EFFECT OF HYDROSTATIC PRESSURE UP TO 4000 kg/cm^{2} ON THE ELASTIC PROPERTIES OF ROCK SAMPLES

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Abstract

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EFFECT OF HYDROSTATIC PRESSURE UP TO 4000 kg/cm^2 ON THE ELASTIC PROPERTIES OF ROCK SAMPLES

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The experimental study of the elastic properties of rocks has recently attracted great interest. Measurements of the velocities of elastic waves, of Young' s and shear moduli, and also of Poisson' s ratio at high pressures and elevated temperatures make it possible to draw conclusions about the properties of rocks in the Earth' s interior.

In the present investigation the elastic parameters of rock samples at high hydrostatic pressures were determined on the basis of measured values of the velocities of longitudinal waves: $V_{\mathrm{P}} = (E/\rho)^{1/2}$—the propagation velocity in a thin rod, and $V_{PM} = [E(1-\sigma)/\rho(1+\sigma)(1-2\sigma)]^{1/2}$—the propagation velocity in an unbounded medium (E—Young' s modulus, ρ—density, σ—Poisson' s ratio) ([1]). The tests were carried out in a high-pressure chamber ([2]), where the pressure could be raised from atmospheric to 4000 kg/cm^2. The electronic apparatus for measuring ultrasonic velocities by the pulse method consisted of a modernized IKL-5 instrument ([3]). Crystals of ammonium dihydrogen phosphate were used as transmitters and receivers. For measuring V_{P} , a pair of crystals with frequencies of 100 kc/s was used, and for measuring V_{PM}—with frequencies of 600 kc/s. Crystals of different frequencies were mounted in one housing and were switched on alternately, so that in the course of one experiment both velocities were measured.

The rock samples were prepared in the form of circular cylinders 3 cm in diameter and 16-20 cm long. The samples were dried and sealed in a thin copper jacket in order to prevent penetration of nitrogen, transmitting the pressure, into the pores of the rock. The following rocks were studied: gabbro 82 from the Shvedskoe deposit, gabbro-diorite 38, granites 247, 248, and 249, quartzite 22 from the Shokshinskoe deposit, sandstone 213, sandstone 94 from the Zubovskoe deposit, sandstone 205, and marls 206 and 207 obtained from the Novo-Alekseevskaya deep borehole. Thus, a set of samples of igneous and sedimentary rocks, as well as quartzite—a metamorphic rock—was represented.

Figure 1 shows graphs of the change in the velocities of longitudinal and transverse waves with pressure. A sharp increase in velocities at low pressures, characteristic of rocks, is observed; then the velocities increase more slowly. This

Fig. 1. Curves of the change in the velocities of longitudinal (solid lines) and transverse (dashed lines) waves in rock samples with pressure (numbers beside the curves are sample numbers; see text)

Figure 1: Fig. 1. Curves of the change in the velocities of longitudinal (solid lines) and transverse (dashed lines) waves in rock samples with pressure (numbers beside the curves are sample numbers; see text)

Fig. 2. Curves of change in Young' s modulus (solid lines) and shear modulus (dashed lines) of rock specimens with pressure (the numbers beside the curves are specimen numbers; see text)

Figure 2: Fig. 2. Curves of change in Young' s modulus (solid lines) and shear modulus (dashed lines) of rock specimens with pressure (the numbers beside the curves are specimen numbers; see text)

change in velocities is due mainly to a reduction in the volume of pores, which occurs under the influence of hydrostatic pressure. It is evident from the graph that more porous and less dense rocks (sandstones 206 and 207, with porosities of 24 and 26% and densities of 1.82 and 1.85 g/cm^3, respectively) exhibit a large change in the velocities of elastic waves, namely by 50-53%. Compact, dense rocks, whose main mass is continuous and free of cracks, such as gabbro 82 ($\rho = 2.98$ g/cm^3) and gabbro-diorite 38 ($\rho = 2.96$ g/cm^3), show only a slight increase in velocities with pressure (by 5-8%).

It was of interest to refine the data obtained for the velocities of longitudinal waves by taking into account the influence of temperature. For this purpose one can use the temperature coefficients of velocity derived by Birch (4), $\frac{1}{V}\frac{dV}{dt}$. For granite it is equal to $-40 \cdot 10^{-6}$ per degree; for gabbro

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$-50 \cdot 10^{-6}$ per degree; for quartzite, $13 \cdot 10^{-6}$ per degree. If these coefficients are taken into account, then for a depth of 15 km, corresponding to a pressure of 4000 kg/cm^2 and a temperature of about 220°, the values of the longitudinal-wave velocities shown in Table 1 are obtained. The results presented agree well with the data from deep seismic sounding ([5]).

Fig. 2. Curves of change in Young' s modulus (solid lines) and shear modulus (dashed lines) of rock specimens with pressure (the numbers beside the curves are specimen numbers; see text).

Figure 2 shows the curves of change in Young' s modulus and the shear modulus with pressure. The values of the moduli, as well as the transverse-wave velocities, were calculated on the basis of the measured velocities $V_{P\text{st}}$ and V_{PM}. In addition, the calculation took into account the change in density with pressure

([6]), which proves to be very small: at the maximum pressure of 4000 kg/cm^2, the density increases by no more than 1%.

Table 2 gives the values of Poisson' s ratio for the rocks studied at various pressures. Poisson' s ratio changes little with increasing pressure, sometimes decreasing slightly, and in a number of cases increasing.

Table 1

	Granite 248	Granite 249	Gabbro 82	Gabbro 38	Quartzite 22
V_p (m/sec), experimental at 4000 kg/cm^2	5850	6120	6800	6520	6000
V_p (m/sec), with temperature taken into account	5800	6070	6730	6450	5980

Thus, the investigation carried out shows that, under the influence of all-round pressure, the elastic parameters of rocks increase, with the exception of Poisson' s ratio, whose change is irregular.

Table 2

Rock	Pressure, kg/cm^2	Pressure, kg/cm^2	Pressure, kg/cm^2	Pressure, kg/cm^2	Pressure, kg/cm^2
	1	500	1000	2000	4000
Gabbro 82	0.31	0.30	0.29	0.29	0.29
Gabbro-diorite 38	0.29	0.28	0.28	0.28	0.28
Granite 247	0.24	0.22	0.22	0.21	0.21
Granite 248	0.12	0.21	0.19		
Granite 249	0.12	0.16	0.19	0.19	0.19

Rock	Pressure, kg/cm^2	Pressure, kg/cm^2	Pressure, kg/cm^2	Pressure, kg/cm^2	Pressure, kg/cm^2
Quartzite 22	0.19	0.19	0.19	0.18	
Sandstone 213	0.18	0.18	0.17	0.15	0.15
Sandstone 205	0.19	0.19	0.19	0.16	0.16
Sandstone 94	0.11	0.12	0.15	0.16	0.17
Marl 206	0.19	0.19		0.19	0.19
Marl 207	0.21	0.19	0.19	0.19	

At the same time, the values of the velocities of longitudinal waves, especially those corrected with allowance for temperature, agree satisfactorily with the data of deep seismic sounding.

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