CHEN Hongyi, MIAO Bingkui, XIE Lanfang and SHAO Huimin, 2017. Siderophile Element Compositions of Pyroxenes in HED Meteorites: Implications for the Differentiation of Magma Ocean on Vesta. *Acta Geologica Sinica* (English Edition), 91(supp. 1): 267-268.

Siderophile Element Compositions of Pyroxenes in HED Meteorites: Implications for the Differentiation of Magma Ocean on Vesta

CHEN Hongyi[1,2,3] , MIAO Bingkui[1, 2,3 *], XIE Lanfang[1] and SHAO Huimin[1]

1 Guangxi Key University's Laboratory of Planetary Geological Evolution, Guilin University of Technology, Guilin 541004, China
2 Guangxi Key Laboratory of Hidden Metallic Ore Deposits Exploration, Guilin University of Technology, Guilin 541004, China
3 Guangxi Scientific Experiment Center of Mining, Metallurgy and Environment, Guilin University of Technology, Guilin 541004, China

1 Introduction

The howardite, eucrite and diogenite (HED) meteorites are ultramafic and mafic igneous rocks and impact-engendered breccias derived from a thoroughly differentiated asteroid 4 Vesta. Diogenites include dunites, harzburgites and norites in addition to the traditional orthopyroxenites. Eucrites include cumulated gabbroic rocks, basaltic rocks, and mixtures of them or with less than 10 % diogenites. Howardites are regolith breccias formed by impact mixing between diogenites and eucrites (Mittlefehldt, 2015). Evidence from oxygen isotope compositions (Greenwood, et.al.,2014) and siderophile element contents favor a model of extensive melting of Vesta forming a global magma ocean that rapidly segregated and crystallized to yield a metallic core, olivine-rich mantle, orthopyroxene-rich lower crust and basaltic upper crust(Shearer, et.al.,2010).

Siderophile elements are at low to very low abundancesin HED igneous lithologies, and are generally highest in the polymict breccias. Chondritic debris is found even in monomict breccias (Mittlefehldt, 1994), and for this reason, the siderophile element contents of HED igneous lithologies need to be evaluated cautiously. So we selected unbrecciated igneous rock types to study. For the most part, the ranges in siderophile element contents of basaltic eucrites, cumulate eucrites and diogenites likely reflect those of pristine igneous lithologies and the progress of magmatic evolution, while the pyroxenes are main minerals in diogenites and eucrites.

This article mainly describes the siderophile element compositions of pyroxenes in eucrites and diogenites, then discusses the magmatic evolution in HED groups' parent body — 4-asteroids Vesta.

2 Samples and Analytical Methods

We selected five samples which came from unwatered desert regions of Northwest Africa. These samples include a diogenite NWA 7831, a cumulated eucrite M16015 and three basaltic eucrites are respectively Tirhert, M16019 and M16020. Of them, Tirhert meteorite is the observed fall in 2014 in Morocco, and Others are find meteorites.

Quantitative chemical compositions of minerals were acquired on a JEOL JXA-8230 electron probe micro analyzer (EPMA) at Guilin University of Technology. Analyses were run at 15 keV and a sample current of 20 nA, with a focused beam and count durations of 15 s. Trace element compositions were acquired using an Agilent 7500cx inductively coupled plasma mass spectrometer (ICP-MS) combined with an NWR-193 nm Laser Ablation system (LA) at the same university.

3 Result

3.1 Petrographic description

NWA7831 is an orthopyroxenite diogenite and composed almost entirely of translucent, yellow-green orthopyroxene with very sparse, tiny included grains of troilite, chromite, anorthite, silica polymorph and clinopyroxene. Orthopyroxene grain size up to about 2 cm. M16015 is a cumulated eucrite and composed of 65% othorpyroxene, 30% plagiocalse and 5% other minerals of chromite, ilmenite, silica polymorph and so on. Tirhert is a basaltic eucrite shows texturally poikilitic with many triple junctions. Pyroxenes show exsolution lamellae. Plagioclase and pyroxene grain size up to about 2 mm. Silica, ilmenite, chromite and troilite present. M16019 and M16020 are basaltic eucrites show texturally granoblastic to poikilitic pyroxene and plagioclase. Pyroxenes show intense exsolution lamellae.

3.2 Mineral compositions

The Mg# of pyroxenes progressively decreases from the diogenites NWA7831 (69.0), and cumulated eucrites M16015 (63.2) to basaltic eucrites Tirhert (35.8), M16019 (39.2) and M16020 (37.0) with the average values rises of FeO of pyroxenes are respectively 17.9%, equilibrated pyroxene and plagioclase, granoblastic to

17.7%, 31.1%, 29.2%, 29.3% (Table 1).

Cobalt is a moderately siderophile element and analytical igneous lithologies show ranges in Co contents from 1.3 μg/g to 8.7 μg/g and up to 41.5 μg/g for cumulated eucrite M16015. Nickel contents from 0.1 μg/g to 3.3 μg/g and up to 40.2 μg/g for cumulated eucrite. Titanium, vanadium, chrome and manganese contents share a same variation tendency with cobalt and nickel. But M16019 sample shows lowest contents for analytical elements. The siderophile elements contents in different samples of basaltic eucrites are different, perhaps they came from different magmatic enviroments.

Table 1 Mineral chemical compositions and siderophile element contents of pyroxenes in HED meteorites

Samples	FeO (%)	Ti	V	Cr	Mn	Co	Ni	Fs	Wo	Mg#
NWA7831	17.9	683.2	105.3	3107.0	4336.9	8.7	2.0	29.8	3.77	69.0
M16015	17.7	4379.2	262.4	7560.8	14200.6	41.5	40.2	35.9	2.50	63.2
Tirhert	31.1	3999.4	120.6	4543.9	4480.7	5.1	0.1	60.2	6.27	35.8
M16019	29.2	681.4	32.2	392.4	2777.5	4.4	3.3	59.1	2.87	39.2
M16020	29.3	1663.8	44.3	581.8	5191.0	1.3	2.6	60.0	4.75	37.0

Note: units of Ti, V, Cr, Mn, Co and Ni elements are ppm. Fs=Fe×100/(Fe+Mg+Ca), Wo = Ca×100/(Fe+Mg+Ca), Mg#=Mg×100/(Fe+Mg). We selected Low-Ca pyroxenes to calculated average values of mineral chemical composition and more than 20 analytical points.

4 Discuss

Abundance of the moderately siderophile elements (Ti, V, Cr, Co, Ni and Mn) in this analytical samples and other HED meteorites (Righter,et.al.,1997) indicate that the parent body 4 asteroid Vesta have been completed molten during its early history. During cooling of a chondritic composition magma ocean, equilibrium crystallization is fostered by the suspension of crystal in a convecting magma ocean. The diogenite orthopyroxenites firstly crystallized after the dunites mantle formed, and then the cummulated eucrites crystallized, the Mg# of the residual magma declined and siderophile elements contents elevated. At last iron-rich basaltic magma intruded or erupted.

Acknowledgements

This work is funded by the National Natural Science Foundation of China (Grant No. 41173077) , Chinese science and technology basic conditions platform project of Ministry of Science and Technology (2005DKA21406-9) and Science and technology plan projects in guangxi(AD16450001). We greatly acknowledge Mr. MIAO Bing-an for his providing the samples of this work.

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