AN EXPERIMENTAL STUDY OF THE BASALT-ECLOGITE TRANSITION

By

Mitsuhiko SHIMADA

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Abstract

The basalt-eclogite transition has been investigated experimentally using natural basalt as the starting material. Temperature interval investigated in this work was not so wide (from the solidus of the basalt to 850°C) that the stability lines extrapolated to lower temperatures has large ambiguity. In spite of this large ambiguity, the result shows that the possibility that the Mohorovičić discontinuity under the continent is caused by the basalt-eclogite transition is not entirely rejected.

1. Introduction

It was discussed by many authors whether the Moho is caused by the basalt-eclogite transition. First experimental investigation related to the transition was described by Robertson *et al.* [1957] who determined the stability of the reaction: albite+nepheline=2 jadeite. It was their result that the basalt-eclogite hypothesis revived by Lovering [1958] was based on.

Yoder & Tilley [1962], Ringwood & Green [1966], Green & Ringwood [1967] and Cohen *et al.* [1967] constructed the equilibrium diagrams for basalt and eclogite from the experimental investigations for natural and synthetic basaltic rocks. Ringwood & Green concluded from their experimental results that the Moho is not caused by the transition.

The present work was attempted to construct a phase relation for a natural rock.

2. Experimental procedures

The high pressure chamber used for this study was a single-stage piston cylinder type. The internal arrangement of the cylinder is shown in Fig. 1. The experimental apparatus and method were described in detail elsewhere (Shimada [1966a]). Data were plotted on a load pressure diagram without the friction correction (*cf.* Shimada [1966b]).

Temperature was measured with Pt/Pt 13% Rh or Chromel/Alumel thermo-

Hole for thermocouple
0.1 mm Pb foil
Sample within Pt capsule

Stainless steel
Pyrophyllite
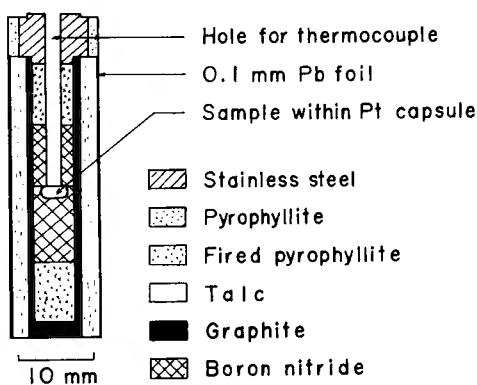Fired pyrophyllite
Talc
Graphite
Boron nitride

10 mm

Fig. 1.   Internal arrangement of the high pressure cylinder.

couples. No correction was made for the effect of pressure on the emf of the thermocouples.

Glass of natural olivine basalt of which locality is Yakuno, Kyoto Prefecture was used as the starting material for most runs. This basalt is a typical olivine basalt which is composed of olivine, augite, plagioclase and small amount of magnetite. The chemical analysis of the rock investigated are

Table 1.   Chemical analysis and norm of Yakuno olivine basalt*

SiO_2	49.51	Or	8.5
TiO_2	1.10	Ab	19.0
Al_2O_3	15.75	An	29.8
Fe_2O_3	3.32	Di	7.6
FeO	9.04	En	18.5
MgO	8.72	Fs	7.7
CaO	7.82	Fo	2.5
Na_2O	2.10	Fa	1.1
K_2O	1.47	Mt	3.6
H_2O^+	0.97	Il	1.6
H_2O^-	0.55		
	100.35		99.9

* Analyst: K. Nishimiya, Geological Institute, Faculty of Education, Yamanashi University.

shown in Table 1.   Three crystalline phases with the same chemical composition were also used as the starting materials for the reverse reactions, which are composed of plagioclase+clinopyroxene, plagioclase+clinopyroxene+garnet and clinopyroxene+garnet.   These starting materials were sealed within platinum capsules immediately after drying.

The quenched samples were examined by X-ray and optical methods.

