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Solubility relations of $(Mg,Fe)SiO_3$ and $CaSiO_3$ perovskites

Kiyoshi FUJINO*[1], Yohei SASAKI[1], Reki ODAWARA[1], Hiroyuki IZUMI[1], Kaushik DAS[1], Naotaka TOMIOKA[2], Ichiro OHNISHI[2], Nagayoshi SATA[3], Takehiko YAGI[3]
[1]Division of Earth and Planetary Sciences, Hokkaido Univ., Sapporo 060-0810, Japan
[2]Department of Earth and Planetary Sciences, Kobe Univ., Kobe 657-8501, Japan
[3]Institute for Solid States Physics, The Univ. of Tokyo, Kashiwa 277-8581, Japan

Introduction

$(Mg,Fe)SiO_3$ and $CaSiO_3$ perovskites are considered to be major constituent minerals of the lower mantle. Mutual solubilities between these two perovskites affect the mineral composition and physical properties of the lower mantle. However, solubility relations of both perovskites under the deep lower mantle conditions are not clear [1].

To clarify these points, laser-heated diamond anvil cell (DAC) experiments of the system $CaMgSi_2O_6$ (Di) - $CaFeSi_2O_6$ (Hd) under the lower mantle conditions combined with analytical electron microscopy (ATEM) of the recovered samples were conducted.

Experimental

Laser-heated DAC experiments were performed at 30-80 GPa, 1700-2200 K using natural and synthetic $Ca(Mg,Fe)Si_2O_6$ pyroxenes and gels as starting materials.

Synchrotron X-ray powder diffraction experiments of the run products were performed at BL-18C or BL-13A at KEK. X-ray diffraction patterns of the run products at high pressures and at atmospheric pressure were collected on an imaging plate detector with the incident beam monochromatized to 20 keV (BL-18C) or 30 keV (BL-13A) and collimated to 15 - 40 µm.

The recovered samples were Ar-ion thinned or sectioned by an ultramicrotome into ATEM foils. Transmission electron images, selected area electron diffraction patterns and chemical compositions of the product phases were obtained using a 200 kV ATEM (JEOL JEM-2010) attached with an energy-dispersive analytical system.

Results and Discussion

The synchrotron X-ray diffraction patterns of the recovered run products combined with ATEM observations revealed the following high pressure phase relations of this system at around 30 GPa and 1700-2200 K. The coexisting phases are $(Mg,Fe)SiO_3$ perovakite ((Mg,Fe)-Pv) + $CaSiO_3$ perovskite (Ca-Pv) for $Di_{100}Hd_0$-$Di_{89}Hd_{11}$, (Mg,Fe)-Pv + Ca-Pv + magnesiowustite + stishovite for $Di_{89}Hd_{11}$-$Di_{45}Hd_{55}$ and Ca-Pv + magnesiowustite + stishovite for $Di_{45}Hd_{55}$-Di_0Hd_{100}. The phase relations at around 70 GPa do not seem to differ much from those described above, although they are not yet fully analyzed.

Table 1 shows the compositions of (Mg,Fe)-Pv and Ca-Pv phases of the recovered samples analyzed by ATEM. For the iron-free sample (A-13) at about 30 GPa, the Ca content in $MgSiO_3$ perovskite is around 1 mole %, and it remained nearly the same with incresing the iron content or pressure. Meanwhile, the Mg content in $CaSiO_3$ perovskite in A-13 is around 4 mole%, a little higher than the Ca solubility in $MgSiO_3$ perovskite. But the (Mg,Fe) content in $CaSiO_3$ perovskite significantly increases to nearly 18 mole% with incresing the iron content at 30 GPa (A-06), and it further increases to nearly 34 mole% at 78 GPa (C-05). The interesting point is that nearly the same amounts of Mg and Fe enter into $CaSiO_3$ perovskite in the iron containing circumstances.

Above results indicate that both $(Mg,Fe)SiO_3$ and $CaSiO_3$ perovskites can survive into the deeper part of the lower mantle, considering the small amount of $CaSiO_3$ perovskite compared to the large amount of $(Mg,Fe)SiO_3$ perovskite in the lower mantle.

References

[1] T. Irifune et al., Geophys. Res. Lett., 27, 3541 (2000).

*fujino@ep.sci.hokudai.ac.jp

Table 1. Compositions of $(Mg,Fe)SiO_3$ and $CaSiO_3$ perovskites analyzed by ATEM

Run No.	A-13	B-02	C-01	A-13	A-06	C-05
Starting compo.	$Di_{100}Hd_0$	$Di_{75}Hd_{25}$	$Di_{100}Hd_0$	$Di_{100}Hd_0$	$Di_{50}Hd_{50}$	$Di_{100}Hd_0$
Phase	Mg-Pv	Mg-Pv	Mg-Pv	Ca-Pv	Ca-Pv	Ca-Pv
Pressure (GPa)	29.7	31.5	60.0	29.7	29.5	78.0
Cation Number (O=3)						
Mg	0.958	0.828	0.889	0.036	0.092	0.182
Si	1.021	1.038	1.049	1.059	1.040	0.986
Ca	0.009	0.003	0.013	0.847	0.741	0.689
Fe	-	0.094	-	-	0.087	0.158
Total	1.988	1.963	1.951	1.942	1.960	2.015

Mg-Pv = $(Mg,Fe)SiO_3$ perovskite, Ca-Pv = $CaSiO_3$ perovskite