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STUDY OF THE PHYSICAL PROPERTIES OF CRYSTALLINE ROCKS IN THE SOUTHEAST VORONEZH ANTECLISE

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STUDY OF THE PHYSICAL PROPERTIES OF CRYSTALLINE ROCKS IN THE SOUTH-
EAST VORONEZH ANTECLISE

By V. S. Dmitriyevskiy, N. S. Afanas'yev and S. M. Frolov

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Study of the physical properties of rocks is very important for improving geological efficiency of geophysical methods for mapping crystalline rocks in the foundation and exploring different geological objects associated with the crystalline foundation, covered by the sedimentary mantle. In addition, studying the physical properties of rocks allows us to solve many questions involving genesis, interrelationship, metamorphism, and so forth.

Complicated rock complexes differing in age, genesis, degree of metamorphism, substance composition and physical properties have been established by now by drilling and geophysical work in the southeast Voronezh anteclise territory. Deeply metamorphized rocks of the gneiss type, amphibolites and their migmatites (gneiss complex), and comparatively weakly metamorphized sandy, aleurite and phyllite-like shales (shale complex) have been found here. However, granitoid rocks, predominantly of palingenic and metasomatic genesis are widespread. Bodies of basic and ultrabasic rocks extended in a chain mainly along the Losevsko-Mamonskiy zone of tectonic dislocations occupy a considerable place in the crystalline foundation structure. Finally, sheet deposits of paleobasalts are intersected in the sedimentary deposits of the Devonian in a number of places by wells.

Brief characteristics of the physical properties of rocks in the crystalline mass of the foundation (and partially the mantle) of the Voronezh anteclise are presented in the summary table, which gives the value of their density (g/cm^3), magnetic susceptibility (10^{-6} CGSM), residual magnetization caused by polarization and the rate of spread of ultrasound in them (m/sec). Measurements of all physical properties were made according to the existing techniques.

*Numbers in margin indicate pagination in original foreign text.

TABLE. TABLE OF PHYSICAL PROPERTIES FOR CRYSTALLINE ROCKS OF THE SOUTHEAST VORONEZH ANTECLISE

Плотность (1)		Минерная порция (2) в %		Средняя влажность (3) в %		Поларизуемость (4)		Скорость ультразвука (5)				
ср. (от-до)	коэф. (7) от-до	ср. (от-до)	коэф. (7) от-до	ср. (от-до)	коэф. (7) от-до	ср. (от-до)	коэф. (7) от-до	ср. (от-до)	коэф. (7) от-до			
1	2	3	4	5	6	7	8	9	10	11	12	13
3,41 3,29-3,66	20	92000 58000-135000	19	quartzites, alkali-amphibole-magnetite		7	8	19	4850 3950-5700	11	(6)	(7)
2,71 2,57-2,92	240	25 2-510	252	shales, biotite-quartz, biotite-sericite-quartz		7	165	5530 4500-6800	5200 4850-5750	18	4850 3950-5700	8
2,72 2,60-2,84	112	20 4-160	132	metasandstones, hornfels, biotite-plagioclase-quartz		7	62	5150 4550-6200	5530 4500-6800	44	5500 4250-6250	175
2,80 2,64-3,21	77	450 2-5500	77	gneisses, biotite-hornblende-plagioclase with garnet		7	52	5200 3950-6100	4550-6200	41	5500 4250-6250	94
2,75 2,61-2,95	64	55 0-590	64	gneisses, biotite-muscovite-plagioclase		7	18	5200 3950-6100	3400-5000	41	5500 4250-6250	53
2,67 2,60-2,80	234	1650 0-5700	234	migmatites, hornblende-biotite-plagioclase, biotite-feldspar		7	6	5200 3950-6100	5200	41	5500 4250-6250	17
2,80 2,73-2,90	38	1300 10-6150	39	granodiorites, biotite-hornblende		7	44	5500 5100-6300	5500 5100-6300	41	5500 4250-6250	50
2,73 2,61-2,83	60	70 5-720	59	plagiogranites, biotite-hornblende-plagioclase		7	13	5150 4400-6500	5150 4400-6500	41	5500 4250-6250	16
2,67 2,60-2,73	61	2250 10-6300	60	granosyenites, biotite-hornblende-microcline		7	48	5500 4300-6600	5500 4300-6600	13	5500 4250-6250	49
2,64 2,58-2,78	227	1100 10-7500	220	granites, biotite-hornblende-plagioclase-microcline		7	110	5500 400-6400	5500 400-6400	48	5500 4250-6250	53
2,63 2,59-2,67	46	500 18-1350	37	granites, biotite-microcline		7	23	5500 4900-6400	5500 4900-6400	110	4850 3200-6100	147
3,18 2,90-3,38	23	90000 4500-58000	23	hornblendites, orthoamphibolites		7	14	4950 3700-5700	4950 3700-5700	23	5350 4300-5900	23

