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**Abstract**

**Full Text**

## **GEOPHYSICS**

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# **INVESTIGATION OF ELASTIC-WAVE VELOCITIES IN ULTRABASIC ROCKS OF THE MONCHEGORSK PLUTON UNDER CONDITIONS OF HIGH HYDROSTATIC PRESSURE**

Among the large number of rocks whose elastic properties have been investigated at high pressure (<sup>1-3</sup>), ultrabasic rocks have so far not been represented. A study of the velocities of elastic waves in the latter under conditions of hydrostatic pressure will make it possible to broaden our conception of the structure of the deep layers of the Earth's crust and the upper mantle of the Earth (<sup>3-5</sup>). In this connection, samples of pyroxenites and peridotites of the Monchegorsk pluton were selected, where these rocks crop out at the surface and have been exposed by numerous boreholes and mine workings.

The Monchegorsk pluton is located in the central part of the Kola Peninsula and is confined to a major tectonic zone of northwestern strike. The geological study of this pluton and the rocks enclosing it has been carried out by a number of authors (<sup>6-9</sup>). The pluton consists of three massifs: Nyuduaivench-Poazuaivench, Sopchuaivench, Nittis-Kumuzh' ya-Travyanaya. The structural analysis carried out made it possible to establish that these massifs constitute a single sheetlike intrusive body, extending to the northwest and dipping gently to the southwest. It is believed that the primary magma corresponded in composition to melanocratic olivine norite. In the western part of the pluton (the Nittis-Kumuzh' ya-Travyanaya massif), feldspar-free rocks predominate—pyroxenites, olivine pyroxenites, and peridotites. Feldspathic rocks occur here in the bottom part of the massif, in the contact zone with the underlying Archean gneisses. In the eastern part of the pluton (the Nyud-Poaz massif), feldspathic rocks predominate—norites, gabbro-norites, and plagioclase pyroxenites. The central part of the pluton (the Sopcha massif) is composed chiefly of pyroxenites. The complex of ultrabasic and gabbroid rocks in the area of Mt. Nittis-Kumuzh' ya has a thickness (down to the bed of Archean gneisses) of about 600 m, and in the area of Mt. Sopcha about 1000 m. On the basis of the detailed structural analysis they carried out, as well as the analysis of deep boreholes, the above-mentioned authors came to the conclusion that the ascent of magma took place along steeply dipping fractures in the Archean gneisses; subsequently

Fig. 1. Dependence of the velocities of longitudinal (1) and transverse (2) waves in rock samples on pressure. The numbers correspond to the numbers in Table 1.

Figure 1: Fig. 1. Dependence of the velocities of longitudinal (1) and transverse (2) waves in rock samples on pressure. The numbers correspond to the numbers in Table 1.

the magma spread along a gently dipping tectonic contact.

The age of the basic rocks of the Monchegorsk pluton is determined by the fact that they cut Archean gneisses and crystalline schists with an absolute age, according to the lead-isochron method <sup>(10)</sup>, of  $3150 \pm 50$  million years. There are geological considerations that the roof of the intrusions of ultrabasic rocks is formed by rocks of the Imandra-Varzuga suite of Proterozoic age. Attempts have been made to determine the absolute age of the ultrabasic rocks themselves. Determinations by the K–Ar method <sup>(11)</sup> on core material from Mt. Nittis and Mt. Travyanaya gave two sharply differing groups of figures. The predominant mass of figures fluctuates around 3000 million years. The other group of figures (3–4 samples) proved to be much more ancient—on the order of 5200–6500 million years. Judging from the data cited <sup>(11)</sup>, such great ages relate to horizons of 320 and 363 m on Mt. Nittis. It should be noted that in rocks of such ancient age, with a radiogenic argon content sufficient for measurements, the potassium content is very low (0.091 and 0.083). The results of age measurements of a large number of rocks of ultrabasic in-

Monchegorsk intrusion and the enclosing rocks by the lead-isochron method <sup>(10)</sup> fit very well on the combined isochron of all the other samples. The combined isochron equation for the ultrabasic rocks corresponds to an age of  $2900 \pm 200$  million years. The authors indicate that, since the experimental scatter of points around the isochron nowhere exceeds the errors of the mass-spectrometric determination of the isotopic composition of lead, this is indirect evidence for the common genesis of all the samples studied. On the basis of the above, the supposition is hardly justified that samples of ultrabasic rocks with an age of 5000–6000 million years (according to K–Ar-method data) belong to xenoliths of subcrustal material of the Earth. Moreover, the preservation of excess argon in a xenolith that entered an ultrabasic melt is improbable. If the accuracy of the analytical data for K does not affect the age figure of the oldest rocks, then the excess argon in ultrabasic rocks is more likely to be explained by its capture by minerals of the crystallizing ultrabasite magma during its interaction with Archean gneissic rocks that had already accumulated radiogenic argon.

**Fig. 1.** Dependence on pressure of the velocities of longitudinal (1) and transverse (2) waves in rock samples. The numbers correspond to the numbers in Table 1.

