

reasons; high Mg^{++} (as in the oceans), hydrophobic organic coatings as with fossils or an anhydrous environment (as in some metamorphic rocks). Studies of the reaction rate have clearly shown that in wet environments, metastable aragonite could not persist for the normal times of a metamorphic or sedimentary cycle. This is well borne out by observations on buried sediments.

The aragonite–calcite transformation is even quite rapid in the solid state at moderate temperatures. At one atmosphere and about $400^{\circ}C$, the transition takes only minutes or hours to occur. But at $200^{\circ}C$ and 1 atmosphere pressure, the time would be of the order of millions of years. Thus in a dry low temperature environment, aragonite, if formed, can survive.

If we study some of the sediments on the West Coast of the United States we find that as they become progressively metamorphosed, calcite is converted to aragonite. If we examine Fig. 1 it will be noted that only very low thermal gradients will allow this transformation. Now let us imagine that burial has followed a path such as A–B–C. During this burial water will be progressively eliminated and at early stages the metastable aragonite would change to calcite and then later, near C, aragonite forms as a stable phase. Now the rocks are unloaded and return to the surface along some path C–D–A and the aragonite survives for us to observe it. Clearly, if we knew all about reaction rates, we could limit possible paths. First, we can say that along the path C–D–A, fluid phases must be absent for if this was not the case, it is impossible to see how the aragonite could survive once in the field of calcite. Second, the higher the thermal gradient, the longer time aragonite will pass through the calcite field and the higher the temperature at which it will enter the calcite field. From studies of the kinetics of the solid state reaction, both temperature and pressure coefficient, it is possible to say that unless the aragonite re-enters the field of calcite stability at about $200^{\circ}C$ or below, then survival is most improbable. This suggests that the thermal gradient during unloading must have been less than $10^{\circ} km^{-1}$. The reaction rates are so temperature sensitive (the activation energy is so large) that this result carries a very small uncertainty, possibly one or two degrees. We thus have an example of reaction rate parameters being used to limit geophysical parameters.

6.4. *Eclogites*

Basaltic rocks are the most common product of volcanism. It is now certain that basaltic liquids originate in the upper mantle at depths of the order of 100 km. When basalts are compressed, they can be transformed into a much denser rock called eclogite. Eclogites have always attracted the attention of geologists for a number of reasons. They are dense considering their chemical composition. They consist of only two minerals; a red garnet and a green pyroxene and can be most attractive in appearance. They have properties which make them appropriate as possible major components of the upper mantle of the earth.

Eclogites occur on the surface of the earth in a number of situations. Minor

Phase changes in the earth's crust

inclusions are sometimes found in lavas and these could represent mantle fragments or products of very deep crystallization. Some are found as fragments in the kimberlites in which diamonds are found. These too, come from the mantle. They occur as lenses and bands in some areas of deeply eroded ancient crust and in some modern active tectonic belts on continental margins. Many workers have tended to consider eclogites as mantle products and if they are found in the crust have considered them introduced by some mechanical process. Other workers have shown that some eclogites are the product of metamorphism of basaltic lavas once on or near the surface of the earth. They have been buried deeply or dragged down by tectonic forces until they were transformed. They thus occur associated with rocks which reflect moderate (400–500°C) to very high temperatures (1200°C).

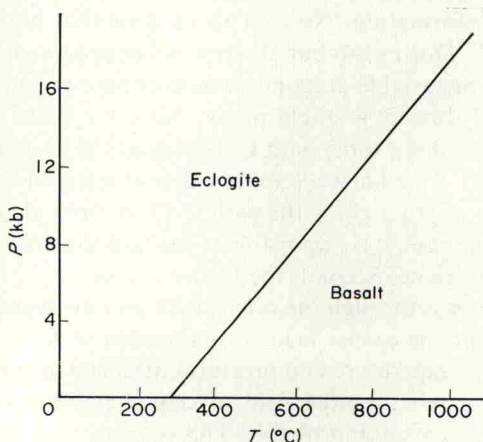


Fig. 9. Approximate position of equilibrium between basalts and eclogites. In reality, this line is a broad band of transition.

The eclogite–basalt transition has been studied experimentally by numerous workers. In Fig. 9 data from Green & Ringwood⁷ is shown. If these data are reliable at low temperatures, it is clear that eclogites can form from dry basaltic materials in the crust. The problem of their formation would then be a problem of reaction rates in a dry medium. There are plenty of deeply buried basalts which have not been transformed.

Basaltic rocks when metamorphosed in the crust, generally become hydrated and form schists rich in hydrated minerals (chlorites–epidotes–amphiboles). These rocks fit the normal pattern of progressive metamorphism where $P_{H_2O} \approx P_{Load}$. It has been suggested that just as analcime is dehydrated at high water–pressures (Fig. 5), these hydrated basaltic rocks could be transformed to dry eclogite, but at very high fluid pressures. Thus the phase relations in the wet