

Oral presentation | R3: High-pressure science and deep Earth's material

📅 Thu. Sep 16, 2021 2:00 PM - 3:00 PM JST | Thu. Sep 16, 2021 5:00 AM - 6:00 AM UTC | 🖥 Zoom

Session 1

R3: High-pressure science and deep Earth's material

Chairperson: Takaaki Kawazoe (Hiroshima University)

[Chairperson]

Takaaki Kawazoe: R3-11 - R3-14

2:00 PM - 2:15 PM JST | 5:00 AM - 5:15 AM UTC

[R3-11] Back-transformation kinetics in high-pressure minerals

*Tomoaki Kubo¹, Ko Kamura¹, Masahiro Imamura¹, Yoshinori Tange², Yuji Higo², Masaaki Miyahara³ (1. Kyushu Univ., 2. JASRI, 3. Hiroshima Univ.)

2:15 PM - 2:30 PM JST | 5:15 AM - 5:30 AM UTC

[R3-12] Possible compositional area of Al bearing anhydrous bridgmanite at the uppermost lower mantle condition

*Masamichi NODA¹, Toru INOUE², Sho KAKIZAWA², Takaaki KAWAZOE², Toru SHINMEI³, Tetsuo IRIFUNE³, Koji OHARA⁴ (1. Hiroshima Uni. Sci., 2. Hiroshima Univ. Adv. Sci. Eng., 3. Ehime Univ. GRC, 4. JASRI)

2:30 PM - 2:45 PM JST | 5:30 AM - 5:45 AM UTC

[R3-13] Density deficit of Earth's inner core revealed by a multi-megabar rhenium pressure scale

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2:45 PM - 3:00 PM JST | 5:45 AM - 6:00 AM UTC

[R3-14] The electrical conductivity of $(\text{FeO})_m(\text{Fe}_2\text{O}_3)_n$ iron oxides at high pressure

[Presentation award entry]

*Shuhou Maitani¹, Ryosuke Sinmyo¹, Takayuki Ishii², Saori Kawaguchi³ (1. Meiji Uni. Sci, 2. BGI/HPSTAR, 3. JASRI)

高圧鉱物の逆相転移カイネティクス

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Back-transformation kinetics in high-pressure minerals

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High-pressure minerals stable at deep mantle pressures have been naturally found on Earth such as shocked meteorites and diamond inclusions, which provides important constraints on detailed processes of planetary collisions and deep mantle dynamics. Because the timescales are limited in these dynamic processes, the reactions often remain incomplete and/or metastable state. Additionally, it is necessary to consider the possibility of the backward reactions to the low-pressure phases. The kinetics on the forward reactions have been widely discussed for this topic, however those on the backward reaction had been very limited so far. Here we present some experimental results on mechanisms and kinetics of the back-transformation.

A conventional method combining MA-type high-pressure apparatus with synchrotron white X-ray (MAX-80@PF-AR NE-5C, SPEED Mk.II@SP8 BL04B1) was used to observe back-transformation behaviors and their kinetics at 0-10 GPa and 300-900°C by collecting XRD data every 10-200 sec. The starting materials are polycrystalline ringwoodite (Rw), bridgmanite (Brg), and lingunite (Lgn), those were synthesized by using another MA press (QDES) at Kyushu Univ. in advance.

Time-resolved XRD measurements have revealed that, in contrast to Rw that simply transforms to the low-pressure polymorph olivine (Ol), Brg and Lgn do not directly transform to their low-pressure phases, but through the amorphous state. In Brg, the amorphization temperature rapidly increases with pressures from 300°C at 1 GPa to 800°C at 7 GPa, whereas the crystallization temperature does not. As a result, Brg directly back-transformed to high-pressure clinoenstatite (HP-CEn) at around 800°C and 8 GPa. Analysis of kinetic data on the back-transformation in Rw and Brg by the Avrami rate equation suggested the rapid nucleation in Rw to Ol and Brg to HP-CEn transformation, and slow nucleation in the crystallization of Opx from amorphous Brg. The amorphization kinetics of Brg is too fast to be constrained by the present kinetic data. On the basis of P and T dependencies of these reaction rates, we can construct P-T-t kinetic boundaries for survival of high-P phases and formation of low-P phases in a given timescale. For example, in the timescales of 0.1 to 10 sec generally considered for shock events in the early solar system (Fig. 1), Rw transforms to Ol at 700-900°C and 800-1000°C at ~1 GPa and ~10 GPa, respectively. Brg is thought to become amorphous state when decompression less than 800°C. At higher than 800°C, Brg rapidly transforms to HP-CEn, and then low-pressure CEn (LP-CEn).