For the study of elastic-wave velocities, the principal varieties of rocks from different massifs of the pluton were selected; among them were also representatives of the basic rocks—norites. The results of the petrographic study and of the determination of the physical properties of the samples are summarized in Table 1. The determination of the velocities of elastic waves in samples of rocks was carried out by the dynamic method ( $\hat{1}$ ), by direct measurement of the propagation velocities of longitudinal and transverse waves in the samples.

The results of measuring the velocities of longitudinal and transverse waves in rock samples as a function of pressure are given in Fig. 1. The velocities of longitudinal waves in the basic rocks are somewhat lower than in the ultrabasic rocks and at a pressure of 4000 kg/cm<sup>2</sup> reach 7050 m/sec. The experimental results presented in the table show the dependence of the value of the elastic-wave velocities ( $v_p$ ) on: 1) the magnitude of the confining pressure, 2) the material (mineral) composition of the rock, and 3) apparently, the total content of readily closing cracks and intergranular spaces. The velocity  $v_p$  in samples at atmospheric pressure depends on the second and third factors. In rocks of predominantly olivine-pyroxene composition (pyroxenites, peridotites),  $v_p$  ranges from 6800 to 7600 m/sec, with deviations from the mean of 7200 by  $\pm 5.5\%$ , increases and at the same time becomes more uniform. The deviation from the mean of 7700 m/sec is  $\pm 4\%$ .

**Table 1**

Sample no.	Place where sample was taken	Rock; depth at which sample was taken	Bulk density	Porosity	$v_p$ , m/s; $p = 1$ kg/cm <sup>2</sup>	$v_p$ , m/s; $p = 1000$ kg/cm <sup>2</sup>	$v_p$ , m/s; $p = 4000$ kg/cm <sup>2</sup>	Mineral composition	Structure, texture, features of the rock
466	Mt. Nittishya Kumuzhatered; 100 m	Gabbro-norite, hyalinated;	2,93	0,27	6500	6700 (3,0%)	6750 (0,7%)	Rhombohedral pyroxene plagioclase (labradorite-anorthite) 37%, quartz 10%, biotite 16%, amphibole 5%, chlorite and ore minerals 4%	Size of primary grains 3-4 mm. Massive fabric. The rock is subjected to biotitization and silicification

Sample no.	Place where sample was taken	Rock; depth at which sample was taken	Bulk density	Porosity	$v_p$ , m/s; $p = 1$ kg/cm <sup>2</sup>	$v_p$ , m/s; $p = 1000$ kg/cm <sup>2</sup>	$v_p$ , m/s; $p = 4000$ kg/cm <sup>2</sup>	Mineral composition	Structure, texture, features of the rock
462	Same	Plagioclase; 21 peridotite; 100 m	3,21	0,32	6970	7830 (12,3%)	8020 (2,4%)	Olivine 61%, rhombic pyroxene 21%, plagioclase — labradorite 10%, ore minerals and reaction products 6%	Grain size 3-4 mm. Massive fabric. Panidiomorphic-granular structure with poikilitic intergrowths

Sample no.	Place where sample was taken	Rock; depth at which sample was taken	Bulk density	Porosity	$v_p$ , m/s; $p = 1$ kg/cm <sup>2</sup>	$v_p$ , m/s; $p = 1000$ kg/cm <sup>2</sup>	$v_p$ , m/s; $p = 4000$ kg/cm <sup>2</sup>	Mineral composition	Structure, texture, features of the rock
457	Same	Pyroxenite, 105 m	3,24	0,37	7140	7400 (3,6%)	7400 (0,0%)	Rhombohedral pyroxene 85%, olivine 5%, labradorite 9%, reaction minerals 1%	Massive fabric. Panidiomorphic-granular structure. Grain size 4-5 mm

Sample no.	Place where sample was taken	Rock; depth at which sample was taken	Bulk density	Porosity	$v_p$ , m/s; $p = 1$ kg/cm <sup>2</sup>	$v_p$ , m/s; $p = 1000$ kg/cm <sup>2</sup>	$v_p$ , m/s; $p = 4000$ kg/cm <sup>2</sup>	Mineral composition	Structure, texture, features of the rock
455	Same	Peridotite, 105 m	3,28	0,38	7400	7700 (4,0%)	7700 (0,0%)	Olivine 56%, pyroxene 25%, plagioclase and reaction minerals, serpentine 14%, ore minerals 5%	Massive fabric. Panidiomorphic-granular structure. Grain size 4-5 mm

Sample no.	Place where sample was taken	Rock; depth at which sample was taken	Bulk density	Porosity	$v_p$ , m/s; $p = 1$ kg/cm <sup>2</sup>	$v_p$ , m/s; $p = 1000$ kg/cm <sup>2</sup>	$v_p$ , m/s; $p = 4000$ kg/cm <sup>2</sup>	Mineral composition	Structure, texture, features of the rock
469	Mt. Sopchaym	Olivine	3,29	0,32	7620	7870 (3,3%)	8000 (1,7%)	Rhombohedral pyroxene olivine plagioclase ore minerals	Massive fabric. Panned olivine iomorphic structure. Grain size 3-4 mm. Plagioclase does not form cement

