

2. Previous experiments

YODER and TILLEY (1962) showed that the stable subsolidus assemblage for many basaltic rocks is amphibolite for $P_T = P_{H_2O} > 2 \text{ kb}$, $< 10 \text{ kb}$, $T > 600 \text{ }^\circ\text{C}$, and concluded that eclogite is unstable in the presence of water for *all* water pressures. However the beginning of melting could develop a positive slope and the disappearance of amphibole a negative slope at high water pressures due to the formation of garnet and the high compressibility of water. The combination of these two effects leads to the stabilization of eclogite relative to amphibolite at sufficiently high water pressures (fig. 1).

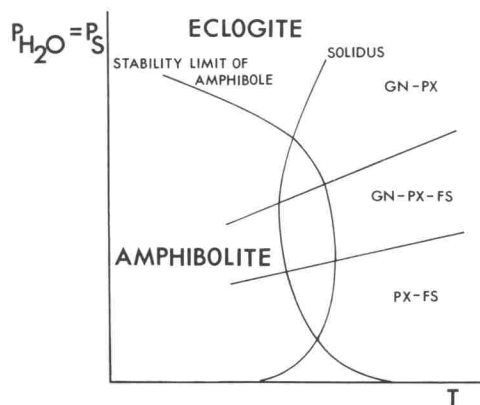


Fig. 1. A possible geometry for the beginning of melting and the stability of amphibole in basaltic rocks. The solid-solid transformation of feldspar to garnet and the high compressibility of water combine to stabilize eclogite at high water pressures.

Fs = Feldspars, Px = Pyroxenes, gn = garnet.

This geometry has been confirmed in preliminary synthesis experiments on hornblende stability under its own composition and in a gabbro by LAMBERT and WYLLIE (1968). HENSEN and GREEN (unpublished) established the synthesis limit of hornblende in an alkali olivine basalt* with similar results also for $P_{H_2O} \approx P_T$ (fig. 2). These experiments show that eclogite is stable at high water pressures but represent syntheses mostly in the supersolidus region.

3. Thermodynamic calculations

Many simple amphiboles can be shown to be unstable at high water pressures by thermodynamic cal-

* The composition of this alkali-olivine basalt as well as the albite-rich quartz tholeiite used in following experiments is listed in GREEN and RINGWOOD (1967).

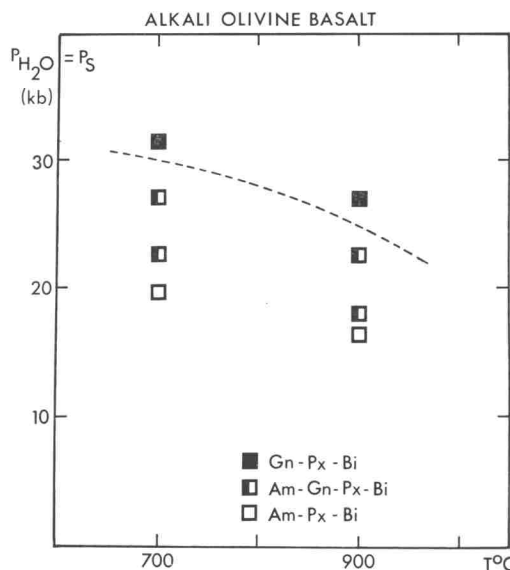


Fig. 2. Stability of amphibole for an alkali olivine basalt as determined by syntheses in cold-sealed gold capsules. The restriction of garnet to relatively high pressures is probably a reflection of the lack of initial garnet nuclei. This stability of amphibole compares well with the hot-sealed synthesis runs of fig. 3, showing that water pressures were not significantly lowered by chance leaks during the run. Am = Amphibole, Bi = Biotite, Px = Pyroxenes.

culations which permit extension of experimental data to higher water pressures (see Appendix 1 for thermodynamic data and procedures)*. The simple dehydration of tremolite (BOYD, 1959) will develop a negative slope at high water pressures due only to the rapid compressibility of water vapor, as predicted by GREEN and RINGWOOD (1967). At high enough water pressures the tremolite = diopside + enstatite + quartz + water curve will cross the talc = enstatite + quartz + water curve and a solid-solid decomposition of tremolite = talc + diopside is found instead (fig. 3). A similar solid-solid transformation predicted for anthophyllite by GREENWOOD (1963) is also shown in fig. 3, though calculations using ROBIE *et al.*'s (1967) volume data would move this curve to at least 50 k \bar{t} . Glaucophane might similarly be expected to break down to talc + jadeite at high pressures (shown schematically in fig. 3), and the curve could be located more exactly if dependable experiments were available for the stability of glaucophane. Amphiboles may also break down at

* These calculations ignore the possibility of partial melting at high water pressures.