Both high-pressure and low-pressure phases are enigmatically present in shocked meteorites and diamond inclusions. To precisely understand their P-T-t histories, not only the forward, but also the backward reaction kinetics shown here need to be considered.

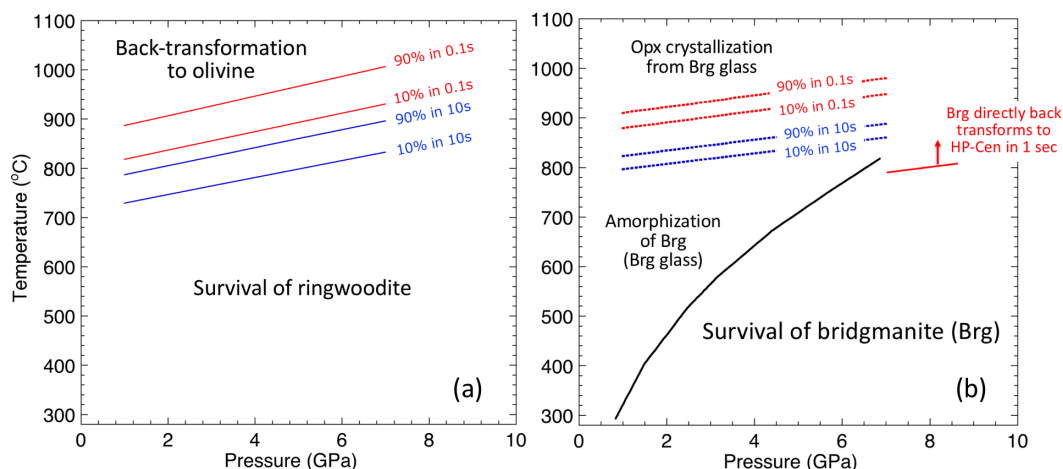


Fig. 1 P-T-t kinetic boundaries for the back-transformation in ringwoodite (a) and bridgmanite (b) estimated from the experimentally obtained kinetic data.

Keywords: high-pressure mineral, back-transformation, kinetics, shocked meteorite, diamond inclusion

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下部マントル最上部条件における Al を含む無水ブリッジマナイトの存在可能領域

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Possible compositional area of Al bearing anhydrous bridgmanite at the uppermost lower mantle condition

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Al は地球を構成する主要元素の 1 つであり、パイロライト組成では Al のほとんどは下部マントルでブリッジマナイト (Brg) 中に固溶する。現在 Brg 中への Al の置換様式には、チェルマック置換型と酸素欠損置換型、含水置換型の 3 種類が存在すると考えられている。先行研究で報告されている Brg の化学組成を注意深く観察すると、純粋なチェルマック置換型はほとんど報告されておらず、また純粋な酸素欠損型の報告はなかった(例えば Irifune et al., 1996, Kubo & Akaogi, 2000; Kojitani et al., 2007)。先行研究では出発物質として粉末試料や粉砕ガラスを用い、また試料をカプセルで封入しないケースもあり、出発物質の表面吸着水の付着および周囲からの水の流入の可能性があった。

これまでに我々は無水 Brg の低 Al 量での置換様式を明らかにするため、出発物質としてガラスの塊を用いて限りなく無水条件下で高温高压実験を行った。出発物質は理想的な置換様式を想定し、4 つの異なる Al 量をもつ試料を用意した。高压実験には愛媛大学 GRC 設置の川井型マルチアンビル高压発生装置 (ORANGE-3000) を用いて、下部マントル最上部条件を想定し、28 GPa、1600-1700°C で 1 時間保持後、急冷回収した。限りなく無水条件下で試料合成したため結晶径がサブミ

クロンとなり、EPMA を用いて個々の Brg の化学組成測定が不可能であった。したがって XRD 分析結果とバルク組成から Brg の化学組成を見積もった。その結果、初めて単相の酸素欠損置換型 Brg (Al=0.025 pfu, 総カチオン 2) の合成に成功し、また Al 量によらず純粋なチェルマック置換型 Brg が存在する可能性を確認した。しかしながら、酸素欠損置換型の場合、Al > 0.025 pfu 領域では極少量の共存相の同定が困難で Brg の化学組成を正確に推定できなかった。