(Table continued on next page)

TABLE. Continued:

1	2	3	4	5	6	7	8	9	10	11	12
3.09 2.87-3.31	193	350 10-1800	194	650 <200-2600	pyroxinites, slightly amphibolized 2-5	126	6250 4300-7300	103	6150 4100-7300		
2.90 2.60-3.25	317	3000 40-32500	315	4100 <80-17500	peridotites, serpentinitized 296 0.7-2.5 12 0.34-81	154	5100 3750-6650	140	5190 2400-5530		
2.91 2.68-3.20	135	600 20-1200	130	2300 130-4800	amphibolites, apopyroxenite and apoperidotite 47 2-5	68	5450 3400-6000	57	3250 3850-6650		
2.66 2.31-2.90	807	4300 20-21000	786	4500 130-62000	serpentinites, apoperidotite 616 1-3 64 0.44-31.1	417	4700 2300-6650	325	4500 1950-6450		
2.46 2.05-2.68	335	5250 25-29600	387	1400 65-13300	serpentinites, apoolieinites 315 0.2-0.8 81 12.9 1.17-55.5	270	3400 1400-5500	157	3500 1570-5700		
3.03 2.90-3.20	85	8000 25-12100	78	2350 140-8200	gabbro, hornblende, melanocrat 26 0.5-0.8	37	5800 4150-6710	33	5800 4400-6050		
2.93 2.76-3.20	314	950 20-12200	286	6500 200-28400	gabbro-norites, gabbropyxene and olleino-pyroxene 210 5-15	143	5500 3900-7000	157	5500 3700-6300		
2.98 2.68-3.14	99	30 10-360	97		gabbro-pyroxinites to pyroxinite, amphibolized	75	6750 6050-7300	78	6700 5700-7200		
2.88 2.60-3.02	108	1250 10-6100	108	1450 140-8200	gabbro-diabases, gabbro-diorites, amphibolized 37	75	5000 4550-6500	51	5000 4700-6500		
2.82 2.69-3.05	117	50 9-650	117		diorites, biotite-hornblende	77	5870 5000-6700	53	5870 5000-6700		
2.84 2.67-2.95	92	2100 300-3800	91	1750 1100-2800	paleobasalts (D3) 17	50	4950 3850-5710	17	4950 3850-5710		

Key:

1. density
2. magnetic susceptibility
3. residual magnetization
4. polarizability
5. ultrasound velocity
6. average (from-to)
7. number of samples

The table includes data that refer to fresh (nonweathered) rocks (see table).

The characterized types of rocks have considerable fluctuations and different ratio in the examined properties.

The density of crystalline formations of the Precambrian and paleobasalts of the Devonian have a very broad range of average values, from 3.43 g/cm³ for ferruginous quartzites to 2.60 g/cm³ for pigmetites.

In the group of basic and ultrabasic rocks, the hornblendites of the Sergeevskiy complex have the highest density properties: /250 in the region of Belgor'ye 3.30 g/cm³, and somewhat less, 3.17 g/cm³ in the region of Sergeevka and Kodintsovka, 30.05 g/cm³. The average density of the pyroxenites is 3.09 g/cm³, and the peridotites 2.90 g/cm³.

In the shale group, the densities are 2.64 - 2.77 g/cm³. Of them the biotites of keratinized analogs have high values, and sericitites have low, which is also linked to their mineralogical features and the degree of metamorphism.

Magnetic susceptibility of the studied rocks fluctuates in very broad limits, not only from group to group, even within one variety of a definite type of rock. These fluctuations are primarily determined by the presence or absence of ferromagnetic minerals, the ratios of the latter, conditions of their isolation, secondary changes and other factors. The highest magnetic susceptibility is in ferruginous quartzites of the Kodintsovka section (average value 92,000 x 10⁻⁶ CGSM) with magnetite content up to 40%; it is somewhat lower (from 18,150 to 33,000) in the orthoamphibolites of the Sergeevka and Belgor'ye sections which have up to 20% magnetite.

Severe fluctuations in magnetic susceptibility are noted in

all types of gabbroids from the first units to 10,000 - 12,000. In this case the low values are generally found in the differences, almost devoid of ore mineral or containing it in single grains. The gabbro-pyroxinites have very low magnetic susceptibility, 30×10^{-6} (average) and the melanocratic pyroxene-hornblende gabbros of the Razdorenskiy massif have the maximum reaching 8,000 units. It has been established that even within one massif one can encounter both magnetite and nonmagnetite differences of gabbroids, which creates definite difficulties for mapping them by magnetic exploration.

