

# Phase transformations in pyrolite and subducted crust compositions down to a depth of 800 km in the lower mantle

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## Introduction

Recent developments in multianvil high-pressure technology have made it possible to investigate the phase transformations in mantle materials under the conditions corresponding to the upper part of the Earth's lower mantle. The author reports here the results of such experimental studies on a pyrolite composition and those of subducted oceanic and continental crust compositions, with some implications for the mineralogy of the mantle and the dynamics of the subducted crust lithologies.

## Experimental method

High-pressure experiments were conducted by means of an MA8 apparatus. The details of the experimental technique have been reported in Irifune *et al.* (1992). Pyrolite was chosen as a representative mantle composition. The compositions of the oceanic and continental crusts were modeled by a mid-oceanic ridge basalt (MORB) and an average upper continental crust composition (hereafter 'granite'), respectively. The latter composition is also close to those of the

terrigenous sediments, and may be used to study the phase transformations in subducted ocean sediments. Table 1 lists the chemical compositions of the starting materials used in the present experiments.

The runs were conducted at pressures between 6 and 28 GPa, at temperatures along a mantle geotherm, for 15-130 minutes. Quenching method was adopted and the recovered samples were examined by optical microscopy, X-ray powder diffraction, and electron microprobe analyses. The results of the present experiments have been partly reported in Irifune and Ringwood (1993), Irifune (1994), and Irifune and Ringwood (in preparation).

## Experimental results

The phase transformations in pyrolite are depicted in Fig. 1a. The gross nature of the phase transformation in the pyrolite composition is consistent with that reported by Takahashi and Ito (1987) for a natural peridotite sample and that inferred on the basis of the results for a pyrolite minus olivine composition (Irifune and Ringwood, 1987). Some notable discrepancy, however, exists between the present and those earlier studies, especially at pressures above 20 GPa. These include absence of the unidentified Al-rich phase (Takahashi and Ito, 1987) in the present study, suggesting the upper part of the lower mantle consists only of MgSiO<sub>3</sub>- and CaSiO<sub>3</sub>-rich perovskites and magnesio-wüstite.

Figure 1b shows the phase transformations in MORB, which crystallizes to an eclogite assemblage and then transforms to garnetite (majorite garnet ± stishovite). The garnetite facies further transforms into an assemblage of CaSiO<sub>3</sub> perovskite + majorite garnet + stishovite + unidentified aluminous phase (probably related to a calcium ferrite-type structure) at pressures above 25 GPa. Majorite garnet was found to persist at pressures greater than 28 GPa, in contrast to the majorite garnet in pyrolite that transforms into a perovskite structure at pressures near 26 GPa.

The granite composition crystallizes into an

TABLE 1. Chemical compositions of the starting materials

	pyrolite	MORB	granite
SiO <sub>2</sub>	44.5	50.4	66.0
TiO <sub>2</sub>	0.2	0.6	0.5
Al <sub>2</sub> O <sub>3</sub>	4.3	16.1	15.2
Cr <sub>2</sub> O <sub>3</sub>	0.4	-	-
FeO	8.6	7.7	4.5*
MgO	38.0	10.5	2.2
CaO	3.5	13.1	4.2
Na <sub>2</sub> O	0.4	1.9	3.9
K <sub>2</sub> O	0.1	0.1	3.4

\*, replaced by CoO

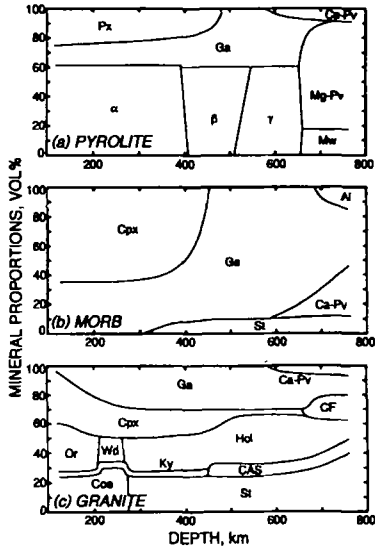


FIG. 1. Mineral proportion changes in (a) pyrolite, (b) MORB, and (c) granite compositions as a function of depth. Cpx = clinopyroxene; Ca = garnet; Ca-Pv =  $\text{CaSiO}_3$ -rich perovskite; Mg-Pv =  $\text{MgSiO}_3$ -rich perovskite;  $\alpha$  = olivine,  $\beta$  = modified spinel, and  $\gamma$  = spinel form of  $(\text{Mg,Fe})_2\text{SiO}_4$ ; Mw = magnesio-wüstite; St = stishovite; Al = unidentified aluminous phase; Or = orthoclase; Wd =  $\text{K}_2\text{Si}_4\text{O}_9$  wadeite; Coe = coesite; Ky = kyanite; Hol =  $\text{KAlSi}_3\text{O}_8$  hollandite; CAS = unidentified Ca- and Al-rich silicate; CF = calcium ferrite-type phase of  $\text{NaAl-SiO}_4\text{-M}^{2+}\text{Al}_2\text{O}_4$ .

assemblage consisting mainly of clinopyroxene, coesite, and orthoclase at 6 GPa, as shown in Fig 1c. It transforms to very dense assemblages including garnet, stishovite, and  $\text{KAlSi}_3\text{O}_8$  hollandite at pressures above 9 GPa. An unknown Ca- and Al-rich silicate was found to crystallize at pressure above 15 GPa. The presence of a calcium ferrite-type phase with a composition in the system  $\text{NaAlSiO}_4\text{-M}^{2+}\text{Al}_2\text{O}_4$  was also confirmed at 24 GPa.

### Discussion

Zero-pressure density changes in pyrolite, MORB, and granite compositions were calculated as a function of pressure, on the basis of the present phase transformation data and those of the estimated densities of the individual high pressure phases (Fig.2). Density changes in pyrolite generally agree with those obtained from the seismic observations (e.g., PREM) within the uncertainties involved in both of these profiles,

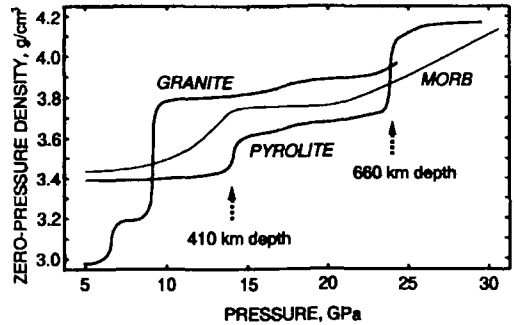


FIG. 2. Zero-pressure density changes in pyrolite, MORB, and granite compositions as a function of pressure. The depths corresponding to the major seismic discontinuities are shown by the arrows.

suggesting that pyrolite is a reasonable model mantle composition.

The behaviours of the subducted oceanic and continental crusts in the mantle are discussed on the basis of the density differences between these compositions and the pyrolite mantle. MORB is significantly denser than pyrolite throughout the upper mantle and the mantle transition region, while it becomes less dense in a limited depth interval between 660–800 km. Thus this component of the slab may easily subduct into the deep mantle but would be trapped at the top of the lower mantle. In contrast, if a fragment of the continental crust subducts into the mantle, its density approaches that of pyrolite at a depth of 200 km and exceeds it below 300 km. Accordingly, once the critical depth of 200 km is exceeded, subduction of the continental crust lithologies (and sediments) to greater depths is possible, which could explain the possible existence of such lithologies in the deep mantle as inferred from recent geochemical and petrological observations.

### References

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