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An experimental study has been carried out on three typical ultrabasic rocks of the Monchegorsk pluton of the Kola Peninsula—olivinites, harzburgites, and bronzitites—and, more recently, on a number of other rocks and monomineralic aggregates. The experiments consisted in measuring the velocities of longitudinal v_p and transverse v_s waves at pressures up to 20 kbar, using a somewhat improved technique already described earlier ([1]). From the measured values of the velocities v_p and v_s and the initial density ρ_0 for the indicated rock types (8–10 samples were cut from each rock), the elastic parameters at different pressures were calculated (Table 1). The density at high pressures was calculated by the method of successive approximations.

For extrapolating the obtained quantities into the region of higher pressures, data on shock compressibility obtained as a result of a specially conducted investigation of the same types of rocks from the Monchegorsk pluton ([2]), as well as data by other authors on minerals ([3,4]), were used.

Table 1

	Olivinite	Olivinite	Olivinite	Olivinite	Harzburgite	Harzburgite	Harzburgite	Harzburgite	Bronzitite	Bronzitite	Bronzitite	Bronzitite
Pressure, kbar	0	2	10	20	0	2	10	20	0	2	10	20
v_p, km/sec	7.48	8.16	8.38	8.47	7.34	7.95	8.17	8.30	7.33	7.68	7.93	8.06
v_s, km/sec	4.30	4.56	4.70	4.75	4.34	4.53	4.64	4.72	4.28	4.43	4.57	4.65
v_p/v_s	1.74	1.79	1.78	1.78	1.69	1.76	1.76	1.76	1.71	1.73	1.73	1.73
ρ, g/cm^3	3.28	3.29	3.31	3.33	3.29	3.30	3.32	3.34	3.24	3.25	3.27	3.30
$\Phi = K/\rho$, km/sec	31.4	38.9	40.8	41.5	28.8	35.9	38.1	39.3	29.7	32.9	35.1	36.1

	Olivinite	Olivinite	Olivinite	Olivinite	Harzburgite	Harzburgite	Harzburgite	Harzburgite	Bronzitite	Bronzitite	Bronzitite	Bronzitite
$K \cdot 10^{-5}$, kg/cm^2	10.3	12.8	13.5	13.8	9.5	11.9	12.6	13.3	9.63	10.7	11.5	11.9

As a result of the analysis carried out, it was possible to reveal the general character of the variation of density and elastic parameters of the aforementioned rock types, as well as of a number of minerals, with pressure up to 200-300 kbar (Fig. 1). In constructing the graph $\rho = f(p)$, results both from static tests and from shock-compression data were used. It is interesting to note that the corresponding quantities obtained by different methods agreed quite well. This made it possible to obtain smooth curves over the entire pressure range considered. It should also be noted that the experimental points for olivine (and olivinite) agree well with the corresponding points obtained by Kumazawa by calculation using the Birch–Murnaghan equation of state ([5]). In Fig. 1, a pressure scale, depth scale, and temperature scale are plotted. In constructing the temperature scale, data ([6–10]) and others were used. These data are somewhat contradictory, especially for a depth of about 100 km. The temperature scale adopted by us down to a depth of 200 km generally agrees with the geother—

Ringwood' s model for the continents, and at greater depths agrees well with the data ([6], [7]). In the same figure, for a number of minerals, curves of density change are given with allowance for the temperature effect; the method used to calculate them is set out below.

From the changes in density as a function of pressure, values of the volume decrement $\Delta v/v_0$ at different pressures were calculated, and the corresponding graphs were constructed. From the graphs $\Delta v/v_0 = f(p)$, the values of compressibility β at different pressures were determined, and from the values of β —the bulk modulus $K = 1/\beta$ and the ratio $\Phi = K/\rho$. As a result, a definite regularity was revealed: the curve $K = f(p)$ for different substances (oxides and silicates) has approximately the same slope to the abscissa axis and is close to the straight line $dK/dp \cong 4$.

Fig. 1. Changes in density with pressure for a number of rocks and minerals. Dashed lines show density changes with allowance for the temperature effect. 1—quartz; 2—labrador; 3—bronzite (bronzitite); 4—diopside; 5—peridotite (garnburgite); 6—olivine (olivinite); 7—eclogite; 8—periclase; 9—spinel; 10—corundum; 11—Kumazawa' s calculated data for olivine; 12—Bullen' s model X.

