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Effect of Pressure on the Melting of Olivine and Spinel Polymorph of Fe_2SiO_4

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The effect of pressure on the melting relations and polymorphism of Fe_2SiO_4 has been studied at pressures up to 76 kb, using the tetrahedral anvil type of high-pressure apparatus. Fayalite, Fe_2SiO_4 olivine, melts congruently to 62 kb, and the data can be fitted by Simon's equation, $P(\text{kb}) = 41 \{[T(°\text{K})/1478]^{4.8}-1\}$. The initial slope is 7.5°/kb, but it flattens to about 3.5°/kb in the pressure range 50 to 60 kb. A significant inflection was found in the melting curve of Fe_2SiO_4 at 62 kb; above that pressure the melting of Fe_2SiO_4 spinel was observed. The initial slope of the spinel melting curve is determined to be 14°/kb. The melting curve is intersected by the polymorphic olivine-spinel transition. The transition curve cannot be fitted by a simple straight line, the deviation of the curve from the straight line being large with increasing temperatures above 1150°C. The transition curve at temperatures below 1150°C is approximately expressed by a linear relation, $P(\text{kb}) = 19 + 0.033T(°\text{C})$. The triple point, fayalite–Fe_2SiO_4 spinel–liquid, was determined to be at 1520°C and 62 kb. These data suggest that a considerable inflection will be found in the melting curve of the earth's mantle at a depth of 400 to 1000 km.

INTRODUCTION

Quantitative knowledge of the effects of high pressure on the melting relations of silicate minerals provides upper temperature limits for the geothermal gradients, as well as estimates of the temperatures of basaltic magmas in the region of their origin. Seismic, geochemical, and petrological evidence all point to an ultrabasic mantle in which olivines $(Mg,Fe)_2SiO_4$ or high-pressure polymorphs of olivines are important phases. The melting curve of forsterite (Mg_2SiO_4) has already been determined at pressures up to 50 kb [*Davis and England,* 1964], and in this paper we present an analogous study of fayalite (Fe_2SiO_4). *Bowen and Schairer* [1935] have calculated the melting curve of fayalite from thermochemical data and quoted in their paper Goranson's result on the direct measurement of the initial slope without specifying experimental conditions. The data reported in this paper are the first direct determination of the melting curve of fayalite over a wide range of pressure.

It is now accepted with high probability that the solid-solid phase transformation of olivine to a spinel polymorph takes place in the high-gradient zone of seismic wave velocities at a depth of 400 to 1000 km in the earth's mantle. Hence estimates of the fusion curve of the spinel polymorph are essential to our understanding of melting in the lower mantle. Although iron-rich olivines are unlikely to occur in the earth's mantle, data on the melting of both olivine and spinel polymorphs of Fe_2SiO_4 reported in this paper may offer useful information about the melting relations that may occur in magnesium-rich $(Mg,Fe)_2SiO_4$ at pressures beyond the range of currently available experimental techniques.

As for the olivine-spinel transition in Fe_2SiO_4, a preliminary stability relation has been published over the temperature range 700 to 1200°C in the pressure range 40 to 70 kb [*Akimoto et al.,* 1965]. However, some ambiguity still remains in the high-temperature runs above 1000°C on account of the decomposition of a part of the Fe_2SiO_4, which resulted from a sample assembly described in a previous paper. Refinements in technique de-

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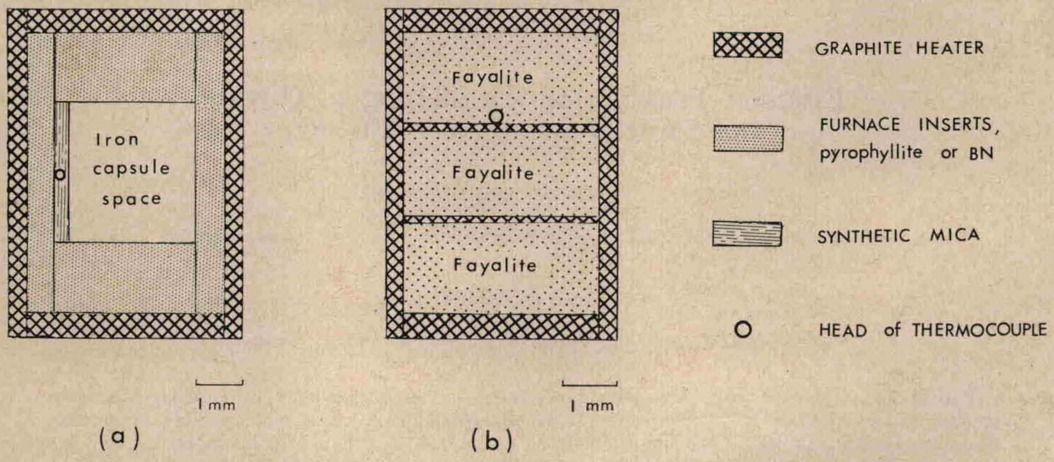

Fig. 1. Furnace assembly for phase equilibrium experiments at high pressures and temperatures. (*a*) Furnace assembly with iron capsule. (*b*) Simple furnace assembly particularly useful for high-temperature runs above 1500°C.

scribed in this paper have permitted the earlier result to be extended and improved.

EXPERIMENTAL PROCEDURE

High-pressure and high-temperature technique. The tetrahedral-anvil high-pressure apparatus used for this study was described in a previous publication [*Akimoto et al.,* 1965]. Two different sizes of anvils made of Mitsubishi GO3-grade tungsten carbide containing about 3% cobalt were used, depending upon maximum pressures desired. An anvil having 25-mm edges was used with a pyrophyllite tetrahedron having 30-mm edges for most experiments in the range 20 to 60 kb. A combination of an anvil and a pyrophyllite tetrahedron having 20- and 25-mm edges was adopted chiefly for runs above 58 kb. The surface of the pyrophyllite tetrahedron was painted with αFe_2O_3 (thick suspension in ethanol). Pressure values in the tetrahedral press were calibrated at room temperature in the usual manner by using resistance transitions in Bi, Tl, and Ba as fixed points. Following the present trend among workers on high pressures, we used the values of 25.4 kb for the bismuth I–II transition, 36.7 kb for the thallium II–III transition, and 59 kb for the barium II–III transition. The pressure of transition was reproducible within an accuracy of ±3%.

The basic design of the furnace assembly used for this study is illustrated in Figure 1*a*. A tubular graphite furnace was placed nearly at the center of the pyrophyllite tetrahedron and used for heating the samples. Fayalite or Fe_2SiO_4 spinel powder samples encased in an iron capsule were set in the center of the graphite furnace. Fired or unfired pyrophyllite and/or boron nitride were used as furnace inserts. Unfired pyrophyllite inserts were used only for the runs of solid-solid transition of Fe_2SiO_4. Pyrophyllite inserts for the use of solid-liquid transition were fired at 1000°C for 6 hours in air.

It has proved impossible to use iron capsules with the cell design shown in Figure 1*a* above about 1500°C for runs of the order of 5 min. When the temperature condition was exceeded, the iron capsule usually began to react with the silicate samples or the furnace inserts. The simple furnace assembly shown in Figure 1*b* was successfully used for high-temperature runs from 1500°C to about 1700°C. In this assembly silicate powder samples, inserted in the graphite furnace without being encased in capsules, were separated into three parts by thin graphite disks. Only the central parts of the samples were used for the phase-equilibrium experiments.

Temperatures were measured with Pt|Pt-13Rh thermocouples. These were placed in contact with the graphite disk when no capsule was used. In runs in which iron capsules were used, the thermocouples were separated from