3.   Experimental results

Table 2.   Results of runs on natural basalt

Pressure, Kb	Temperature, °C	Time, hr	Starting material*	Products*
10.9±0.3	950±8	6	Gl	Pl+Cpx
11.5	850±4	12	Gl	Pl+Cpx
11.9	1050±7	6.5	Gl	Pl+Cpx
11.9	950±5	6	Gl	Pl+Cpx

12.5	1021±5	6	Pl+Cpx	Pl+Cpx
12.5	976±4	6	Gl	Pl+Cpx
12.5	901±4	12	Gl	Pl+Cpx+((Ga))
12.8	950±4	6	Gl	Pl+Cpx+(Ga)
12.9	1050±7	5	Pl+Cpx+Ga	Pl+Cpx
13.0	1076±5	5	Cpx+Ga	Pl+Cpx
13.0	1027±5	5	Gl	Pl+Cpx+Ga
13.1	1099±8	5	Pl+Cpx+Ga	Gl+Pl+Cpx
13.1	997±7	5	Gl	Pl+Cpx+(Ga)
13.5	1057±5	6	Pl+Cpx+Ga	Pl+Cpx+Ga
14.0	1075±8	5	Pl+Cpx+Ga	Pl+Cpx+Ga
15.0	1050±6	5	Gl	Pl+Cpx+Ga
15.7	1100±7	4.5	Pl+Cpx	Gl+Pl+Cpx+Ga
18.0	1103±8	4	Pl+Cpx	Gl+Pl+Cpx+Ga
20.1	1102±6	5	Gl	(Pl)+Cpx+Ga
20.1	1050±7	1	Gl	Pl+Cpx+Ga
20.1	950±8	6	Gl	(Pl)+Cpx+Ga
20.7	1005±6	5	Gl	Pl+Cpx+Ga
21.1	1051±7	4	Gl	Pl+Cpx+Ga
21.1	851±4	12	Gl	Pl+Cpx+Ga
21.3	969±5	6	Gl	(Pl)+Cpx+Ga
21.3	900±5	9	Gl	(Pl)+Cpx+Ga
21.5	1076±8	5	Cpx+Ga	((Pl))+Cpx+Ga
22.0	1100±6	5	Pl+Cpx	(Pl)+Cpx+Ga
22.0	1050±7	5	Pl+Cpx+Ga	(Pl)+Cpx+Ga
22.0	999±7	5.5	Gl	Cpx+Ga
22.0	991±5	8	Pl+Cpx+Ga	Pl+Cpx+Ga
22.0	925±4	7	Gl	(Pl)+Cpx+Ga
22.5	1100±5	4	Gl	((Pl))+Cpx+Ga
22.5	1077±5	4	Gl	((Pl))+Cpx+Ga
22.5	1027±5	6	Gl	Cpx+Ga
22.5	1002±5	7	Gl	(Pl)+Cpx+Ga
22.5	991±5	8	Pl+Cpx+Ga	((Pl))+Cpx+Ga
22.5	900±4	14	Gl	((Pl))+Cpx+Ga
22.7	1150±8	4	Gl	Gl+Cpx+Ga
23.0	1125±5	5	Cpx+Ga	Cpx+Ga
23.0	1051±7	5	Gl	Cpx+Ga
23.1	1103±6	5	Pl+Cpx+Ga	Cpx+Ga
23.1	1077±5	6	Gl	Cpx+Ga
23.1	991±4	9	Pl+Cpx+Ga	Cpx+Ga
23.1	950±4	6.5	Gl	Cpx+Ga
23.9	1100±7	5	Pl+Cpx	Cpx+Ga
24.0	1150±8	3.5	Gl	Gl+Cpx+Ga
27.3	810±8	3.5	Pl+Cpx	Cpx+Ga

* Gl=Glass, Pl=Plagioclase, Cpx=Clinopyroxene, Ga=Garnet, ( ): small amount, (( )): trace amount.
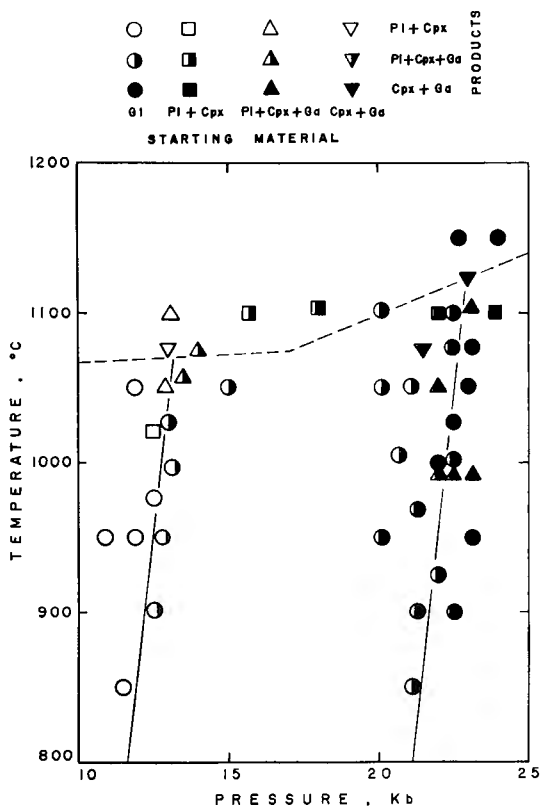
Fig. 2. Experimental determination of the basalt-eclogite transition for a natural basalt. The dashed line is the solidus of the same basalt (after Shimada [1966b]).

