

system would be as in Fig. 10(a). In terms of geological occurrence, there is much to commend this form of diagram.

As yet, while there is experimental data on curves A-B and B-C of this diagram, there have been no studies of curve B-D at low temperatures and there is every indication that the rates of reaction are very slow indeed. In part this is due to the complex chemistry of the system and the statistical difficulties of attaining an equilibrium state; many atoms must move in this transformation.

When a problem of this type is faced, time after time, simple thermodynamic arguments can help. With mineral reactions we almost always have data on

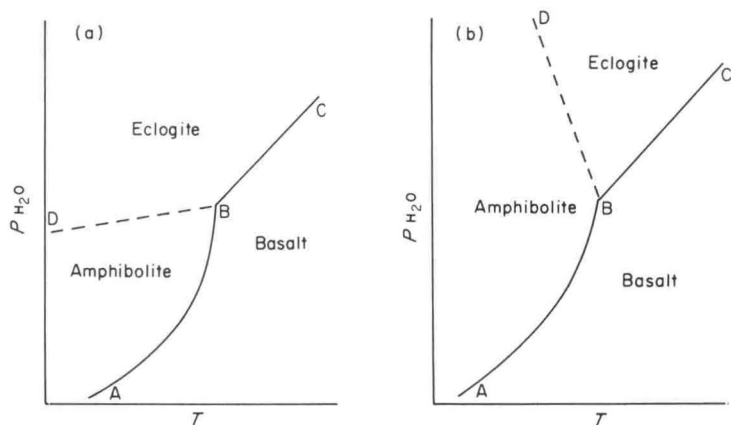


Fig. 10. Possible phase relations in the wet basalt system (ignoring regions of partial melting). (a) A diagram suggested by field occurrence. Eclogite could be stable in wet crust. (b) The most probable form demanded by thermodynamic arguments. Eclogite only stable in dry crust.

volume changes. We can thus use the relation

$$\left(\frac{\partial \Delta G}{\partial P}\right)_T = \Delta V$$

if we can get some fix on ΔG at any one pressure. In the present case we have an equilibrium curve for reactions:



and



and hence we have some points where ΔG 's for (1) and (2) are zero. Because of the properties of the free energy function we can add ΔG 's of (1) and (2) to get ΔG 's for the reaction:



and as we know the ΔV terms, we can draw the phase diagram. If we do this,

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we see that Fig. 10(a) cannot be correct and the true equilibrium diagram must be more like Fig. 10(b).

If this diagram is correct and if crystal rocks are metamorphosed to eclogites then water pressures must be much lower than load pressures. The products of metamorphism are totally different from those occurring in the more common wet conditions. Moreover when and how the reaction proceeds is rate-controlled and may seldom represent an equilibrium state. It seems possible that there may be many other cases of metamorphism, where aqueous phases have had only a limited influence. These factors must be recognized before we decide what significance should be attached to a given type of reaction in a given geological situation.

7. A case history—burial metamorphism on the Pacific margin

To conclude this essay, I would like to briefly mention some results from field and laboratory studies of the rather unique series of metamorphic rocks which are found scattered in large and small fragments around almost the entire Pacific margin. The rocks are all of similar age. Other comparable belts run through the Alps, Greek Islands, Turkey and Northern India, and another in the Urals. It is possible that some too, may have been obliterated by later events. While the characteristic minerals to be described are widespread in these narrow belts of global length, they are strikingly absent from other metamorphic rocks making up a much larger contribution to the metamorphic terranes of the earth's crust. These same belts are closely related to the modern seismic and volcanic zones of the earth. Some of the most active fault systems of the earth, with enormous lateral displacement, run through the belts. Today we recognize that these zones are in regions where ocean sediments are driven deep beneath the continental margins by convective forces which also drive the ocean floor spreading process.⁸

The rocks in these belts are dominated by volcanic debris. Thicknesses are unknown but considered in places to be of the order of 15 km. But if convective forces are at work, thickness should not be confused with burial for materials may be driven to much greater depths. Many of the rock types are little altered but in places there is widespread development of the characteristic minerals jadeite, lawsonite, aragonite, glaucophane. The first three can be considered to develop by the rather simple reactions which seem to occur in the following sequence:

