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Temperature and Discontinuities in the Transition Layer within the Earth's Mantle: Geophysical Application of the Olivine-Spinel Transition in the Mg_2SiO_4-Fe_2SiO_4 System

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The nature of the transition layer (the C layer) is considered with the homogeneous chemical composition model. The physical properties of the transition layer are determined essentially by the mineral assemblage and the Fe/Mg ratio of mantle materials. The upper mantle is believed to be composed mainly of olivine and pyroxene, and the content of olivine possibly amounts to about 80% of the whole. The plausible values for the Fe/Mg ratio of mantle minerals lie between 1:9 and 2:8, and from the petrological evidences the magnesium-rich side in this range seems more probable. The olivine-spinel transition accounts for the sharp discontinuity that starts at the depth of about 370 km in the mantle and whose thickness is of the order of several tens of kilometers, according to the latest velocity models. The temperature at this depth is estimated to lie in the range between 1150° and 1530°C, using the Fe/Mg ratio of 1:9. The thickness of the transition region is directly related to the temperature distribution in it. The 50-km thickness requires a constant temperature distribution, but, to spread the thickness over a 70-km interval, the temperature must be raised by 100°C within this region, for a Fe/Mg ratio of 1:9. The location and the sharpness of discontinuities in the transition layer expected from the recent progress of high-pressure mineralogy show a substantial agreement with the latest seismological evidences. Contrary to the traditional interpretation, the actual transition region might not spread over the entire C layer, and there is a growing possibility that there exist several discontinuities in the transition layer that arise from successive polymorphic transitions in mantle minerals. The mode of sequence of seismic discontinuities in the transition layer varies with the ratio of olivine to pyroxene. If the content of coexisting pyroxene in the upper mantle increases, another seismic discontinuity corresponding to the pyroxene breakdown may become observable at the depth between olivine-spinel and post-spinel transitions.

INTRODUCTION

The transition layer (C layer) in the earth's mantle extends from about 300 to 900 km and is characterized by a rapid rise of seismic velocity with depth. In a series of classical investigations on the origin of this region, it was strongly suggested that the ferromagnesian silicates, of which the upper mantle is supposed to be composed, would gradually transform to high-pressure modifications, probably close-packed oxides, in the transition layer [e.g., *Birch*, 1952]. Recent progress in high-pressure mineralogy strongly supports this hypothesis.

In the early stages of the investigation, it was widely thought, on the basis of the continuous velocity-depth curve, that the C region was a region of gradually transitional spreading over the depth interval from about 300 to 1000 km. Various attempts have been made to explain this wide spreading of the transitional region. In the light of the recent experiments on the phase change in mantle minerals, it has become clear that an actual transition region should not spread over such a wide thickness. It is highly probable that there would exist several discontinuities in the transition layer that arise from successive phase changes in mantle minerals. Consequently, the discontinuous velocity-depth curve could possibly be obtained when the observation would become more accurate. Recently, this kind of velocity-depth curves has been obtained [e.g., *Anderson and Toksöz*, 1963; *Johnson*, 1967; *Kanamori*, 1967]. The sharpness and the locations of these discontinuities are controlled by the mineral composition, the ratio of Fe to Mg in the mantle materials, and the temperature distribution in the transition layer.

In the first two sections of this paper, the

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mineral composition and the Fe/Mg ratio in mantle materials will be determined from considerations of the elasticity, the density, and the petrological observations in the mantle. Then by comparing directly the experimental phase diagrams of the probable mantle minerals with the observed seismic velocity-depth curve, the locations and the sharpness of discontinuities in the transition layer will be discussed. In this discussion, if a close correlation can be established between a given seismic discontinuity and a given phase transition, the temperature at the depth of discontinuity can be determined with the aid of the knowledge of the phase relation considered. Now making use of the phase diagrams of the olivine-spinel transition in the Mg_2SiO_4-Fe_2SiO_4 system just obtained [*Akimoto and Fujisawa,* 1967] (see Figure 1), we will try to estimate the temperature at the top of the transition layer in the mantle, since it appears likely that the olivine-spinel transition occurs at the top of the transition layer. In this procedure the knowledge of mineral composition and the Fe/Mg ratio previously determined are essential.

The temperature distribution within the earth is one of the main unsolved problems in solid earth science. There have been many attempts to estimate the temperature distribution within the earth, but in all procedures used to make these estimates many grave assumptions have been introduced [e.g, *Miki,* 1954; *Verhoogen,* 1954]; therefore, the results are not necessarily convincing. Present estimations of temperatures in the mantle might, therefore, contribute to the study of the thermal state of the earth's interior.

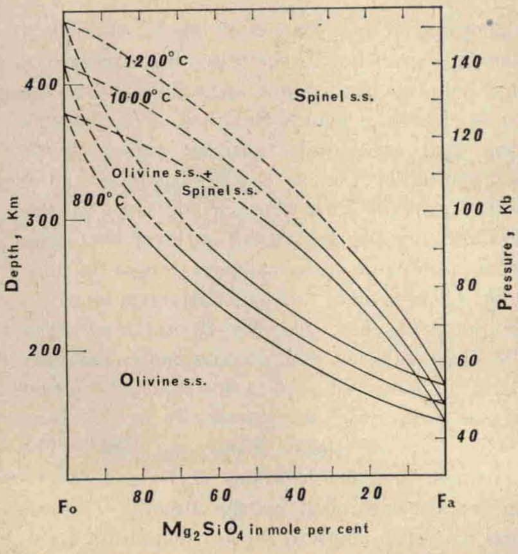

Fig. 1. Stability relation of olivine-spinel transition in the Mg_2SiO_4-Fe_2SiO_4 system at 800°, 1000°, and 1200°C [after *Akimoto and Fujisawa,* 1967].

MINERALOGICAL COMPOSITION ABOVE TRANSITION LAYER

In the present discussion the following assumption is essential: The chemical composition of mantle materials does not change throughout the mantle, but the component minerals transform and break down to denser structures. Therefore, the knowledge of materials in the upper mantle helps us to consider the mineral assemblage and the chemical composition in the whole mantle.

There are two main hypotheses on the mineralogical composition of the upper mantle: the peridotitic and the eclogitic hypotheses.

At first we assume the peridotitic mantle, based on the thorough petrological discussion of *Ringwood* [1966, pp. 298–307]. In the following discussions, however, we neglect, as a first approximation, a basaltic material that is important in a 'pyrolite' model [*Ringwood,* 1966, pp. 306–307]. For the upper mantle a pyrolite model might be better than a model in which the basaltic matter is neglected, but this would not necessarily be true for the lower mantle. Since the mineralogical composition of the lower mantle is directly correlated with that of the upper mantle in the present model, we must take account of the lower mantle. For this reason the basaltic material is neglected. This kind of consideration in petrology can, however, give only qualitative information about the mineralogical constitution of the upper mantle.

For quantitative arguments of the mineralogical composition of the upper mantle, the most convincing method is a direct comparison of the observed elastic properties of the upper mantle and elastic properties of various rocks determined experimentally under high pressures. By this method *Kanamori and Mizutani* [1965] obtained clear-cut results for upper mantle materials. Two of their results are as follows:

1. *P-wave velocity.* Among common rocks only peridotite, dunite, and eclogite have veloci-