Sample no.	Place where sample was taken	Rock; depth at which sample was taken	Bulk density	Porosity	$v_p$ , m/s; $p = 1$ kg/cm <sup>2</sup>	$v_p$ , m/s; $p = 1000$ kg/cm <sup>2</sup>	$v_p$ , m/s; $p = 4000$ kg/cm <sup>2</sup>	Mineral composition	Structure, texture, features of the rock
470	Same	Olivine-bearing norite; 300 m	3,22	0,41	5900	6720 (14,0%)	7050 (5,0%)	Rhombohedral pyroxene 76%, plagioclase – labradorite fills in-terstices, forming “cement” 16%, olivine 5%, ore and reaction minerals 3%	Inequigranular, panned-idiomorphic phic structure. Grain size 0,5 mm. Trachystoid texture

Sample no.	Place where sample was taken	Rock; depth at which sample was taken	Bulk density	Porosity	$v_p$ , m/s; $p = 1$ kg/cm <sup>2</sup>	$v_p$ , m/s; $p = 1000$ kg/cm <sup>2</sup>	$v_p$ , m/s; $p = 4000$ kg/cm <sup>2</sup>	Mineral composition	Structure, texture, features of the rock
472	Same	Olivine pyroxenite; 800 m	3,24	0,42	6750	7670 (13,6%)	7670 (0,0%)	Rhombohedral pyroxene 61%, olivine 25%, plagioclase and reaction minerals 8%, ore minerals 3%	Massive fabric. Pseudomorph structure. Grain size 3-4 mm

Sample no.	Place where sample was taken	Rock; depth at which sample was taken	Bulk density	Porosity	$v_p$ , m/s; $p = 1000$ kg/cm <sup>2</sup>	$v_p$ , m/s; $p = 1000$ kg/cm <sup>2</sup>	$v_p$ , m/s; $p = 4000$ kg/cm <sup>2</sup>	Mineral composition	Structure, texture, features of the rock
468	Mt. Nyud	Melanocrinite; 298 m	3.15	0,21	6750	7050 (4,5%)	7050 (0,0%)	Rhombohedral pyroxene 75%, olivine 5%, labradonite and reaction minerals forming "cement," 20%	Panidiomorphic-poikilitic structure. Grain size 5-6 $\mu$ m. Massive texture.

The materials presented confirm a substantial increase in the velocities  $v_p$  when all-round compression reaches 1000 kg/cm<sup>2</sup>. For peridotite No. 462 the velocity increases by 12.3%, for pyroxenite No. 472 by 13.6%, and for norite No. 470 by 14%. These rock specimens probably have the greatest microfracturing. For the remaining rocks subjected to testing, the velocity  $v_p$ , as pressure is raised to 1000 kg/cm<sup>2</sup>, increases by 3-4%. Only for these same rocks Nos. 462 and 470 is there a noticeable increase (by 2.5-5%) in the velocity of longitudinal waves when the pressure is raised from 1000 to 4000 kg/cm<sup>2</sup>. In all other cases either no further increase in  $v_p$  is observed, or it does not exceed 1.5%. In two specimens of ultrabasic rocks (Nos. 462 and 469) the velocity reached 8000 m/sec at a pressure of 4000 kg/cm<sup>2</sup>.

Using material from the city of Sochi, petrographically uniform specimens (Nos. 469 and 472) from different depths, at atmospheric pressure, do not show an increase in velocity with depth of occurrence. This indicates the absence of residual changes in the elastic properties of the rock, which had for a long time been in a stressed state under a pressure of the order of 300 kg/cm<sup>2</sup>. Micro-

scopic study made it possible in a number of cases to connect the decrease in the velocity of longitudinal waves with a significant, up to 15–20%, content of plagioclase in the ultrabasite, creating a specific rock structure—the mineral of residual crystallization. In these cases plagioclase fills the spaces between already crystallized grains of olivine and pyroxene; along the boundary of plagioclase with olivine and pyroxene, aggregate reaction rims of a scaly-fibrous mineral are formed. As a result, plagioclase and the minerals of the reaction series, located in the interstices between olivine and plagioclase, form a kind of “cement” of the rock.

The values of the velocities of transverse waves in the rocks studied are contained in the interval from 3200 to 4200 m/sec. From the data for the velocities of longitudinal and transverse waves the Poisson coefficients were calculated. For ultrabasic rocks their magnitude does not differ from the Poisson coefficients for basic rocks and has values of 0.28–0.30 at atmospheric pressure. With increasing pressure the Poisson coefficients change only slightly and at 4000 kg/cm<sup>2</sup> amount to 0.28–0.33.

The study carried out will make it possible to interpret more definitely the data of deep seismic sounding in the forthcoming comprehensive geological-geophysical investigation of the Baltic Shield.

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