本研究では、酸素欠損置換型無水 Brg の Al > 0.025 pfu 領域での置換様式を明らかにするため、加熱保持時間を 1 時間から 100 時間に変えて広島大学及び愛媛大学設置の超高压発生装置を用いて行った。そして Brg を粒成長させることにより、個々の Brg の定量分析を試みた。結果、MgO 飽和条件下における Al > 0.025 pfu 領域での無水 Brg の存在可能領域が明らかとなった。

References

- [1] Irifune et al. (1996) Phys. Earth Planet. Inter., 96, 147-157.
- [2] Kubo and Akaogi (2000) Phys. Earth Planet. Inter., 121, 85-102.
- [3] Kojitani et al. (2007) Phys. Chem. Minerals, 34, 257-267.

Keywords: Al bearing bridgmanite, extremely anhydrous condition, the uppermost lower mantle

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Density deficit of Earth's inner core revealed by a multi-megabar rhenium pressure scale

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Precise information about the composition of the Earth's core is critical to understand planetary evolution and for discussing geodynamic behaviors, such as the core-mantle boundary heat flow. Our knowledge on the Earth's core is based on comparison of laboratory measurements with seismological observations, informed by meteorite composition, and indications of the Earth's core temperature. One of the most interesting results of such work has been the suggestion that Earth's inner core must contain light elements because the density of the core, as determined from seismological measurements, is lower than the density of pure iron, its main constituent, as determined from laboratory measurements and/or theoretical work: the density deficit of the inner core has been considered ~4%. However, this conclusion relies critically on an accurate pressure scale to relate laboratory generated pressures to geological pressures. Establishing such a scale has been the subject of intensive research but still involves significant extrapolation and approximations, especially at higher pressures of the Earth's core. Further, a pressure scale to the multi-megabar pressures is indispensable for discussing super-Earth planets. We report here the first primary pressure scale extending to the multi-megabar pressures of Earth's core by measuring acoustic phonon velocities using inelastic X-ray scattering from a rhenium sample in a diamond anvil cell. Our new pressure scale agrees with previous primary scales at lower pressures and also shock compression experiments, but it is lower than previous secondary and theoretical scales at Earth's core pressures: previous scales have overestimated laboratory pressures by at least 20% at 230GPa. Our new scale suggests the density deficit of the inner core is ~9%, doubling the light-element content of the inner core.

Keywords: primary pressure scale, high pressure, Earth's core, density deficit, inelastic x-ray scattering.

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(FeO)_m(Fe₂O₃)_n 酸化鉄の高圧力下電気伝導度

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The electrical conductivity of (FeO)_m(Fe₂O₃)_n iron oxides at high pressure

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鉄はマントル内で3番目に多い陽イオン元素であり、価数が容易に変化する元素としては地球で最も豊富な元素である。酸化鉄は最も単純な含鉄鉱物であり、その高圧力下における安定性や物理的性質は、マントル内部の構造や酸化還元状態を議論するために長い間研究され続けている。大気圧下ではFeO, Fe₃O₄, Fe₂O₃のストイキオメトリーを持つ酸化鉄のみが安定であるが、近年の高圧力実験から、(FeO)_m(Fe₂O₃)_n であらわされる新しい酸化鉄グループがマントル条件で安定となることが明らかになった。ダイヤモンド包有物中に、これらの酸化鉄がマントル内に存在していた痕跡も報告されている。しかし、これらの新しい酸化鉄相の安定性と物理的性質は、未だよくわかっていない。今回、私たちはダイヤモンドアンビルセルを用いFe₄O₅, Fe₅O₆, Fe₇O₉の電気伝導度を60 GPaまで常温・低温下で測定した。常温高圧力下の測定結果から、全ての相において40 GPa付近に電気伝導度の変曲点がみられた。これは

先行研究で示唆された、高スピン低スピントロスオーバーがおこる圧力と一致している。得られた結果から、マントルに相当する温度圧力条件下での(FeO)_m(Fe₂O₃)_nの電気伝導度を推定した。発表ではマントル内に観測される電気伝導度異常と高圧酸化鉄相の関係を議論する。