MELTING AND SUBSOLIDUS PHASE RELATION OF MANTLE PERIDOTITE UP TO 25 GPa

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Melting phase relations and subsolidus mineral paragenesis of fertile peridotite (KLB-1 and PHN-1611) were studied in the pressure range 1 atm to 25 GPa (250 kilobars). The main scope of the present study is two-fold. First is to clarify mineralogy and chemistry of the Earth's deep interior. Second is to study the origin of mantle peridotite, a question to ask from what source material and by what processes the peridotitic nature of the Earth's upper mantle has been established in its early history.

The starting materials are; KLB-1, a fertile spinel lherzolite xenolith with Mg*=89 from the Kilborne Hole Crater, New Mexico, U.S.A. (Takahashi, 1986), and PHN-1611, a sheared garnet lherzolite xenolith with Mg*=88 from Thaba Putsoa kimberlite pipe, Lesotho (Nixon & Boyd, 1973; specimen by the courtesy of F.R.Boyd and P.H.Nixon). A 5000 ton uniaxial split-sphere apparatus of Okayama university (USSA-5000) was employed (Fig. 1) in which eight tungsten carbide cubic anvils (32 mm edge length) are simultaneously compressed and a pressure medium of MgO octahedron is put in the geometric center of the tungsten carbide anvils. High-pressure and high-temperature experiments up to 27 GPa and 2000°C are routinely conducted in the USSA-5000 apparatus (Ito et al., 1984). The size of the MgO pressure medium varies as a function of maximum pressure of the experiments; edge length of MgO octahedron is 18 mm up to 8 GPa, 14 mm up to 14 GPa, 10 mm up to 20 GPa, 7 mm up to 24 GPa and 6 mm up to 27 GPa. Cylindrical graphite heater (4.0 mm OD, 3.0 mm ID and 15 mm long) was used in the experiments below 8 GPa and cylindrical LaCrO3 heaters of various size were employed at pressures above 8 GPa.

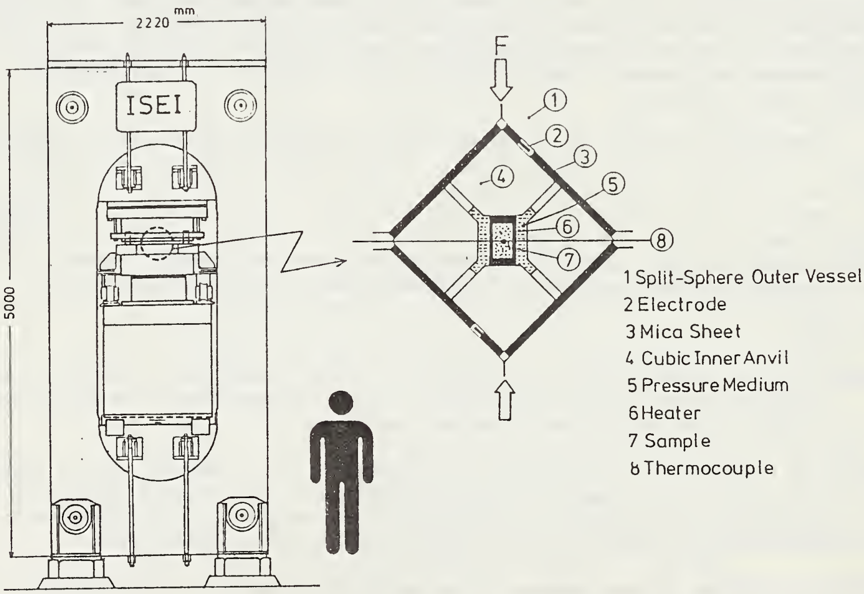
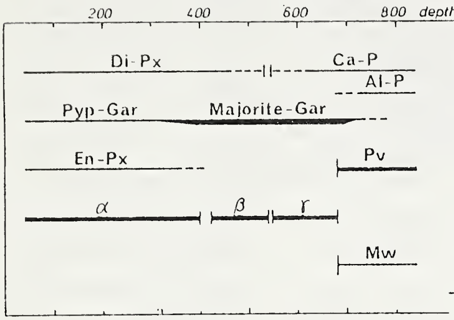