The influence of temperature on the elastic parameters of oxides and silicates is more difficult to assess, since up to the present the question of the change in compressibility with temperature (or of the coefficient of thermal expansion with pressure) remains little studied. Recently, however, some new data have been obtained. Thus, for periclase, corundum, and forsterite, and partly for pyrope-almandine, linear changes in the bulk modulus (and shear modulus) with

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temperature have been established in the range 298—1200°K ([11]-[13]). Theoretically, using the Mie-Grüneisen equation, the experimental data have been extrapolated to temperatures of the order of 2500°K. These data are still preliminary, but apparently deserve considerable attention, since in the case of a linear change of the elastic moduli of oxides and silicates with temperature, the problem of determining the elastic parameters of the corresponding substances under the pressure and temperature conditions of the upper mantle is reduced to summing the effects according to the equation

$$\Delta K = (\partial K/\partial p)\Delta p - (\partial K/\partial T)\Delta T.$$

We attempted to compare these data with those of other authors, in particular Birch ([14]), and also to calculate the values of $\Delta K/\Delta T$ from the mean values of the coefficient of volumetric thermal expansion α_{av} and the mean compressibility β_{av}. It was assumed here that the ratio $\alpha_{\text{av}}/\beta_{\text{av}} =$

Table 2

No.	Object	$\alpha_{\text{av}} \cdot 10^6$, 1/deg	$\beta_{\text{av}} \cdot 10^6$, 1/bar	$\Delta p/\Delta T$, bar/deg	$-\partial K/\partial T$, calculated, kbar/deg	$-\partial K/\partial T$, according to ([11]—[13]), kbar/deg
1	Dunite				0.32	
2	Bronzitite				0.16	
3	"Eclogite"				0.12	
4	Olivine	30	0.76	40	0.16	0.13
5	Bronzitite	28	0.9	31	0.12	
6	Labrador	15	1.3	11.5	0.05	
7	Periclase	30	0.55	54	0.22	0.20
8	Corundum	20	0.39	51	0.20	0.23

No.	Object	$\alpha_{\text{av}} \cdot 10^6$, 1/deg	$\beta_{\text{av}} \cdot 10^6$, 1/bar	$\Delta p/\Delta T$, bar/deg	$-\partial K/\partial T$, calcu-lated, kbar/deg	$-\partial K/\partial T$, accord-ing to ([11]—[13]), kbar/deg
9	Diopside	28	0.8	35	0.14	
10	Pyrope	25	0.6	42	0.16	0.20

$= \Delta p/\Delta T$ changes little with pressure and temperature in the interval under consideration. The results of the calculations are presented in Table 2.

In Table 2, Nos. 1-3 correspond to Birch' s data ([14]) on the change in velocities of transverse waves for the corresponding rocks at pressures of 5-6 kbar in the temperature interval 20-500°C. In the calculations for substances Nos. 1-3, the values $v_p/v_s = 1.78$; 1.74; 1.77, respectively, were adopted. In the right-hand column of the table are given data from works ([11]—[13]). It is seen from the table that the values of $\Delta K/\Delta T$, obtained by different methods, agree more or less well for the corresponding minerals; the only exception may be considered the olivine rock (dunite, studied by Birch). Therefore, as a first approximation, Table 2 may be taken as a basis

Fig. 2. Changes in the elastic parameters $\Phi = K/\rho$ (a) and K (b) as functions of depth for a number of rocks and minerals. 1 —olivine; 2 —bronzitite; 3 —diopside; 4 —labrador; 5 —pyrope; 6 —periclase; 7 —corundum; 8 —garnierite; 9 —olivinite; 10 —eclogite; 11 — "peridotite" of layer B of the continents; 12 and 13 —values of $\Phi = K/\rho$ in the Earth' s mantle according to Gutenberg and Jeffreys.

for further calculations of the moduli K and the parameter $\Phi = K/\rho$ under the temperature conditions of the upper mantle.

The results of calculations for a number of rocks and minerals are presented as graphs in Figs. 1 and 2. In constructing these graphs, polymorphic transformations were not taken into account.

It is evident from Fig. 2 that rocks of the bronzitite and harzburgite types, in their properties, are not suitable for the upper mantle of the continents; they are also unsuitable in density (Fig. 1). Rocks of the olivinite type of the Monchegorsk pluton are well suited in terms of elastic parameters, but are not entirely suitable in density; the same may be said of pure olivine, close in composition to forsterite. In terms of elastic properties and density, eclogites are well suited (an ideal eclogite consisting of pyrope and diopside is taken as the basis). The symbolic "peridotite" that underlies the continents and has the following elastic parameters at a depth of 35 km[1] lies almost exactly on Gutenberg' s curve: $\rho = 3.32$ g/cm^3; $v_p = 8.12$ km/sec; $v_s = 4.65$ km/sec; $v_p/v_s = 1.75$; $K/\rho = 37.8$ (km/sec)^2. However, if the temperature effect is taken

[1] B. Gutenberg, *Physics of the Earth' s Interior*, IL, 1963.

into account, then this "peridotite," in its elastic properties, should be assigned rather to dunite or olivinite. In its elastic properties this rock agrees well with the Gutenberg and Jeffreys models down to a depth of 200–250 km; however, in density it does not fully correspond to Bullen' s model X. It is interesting to note that almost all the substances considered, except labradorite, showed a decrease in the values of the elastic parameters in the depth interval 50–150 km, which agrees well with the presence in the upper mantle of a low-velocity zone at these same depths. This question will be considered in greater detail later.

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Note: Figure translations are in progress. See original paper for figures.