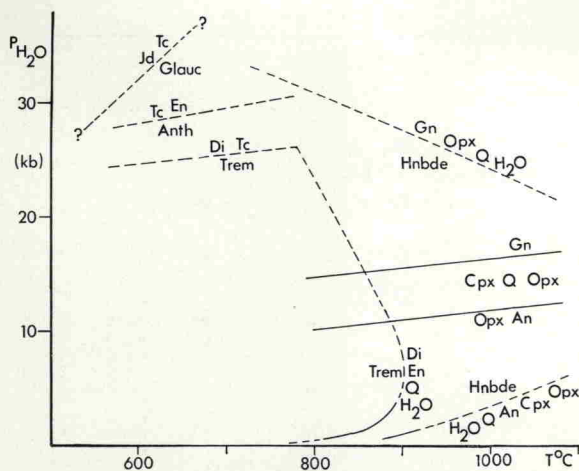
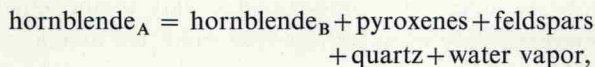


Fig. 3. Stability of various amphiboles estimated at high water pressures. Trem = Tremolite, Di = Diopside, En = Enstatite, Q = Quartz, Hnbde = "Hornblende", Gn = Garnet, Opx = Orthopyroxene, Cpx = Clinopyroxene, An = Anorthite, Anth = Anthophyllite, Tc = Talc, Jd = Jadeite, Gl = Glaucophane.

high water pressures because the products themselves react to form denser phases, as shown in fig. 3 for a "hornblende" - $\text{Ca}_2\text{Mg}_4\text{Al}_2\text{Si}_7\text{O}_{22}(\text{OH})_2$. The initial point for the curve "hornblende" = anorthite + diopside + enstatite + water is taken at 900 °C and 1 kb* and when the feldspar reacts with pyroxenes to yield garnet the stability of this amphibole is sharply back-bent (fig. 3). While the true stability of this "hornblende" may be represented instead by some reaction as



the effect of high water pressures when garnet is produced may be qualitatively represented as in fig. 3**.

The instability of these amphiboles at high water pressures disagrees markedly with similar estimates by O'HARA (1967), who extended the stability of amphiboles vertically regardless of reactions among the products giving garnet at the expense of feldspars. O'Hara's schematic amphibole stability curves are unrealistic and

* This is an estimate taken from BOYD'S (1959) experiments. When Boyd attempted to determine the stability of pargasite + quartz the pargasite broke down to form an amphibole close to $\text{Ca}_2\text{Mg}_4\text{Al}_2\text{Si}_7\text{O}_{22}(\text{OH})_2$ stable to ~900 °C, 1 kb.

** Following preparation of this manuscript, GILBERT'S (1969) note on the experimental stability of end-member amphiboles appeared in the Ann. Rept. Geophys. Lab. Carnegie Inst. Wash. Gilbert's preliminary experiments on tremolite and "hornblende" are generally consistent with the calculations shown in fig. 3.

should be disregarded. Extrapolation of simple amphibole stabilities to high water pressures demonstrates that they may decompose by increasing water pressure but bear little on the stability of complex amphiboles which may first react with other phases in natural basaltic compositions.

4. Present experiments

The writers attempted to establish the upper stability limit of amphibole in an alkali olivine basalt and a quartz tholeiite for $P_{\text{H}_2\text{O}} = P_s$ by sealing glassy and crystalline samples with water and holding them in a piston cylinder apparatus at P and T for >24 hours (see appendix II for details of experimental procedure). Amphibole disappeared rather sharply within a 2 kb interval (figs. 4, 5) and in the case of the alkali olivine basalt, compared rather well with earlier experiments with cold-sealed capsules (fig. 3). When the crystallized mixtures of the earlier runs (amphibolite and eclogite) were rerun, amphibole was found to be unstable in the region where it had previously been synthesized, and it did not perceptibly grow at the expense of the garnet and pyroxene until the pressure had been lowered 5–10 kb below the original synthesis limit. While the reversal limits are rather wide in these preliminary experiments, they illustrate the danger of accepting short-time synthesis experiments as representing equilibrium at these relatively low temperatures, even if the syn-

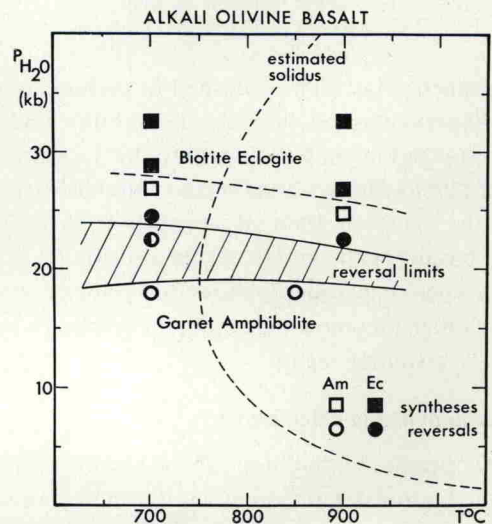


Fig. 4. Stability limit of amphibole in an alkali olivine basalt, comparing synthesis runs with reversals. Am = Amphibolite, Ec = Eclogite.