The results for the quenched samples are shown in Table 2 and plotted in Fig. 2.

In this paper plagioclase and garnet were regarded as the characteristic minerals for basalt and eclogite. As pressure increases, garnet appears and plagioclase, clinopyroxene and garnet coexist until plagioclase disappears at the higher pressure. The latter state is regarded as the stable state of eclogite and the former as the coexisting region of both basalt and eclogite, or the transition zone.

The dashed line in Fig. 2 shows the solidus of the same basalt determined previously (Shimada [1966b]). The boundary for appearance of garnet was consistently determined, but for disappearance of plagioclase was not. This reason can be considered whether the rate for the transformation of disappearance of plagioclase is so slow that the duration of runs at lower temperature in this work was not satisfied to complete the transformation, or the discrepancy is within the experimental error. Thus the latter boundary was determined from higher temperature runs than 950°C. Cohen et al. [1967] determined the phase relations of melting regions of basalt and eclogite. According to their results, the boundary for disappearance of plagioclase above the solidus was inclined toward lower pressure side at the intersecting point of the boundary with the solidus.

It is found from Fig. 2 that the transition zone lies in wide pressure range of about 10 kilobars. Yoder & Tilley [1962] constructed a phase diagram of the basalt-elogite transition. Their transition zone is rather narrower, about 4 kilobars (Fig. 3). Ringwood & Green [1966] investigated the transition on 6 basaltic rocks and determined one phase diagram and five transition zones at 1,100°C, of which results are illustrated in Fig. 3 by dotted lines and arrows.
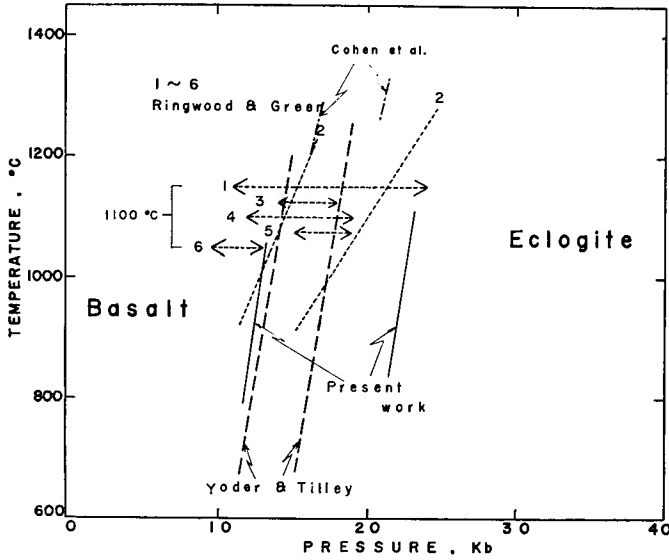
Fig. 3. Comparison of the equilibrium relations of the transition for natural basalt with Yoder & Tilley's [1962], Ringwood & Green's [1966] (1: High alumina basalt, 2: Quartz tholeiite, 3: Alkali-poor quartz tholeiite, 4: Alkali olivine basalt, 5: Oxidised alkali olivine basalt, 6: Alkali-poor olivine basalt), and Cohen *et al.*'s [1967].

The transition zone varies from 3.4 to 12 kilobars in different basalts.

4. Concluding remarks

From the inclination of the transition boundary, Ringwood & Green [1966] (Fig. 3) emphasized that eclogite is thermodynamically stable under the P, T conditions existing in very large regions of normal continental crust, and conversely gabbro and basalt are thermodynamically unstable under those conditions.

