4+2C=2Fe+2CO+SiO_2+Mg_2SiO_4 \quad (1)$$

This equation can explain reasonably the formation of the reduced forsterite.

The contents of CaO, Cr_2O_3, FeO and MnO in pyroxene were homogeneous (Figure 2b), in contrast to the trends observed for olivine. The homogeneous compositions of pyroxene indicate that GRV 024237 has not suffered heavy reduction.

Based on the presence of clasts, ureilites can be classified into monomict ureilite and polymict ureilite[13]. Monomict ureilite contains no breccias, but polymict ureilite contains several kinds of breccias. Furthermore, monomict ureilites can be further subdivided by texture into two main types: "typical" and "poikilitic" mono-clast ureilites. The "typical" ureilite texture is characterized by large olivine and pigeonite grains, which meet in triple junctions. In this manner, GRV 024237 can be further characterized as a typical monomict ureilite.

By their structure and other signs reflecting the strength of impact, Vdovykin[14] classified ureilites into two types: Type I and Type II. Type I has bigger mineral crystals, clearer clinopyroxene twinning, and smaller graphite or diamond grain sizes than Type II. There are net-like iron veins in Type I ureilites. However, there are only iron plates between silicate grains in Type II ureilites. The Type I ureilites have experienced a less intensive impact than those in Type II. GRV 024237 has normal extinction and clear twinning, no diamond, small grains of carbonaceous and net-like iron or limonite veins (Figure 1b, 1d). Based on this model, GRV 024237 can be classified as a Type I ureilite.

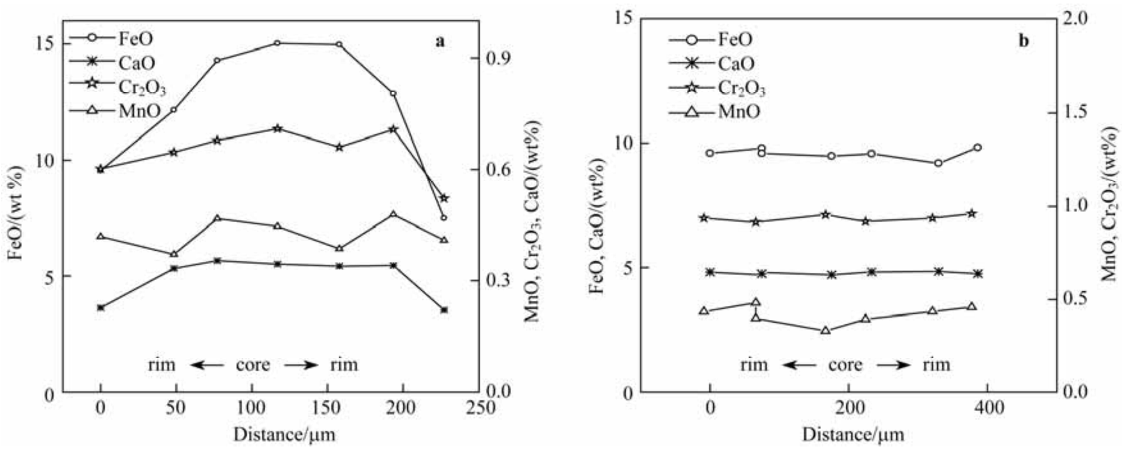

Figure 2 Variation of composition in olivine and pigeonite of GRV 024237.

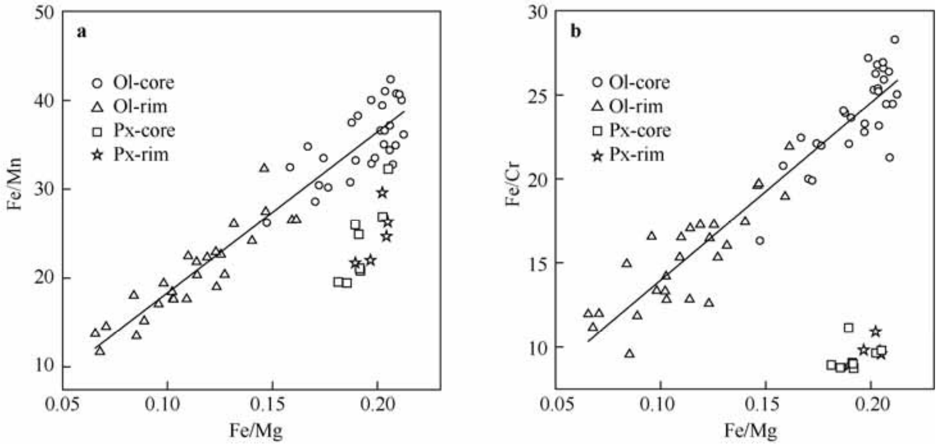

Figure 3 Plot of Fe/Mn-Fe/Mg and Fe/Cr-Fe/Mg for olivine and pigeonite in GRV 024237.

Based on the igneous cumulate theory, Berkley et al.[15] proposed a ureilite classification by mineral chemistry. His method has been accepted by most meteoriticists. Thus, petrological characteristics are ignored, and instead the relationship between FeO and MgO in coexisting olivine or pigeonite is acknowledged. Based on molar FeO/MgO in olivine, ureilites can be divided into three groups. Group 1 has high FeO/MgO ($Fo_{78.6\text{-}79.3}/Fa_{20.7\text{-}21.4}$) ratios, Group 2 has moderate FeO/MgO ($Fo_{83.6\text{-}85.1}/Fa_{14.9\text{-}16.4}$) ratios and Group 3 has low FeO/MgO ($Fo_{91.4}/Fa_{8.6}$) ratios. Therefore, GRV 024237 is classified into Group 2 with moderate FeO/MgO ($Fo_{84.8}/Fa_{15.2}$) (Figure 4).

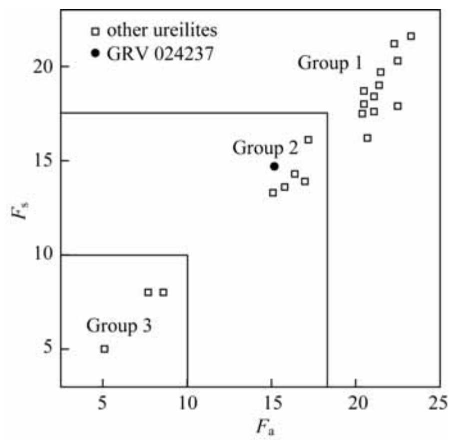

Figure 4 Subdivision of ureilites (From Berkley and Keil[15]). Other ureilites in this figure are from Miao et al.[12], Treiman and Berkley[16], Berkley et al.[17], Berkley[18], Goodrich and Jones[2], and Singletary and Grove[19].

4 Conclusions

In this study, we analyzed the GRV 024237 meteorite, and classified it as a ureilite. Through observing petrographic features and measuring its composition, we further divided it based on mineral-petrological characteristics[13]. Hence, the meteorite is a typical monomict ureilite. Using Berkley's model[15], the meteorite belongs to Group 2, with $Fo_{84.8}/Fa_{15.2}$. According to Vodvykin's model[14], the meteorite may be classified as a Type I ureilite.

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