Fig. 1 A whole plan of the uniaxial split-sphere type ultrahigh pressure apparatus (USSA-5000) of Okayama University (left) and a schematic cross-section of the high-pressure vessel with the furnace assembly (right). Eight tungsten carbide cube anvils (32 mm edge length), each with one truncated corner (12 to 1.5 mm edge), are compressed with the aid of the 5000 ton press. After Ito et al.(1984).

Eight subsolidus experiments (60 min long each) were carried out using PHN-1611 along a model adiabatic geotherm beneath the African shield which passes through 1400°C at 200 km depth and 1600°C at 700 km depth. Coexisting phases were identified with X-ray diffractometry and EPMA analysis. Mineral paragenesis in the model mantle is estimated based on these experiments (Fig. 2). In the upper mantle down to 400 km depth, olivine (α-phase), enstatite, diopsidic clinopyroxene and pyropic garnet are the major constituent minerals of peridotite. In the transition layer between 400 and 670 km depth, olivine undergoes successive phase transitions from α to β (modified spinel) and then β to γ (spinel). The amount of majorite component in garnet solid solution increases continuously in the depth range 200 to 500 km (Fig. 3) and eliminates enstatite at about 400 km depth. Diopsidic clinopyroxene survives to about 500 km depth and transforms to an unquenchable phase (Ca-P). In the lower mantle beneath the 670 km discontinuity, magnesian perovskite of $MgSiO_3$ stoichiometry is the dominant constituent phase (Ito et al., 1984). Minor amount of magnesiowustite (Mg*≒75), Ca-P of either diopsidic or wollastonite-like composition and an unknown aluminous phase (Al-P) are also found to be present.



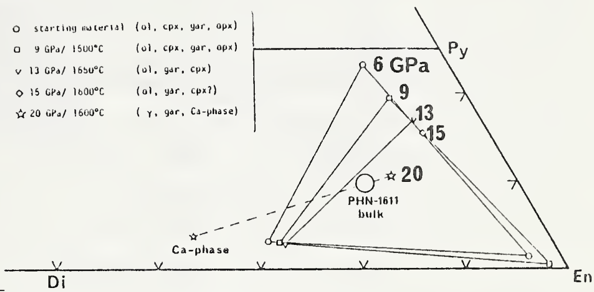


Fig. 2 Mineral paragenesis of mantle peridotite along a model geotherm down to 700 km depth. Dominant phases likely to be present in more than 30 vol% are indicated with heavy lines.

Fig. 3 Composition of garnet and pyroxenes of a peridotite PHN-1611 along a model geotherm. Projection on the plane $(Al_2O_3+Cr_2O_3)-(Mg \cdot Fe \cdot Mn)SiO_3-CaSiO_3$.

Melting phase relations of the mantle peridotite KLB-1 and PHN-1611 were studied in the pressure range from 1 atm to 25 GPa. Phase diagram of KLB-1 up to 14 GPa is shown in Fig. 4 (that of PHN-1611 show similar results). At low pressures, the peridotite has a large melting temperature interval (>600°C at 1 atm), whereas the melting interval contracts to less than about 150°C at 14 GPa due to relatively gentle dT/dP slope of liquidus and relatively steep solidus curve. In the pressure range up to 14 GPa, liquidus phase is olivine of Fo=96±1. The second mineral to crystallize changes successively; enstatite (1 atm to 3 Gpa), pigeonitic clinopyroxene (3 to 7 GPa), garnet of pyrope (at 7 GPa) to majorite (at 14 GPa) compositions.