In Fig. 2, the determined boundary for appearance of garnet, though it was consistently drawn, as well as that for disappearance of plagioclase has considerable ambiguity. This ambiguity of Fig. 2 is shown in Fig. 4
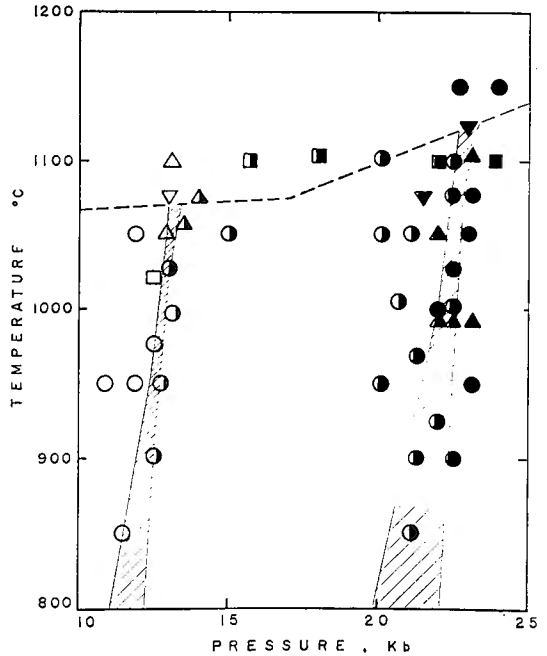

Fig. 4. Ambiguity of the transition boundaries.

by hatched zones. This shows that the slope of boundary could be taken more flat and the transition zone be made narrower toward lower temperatures like Ringwood & Green's. The extrapolated boundary which has such ambiguity as stated above intersects with the pressure axis, but not the temperature axis. The extrapolated boundary with the ambiguity and geotherms are shown in Fig. 5 together with the melting relations previously described by the author (Shimada [1966a, b]).
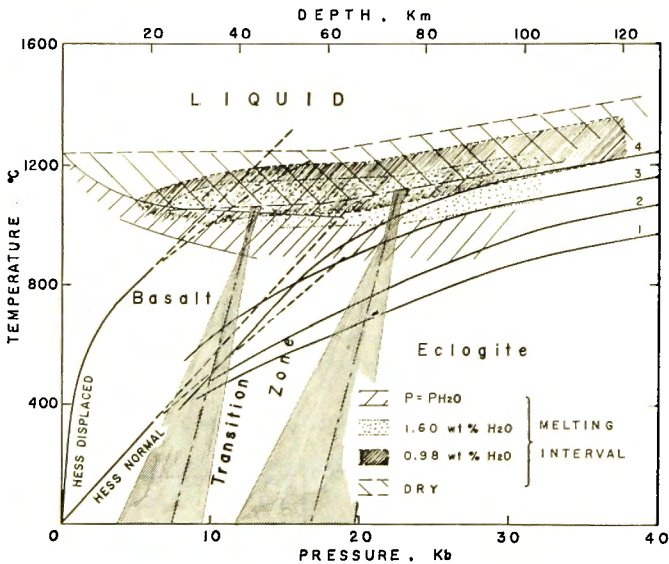

Fig. 5. Extrapolated equilibrium relations between basalt and eclogite and melting relations (after Shimada [1966b]) compared with the geotherms after Clark & Ringwood [1964] (1: P. C. shield, 2 and 3: continental upper mantle, 4: oceanic one) and Hess' normal and displaced gradients (after Hess [1962] and Nicholls [1965]).

It is found from Fig. 3 that the width of the transition zone and the boundaries vary widely according to the basaltic composition. Ringwood & Green [1966] stated that the variations for their results is caused by small differences in chemical composition. Cohen *et al.* [1967] also stated that data from synthetic and natural basalt systems show that the lowest pressure at which garnet appears near the solidus of basaltic assemblages is probably 15 to 16 kilobars for basalt with a wide range of composition, but that the pressure at which feldspar disappears is more variable.

It is certain, however, from the present work and others' that basalt is transformed into eclogite at pressure corresponding to a certain depth in the upper mantle or the lower crust. But it cannot be concluded that the Moho is caused by the transition though the possibility of it is not entirely rejected.

The fact that minor changes in chemical composition strongly affect the equilibrium relations makes it difficult to interpret the Moho, which is considered ubiquitous and to lie in the uniform depth in continental regions, by the transition hypothesis. Before detailed discussions, it will be required to make effort to eliminate large ambiguity for the extrapolated boundaries of the transition, especially runs for lower temperatures are required.

Acknowledgements

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