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Elasticity and Equations of State of Olivines in the Mg_2SiO_4-Fe_2SiO_4 System

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Summary

Presented first in this paper are the elasticity data of seven olivines as a function of pressure, temperature, and Fe/Mg ratio. The elasticity data include (i) *P* and *S* wave velocities and their first derivatives with respect to pressure and temperature, (ii) the shear and bulk moduli and their first pressure and temperature derivatives, and (iii) Poisson's ratio and its pressure and temperature derivatives (all evaluated at zero pressure and at ambient temperature). The critical thermal gradients for density and for *P* and *S* wave velocities are presented for olivine with different Fe/Mg ratios. Also presented are the Debye temperature and Gruneisen's parameters γ_G and δ_s for olivine as a function of Fe/Mg ratio. Next, incorporating these elasticity data with theories, equations-of-state parameters of olivine and olivine-transformed spinel as a function of Fe/Mg are found. The equations of state of olivine are then presented; a pressure-volume-temperature (PVT) relation for olivine is examined as a function of temperature and Fe/Mg ratio. Finally, based on F. Press's recent Monte Carlo solutions, the present elasticity data are related to the Earth's upper mantle within the framework of a peridotitic model. Typically, for 100 Fo, 50 Fo, and 100 Fa olivines, values of density ρ_0 (in $g\,cm^{-3}$), the *P* and *S* wave velocities (in $km\,s^{-1}$), the adiabatic bulk modulus K_s (in mb) and its pressure derivative dK_s/dp, Gruneisen's parameters γ_G and δ_s, the Debye temperature θ_D (in °K), and the critical thermal gradients G_i, where *i* stands for density and *P* and *S* wave velocities, are as follows:

Fe/Mg ratio	Phase	ρ_0	V_p	V_s	K_s	$\frac{dK_s}{dp}$	γ_G	δ_s	G_p	G_s	G_ρ	θ_D
0/10	01	3·217	8·534	4·977	1·281	5·04	1·21	4·0	24	12	31	753
	Sp	3·556	9·66	5·54	1·86	4·4	—	—	—	—	—	869
5/5	01	3·800	7·534	4·213	1·256	5·44	1·10	4·4	24	8	33	633
	Sp	4·209	8·85	4·92	1·93	4·8	—	—	—	—	—	765
10/0	01	4·393	6·637	3·494	1·220	5·92	1·02	4·7	23	2	35	523
	Sp	4·849	8·05	4·28	1·96	5·1	—	—	—	—	—	662

1. Introduction

A realization of the constitution of the Earth's interior is limited by our knowledge of the properties and the behaviour of various materials at high pressure and high temperature. This paper presents the elastic parameters of olivine measured as a function of pressure, temperature, and composition, and discusses equations of state of olivine as a function of varying the iron/magnesium ratio in the olivine lattice. Olivine, $(Mg_x Fe_{1-x})_2SiO_4$, is an important rockforming mineral believed to be abundant in the Earth's upper mantle. Determination of the equations of state for olivine is therefore of particular interest to the study of the physical state and the chemical composition of this region of the Earth's interior. This paper studies some of the more important geophysical and thermodynamic properties associated with the effects of iron in olivine. The present report is a continuation of an earlier paper by this author on the elasticity of olivine in the forsterite-fayalite series at ambient conditions (see Chung 1970; referred to below as C1); it includes the elasticity data obtained under various pressure and temperature conditions.

There is abundant literature concerned with the elasticity of olivine. An extensive survey of the literature was made in the earlier report (see C1, p. 7357). A systematic comparison and discussion of these elasticity data at ambient conditions was also presented, and this will not be repeated in the present paper.

The first section of this paper presents a brief description of experimental procedure and olivine samples used, followed by the elasticity data of olivine as a function of pressure, temperature, and compositions. In the second part, equations of state for various olivines with different iron/magnesium ratios are given. A discussion is presented of the present olivine data and their relation to the Earth's mantle.

2. Olivine samples

The olivine samples used in this study were the same as those of the previous work by this author. They were produced by a pressure-sintering method. Along with the two end-member olivines, five other olivines with the following compositions were studied: 95 per cent Fo, 90 per cent Fo, 85 per cent Fo, 80 per cent Fo, and 50 per cent Fo, where " per cent Fo " designates a mole percent forsterite. The emphasis on these olivine compositions in this study was instigated by the present state-of-the-art hypothesis on the chemical composition of the Earth's upper mantle. The earlier paper discussed the chemical purities and character of these olivine samples (see C1, p. 7354), and readers are referred to the description found in that report.

3. Experimental method and procedure

The measurement of sound velocities at room conditions (at 23 °C and 1 bar), as a function of hydrostatic pressure to about 7·5 kb, and also a function of temperature, were made with the pulse-echo-overlap method. We used a simple piston-cylinder set-up of standard design (see Brace, Scholz & La Mori 1969, for example) as our pressure system. The pressure medium was reagent grade petroleum ether, and the pressure was read directly from a precalibrated 7500-bars Heise gauge. The readability of this gauge was better than 0·2 per cent of the pressure reading. X-cut and AC-cut quartz transducers with resonance frequencies of 10 to 20 MHz were used for generating compressional (*P*) and shear (*S*) waves respectively. The following materials for acoustic bonding between specimen and transducer were used: in the ultrasonic-pressure experiments, a 50 per cent mixture (by volume) of phthalic anhydride and glycerine; in the ultrasonic-temperature experiments, Nonaq stopcock