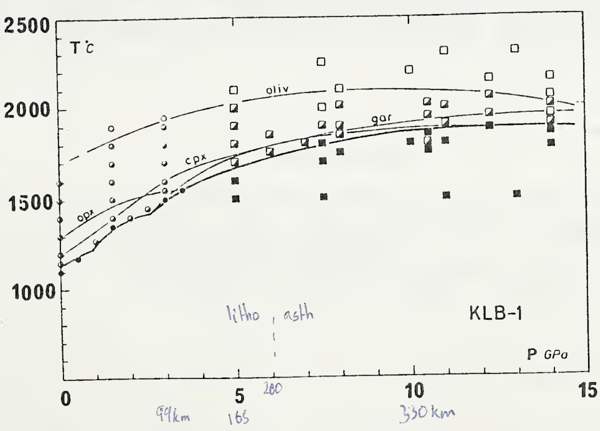


Fig. 4 Melting phase relation of a fertile peridotite KLB-1 under dry conditions up to 14 GPa (after Takahashi, 1986).

Preliminary melting phase relations of the mantle peridotite in the pressure range between 15 and 20 GPa are shown in Fig. 5. The results for the peridotite KLB-1 and PHN-1611 are indistinguishable in the resolution in pressure and temperature of Fig. 5. Olivine appears as a liquidus phase up to about 17 GPa. However, majorite-garnet appears on the liquidus as well as olivine at 16 and 17 GPa runs. At pressures above 18 GPa, β-spinel and majorite garnet coexist on the peridotite liquidus. As noted by Kato & Kumazawa (1986), under slightly hydrous conditions, the liquidus phase is a hydrous phase-B ($Mg_{23}Si_8O_{42}H_6$) coexisting with majorite at 18 to 20 GPa pressure range. In a melting experiment at 25 GPa and ~3000°C, peridotite PHN-1611 was completely molten, whereas a charge of $(Mg_{0.8}\cdot Fe_{0.2})_2SiO_4$ composition was partially molten and the liquidus phase was perovskite of almost pure $MgSiO_3$ composition.

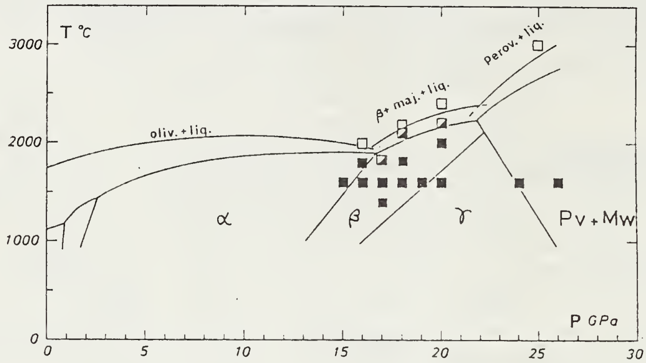


Fig. 5 A preliminary phase relation of peridotites KLB-1 and PHN-1611 up to 25 GPa under dry conditions.

Compositions of partial melts formed near the peridotite solidus were determined by analyzing quenched liquid segregated from the peridotite matrix with a defocused electron beam (50 to 100 μm diam.) by EPMA. MgO content (or normative olivine component) of the peridotite partial melt increases systematically with increasing pressure (hence temperature); olivine tholeiite (1 GPa and 1300°C, MgO=9.5 wt%), picrite (3 GPa and 1550°C, MgO=19.5 %), peridotitic komatiite (5 to 8 GPa, MgO>30 %; Takahashi & Scarfe, 1985), and peridotite itself!! (15 to 20 GPa, MgO=37-40 wt%).

Based on the following observations; (1) convergence of the liquidus and solidus at pressure >15 GPa, (2) the near solidus partial melt composition very close to the bulk rock at 15-20 GPa, (3) eutectitic melting relation between majorite-garnet and M_2SiO_4 phases at 16-20 GPa, it is proposed that the upper mantle peridotite was generated as an ultrabasic magma (or magmas) by partial melting of primitive earth at great depth during or soon after the accreational stage. Likely candidates for the residue of the Earth's deep melting are majorite garnet (400-600 km depth) and $MgSiO_3$ perovskite (>600 km depth).

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