Al_2O_3 in solid solution at atmospheric pressure. At 20 kilobars or so it can dissolve nearly 20 per cent Al_2O_3 and its composition may approach that of pyrope. Natural enstatitic pyroxenes have been found with up to 9 per cent Al_2O_3, which again implies high pressures of formation.

These results imply either that metamorphic rocks now at the surface have been buried to depths of 30 km or so during metamorphism, or that during metamorphism pressures are systematically higher than those that would be found at equivalent depths in a heavy liquid. No choice between these alternatives can presently be made; much interpretation of these experimental results must still be done.

CONSTITUTION OF THE CRUST

Seismic velocities in the crust range from these characteristic of granitic to those characteristic of gabbroic rocks. Their dependence on depth is uncertain, but laboratory observations may be brought to bear on this question. If the mineralogical makeup of the crust or any part of it is uniform, the velocity will be virtually independent of depth below about 6 km.[18] The reduction in velocity due to rising temperature may be expected nearly to offset the increase due to rising pressure. Compositional layering could lead to stepwise increases in velocity, and a progressive change in composition could lead to a progressive increase in velocity. It is difficult to understand how such changes in composition could survive the large vertical movements that seem to be recorded in rocks, unless they are the natural consequence of the increasing pressure and temperature at depth.

Two processes leading to an increase in velocity with depth suggest themselves. The first follows from the observation that seismic velocities in pyroxenes are higher than those in amphiboles, or in micaceous minerals.[5] Micas and amphiboles contain water, but pyroxenes are anhydrous. If the hydrous minerals are broken down at depth, a stepwise increase in velocity could result. Another way of obtaining an increase in velocity with depth involves the decomposition of feldspar. Plagioclase feldspars are solid solutions between albite, $NaAlSi_3O_8$, and anorthite, $CaAl_2Si_2O_8$. In the presence of the pyroxene diopside, $CaMgSi_2O_6$, the albite component of the plagioclase may break down to jadeite and quartz. The jadeite will enter into solid solution with the diopside, and the increase in velocity resulting from the higher percentage of pyroxene in the rock will offset the reduction in velocity resulting from the formation of additional quartz. But plagioclases high in anorthite have higher velocities than those rich in albite, so that this reaction should raise the velocity in the rock.

The above suggestions about the crust are but two of a number of possibilities. Neither has yet been investigated experimentally because of the chemical complexities involved. A special complication affects the dehydration reactions, since the vapor pressure of water need not be the same as the pressure experienced by the solid phases.

THE OUTER MANTLE

The outstanding problem here is closely connected with the cause of the Mohorovicic discontinuity. Does this feature result from a change in composition, phase, or both? Geologic evidence bearing on this question comes from the composition of inclusions brought up in volcanoes and diamond pipes. Inclusions of olivine, approximately Mg_2SiO_4 with some magnesium replaced by ferrous iron, and of eclogite, a rock consisting essentially of a jadeitic pyroxene and a magnesian garnet, are widespread. Evidence that the diamond pipes came from the mantle is provided by the presence of the diamonds themselves. If they formed in their field of stability, the rocks must have come from depths greater than 100 km. Some of the volcanic eruptions in Hawaii are immediately preceded by earthquakes with focal depths of 20 miles or more. This is deeper than the Mohorovicic discontinuity beneath Hawaii. The pattern of the earthquakes strongly suggests that the lava is also originating in the mantle; it is known to contain inclusions of both olivine and eclogite.

The assumption that the outer mantle consists mainly of olivine, pyroxenes, and garnets is consistent with seismic data. In fact, these are the only abundant groups of minerals which have the requisite elastic properties. The Mohorovicic discontinuity is then to be regarded as due in part to a phase change, with a pyroxene-feldspar assemblage giving way to a different pyroxene and garnet. This is consistent with presently available data on the breakdown of albite and the appearance of garnets. But the reaction which is presumed to take place in the earth involves several phases, each of which is a solid solution. The problem in its full complexity has not yet been investigated in the laboratory. Another question concerns the behavior of anorthite. By itself it appears to be stable to very high pressures, but it may be consumed by reaction with another phase, for example enstatite, in the earth.

THE MANTLE BELOW 400 KILOMETERS

One of the earliest interpretations of the rise in velocity between 400 and 1000 km was made by Bernal,[19] who noted that two polymorphs of Mg_2GeO_4 exist. One is isostructural with olivine and the other, which is about 10 per cent denser, has the spinel structure. Bernal suggested that an analogous transition in olivine, which would be spread over an interval of depth by solid solution, might account for the behavior of the seismic velocities in this part of the earth.

This question has been investigated by Ringwood[20,21] and by Dachille and Roy.[22] They have mainly studied this inversion in solid solutions of Mg_2SiO_4 in Mg_2GeO_4 or Ni_2GeO_4. The conditions under which pure Mg_2SiO_4 might be expected to invert were estimated by extrapolation. In addition, Ringwood[21] produced the olivine-spinel inversion in the mineral fayalite, Fe_2SiO_4. The results of these investigations roughly confirm Bernal's hypothesis, but the accuracy of the experimental data is not high. There is great incentive to develop equipment in which the possible olivine-spinel inversion in Mg_2SiO_4 can be studied directly.

MELTING RELATIONS UNDER PRESSURE

The fact that a measurable amount of energy is carried by transverse elastic waves in the outer mantle implies that the material here is mostly solid. On the other hand, the widespread occurence of basaltic lava, both at the present time and in the past, shows that liquids may readily be generated locally. This suggests that melting is closely approached in the outer mantle, which in turn implies that inferences about temperatures in the earth can be drawn from melting relations of rocks at high pressures.

The mean slopes of the melting curves of the pyroxene diopside, the feldspar albite, and the garnet pyrope are, respectively, 10° to 13°, 11°, and 14°C/kilobar.[17,23,24] The similarity in the slopes is striking in view of the differences in crystal structure and other physical properties of these minerals. Theoretical considerations suggest, however, that the effect of pressure on minimum melting points in multicomponent systems is smaller than in these cases, in which melting occurs as in a one-component system. Little work on more complicated systems has been done at high pressure. Preliminary data by Boyd and England[17] on the system