In the granitoid rocks, the magnetic properties are also exposed to sharp fluctuations (from zero to 7500). Their minimum values are in pegmatites, zero - 7 units, higher in fine-grained and leucocratic differences (average 560) and maximum (2250) in porphyraceous granosyenites in the central band of the region. In this case, both as in the gabbro, the magnetic susceptibility of the granitoid rocks on the whole is determined by the content of ore mineral (primarily magnetite), whose quantity sometimes rises to 5%. /252

Granites of the Kodintsovka , and in the overwhelming majority of the Sergeyevka sections, by the way, which almost do not contain ore mineral, are essentially nonmagnetic. High values of magnetic susceptibility of granitoids in the central band of the region (Pavlovsk, Basovka, Shkurlat) are apparently due to the fact that these granitoids develop through the rocks with considerable content of dark-colored components in the composition. Recently amphibolites, gabbro-amphibolites and others which differ in shape and body size have been established in this region. Granitization of these rocks is accompanied by release of magnetite and other ore minerals.

Amphibolites, gneisses, and migmatites, like the granitoids, have variable magnetization. Its maximum value is found in migmatites, 1650×10^{-6} , as well as those confined to the central band of the region. It has been established that at a definite stage of migmatization of gneisses, especially amphibolites, magnetic

susceptibility reaches a certain maximum. The magnetic properties decline with further development of the process. The gneisses and migmatites, in the same way as the granites on the sections of Sergeyevka and Kodintsovka are essentially nonmagnetic or slightly magnetic. Considerable magnetization is only found during migmatization of the hornblendites (wells 185, 186).

Rocks in the shale complex are usually nonmagnetic (up to the first dozen units). However several shale samples on the Kodintsovka section associated with ferruginous quartzites that have magnetic susceptibility to $13,700 \times 10^{-6}$ have been noted.

Paleobasalts containing 5 - 7% ore mineral (titanium-magnetite) have stable magnetic susceptibility, 2100×10^{-6} (average).

Magnetic susceptibility of peridotites and pyroxinites fluctuates from 350 to 3000 units, serpentinites 1300 - 5250 units, and apopyroxinite amphibolites 600 units. Fluctuations in magnetic susceptibility in rocks of the pyroxinite-peridotite-serpentinite complex are due to a series of factors, of which the primary are: composition of primary ore mineralization, degree of substitution of sulfide mineralization by allometamorphic, and partially autometamorphic magnetite, the degree of auto- and allometasomatic reprocessing of the primary rocks, and the appearance of veined mineralization.

Residual magnetization (I_r) and the Q factor (ratio J_r/I_i) of crystalline formations of the southeast Voronezh anticline have the most diverse values for individual rock groups. Their maximum quantities are noted in the gabbro-norites and the olivine-pyroxene gabbros: 6500×10^{-6} , residual magnetization, from 5 to 40, Q factor. High parameters of I_r and Q indicate thermal magnetization of the rocks at high temperatures (above the Curie point of magnetite) [2, 3, 4, 5]. Residual magnetization and the Q factor of pyroxene-hornblende gabbros are 2350×10^{-6} and 0.5 - 0.8. In all probability, isolation of the ore mineral (magnetite) here occurred during

substitution of pyroxene by the hornblende at temperatures below the Curie point. Low values of residual magnetization and the Q factor are noted for hornblendites, 2500×10^{-6} and 0.2 - 0.5, and very low for amphibolites, gneisses, migmatites and granites, which also indicates relatively low temperatures for the formation of ferromagnetics of these rocks.

Among the ultrabasites of the Mamonskiy complex, maximum residual magnetization (in absolute value) is found in the peridotites and apoperidotite serpentinites, 4100 and 4500×10^{-6} . With ratio J_r/I_i equal to 1 - 3, the Q factor of pyroxinites reaches 5 with relatively low magnetic properties (350 magnetic susceptibility and 650 residual magnetization). With noticeable manifestation of hydrothermal reprocessing of the serpentinites (carbonatization, chloritization, talc formation, substitution of sulfides by allometamorphic magnetite) and with considerable rise in magnetic susceptibility, the Q factor drops to 0.2 - 0.8 (here the magnetite is clearly low-temperature). The induced polarization was measured on a small number of samples mainly for peridotites and serpentinites. Its increased values are noted in zones with noticeable sulfide impregnation. The nature of the bond, polarizability and content of different ore minerals (including magnet) in the rock are not yet clear. Work in this area has been started and is underway. /253

Rate of ultrasound spread in its absolute values is characterized by comparatively close quantities (averaging 5200 - 5700 m/sec) for the majority of rocks in the region, excluding gabbros, pyroxinites, where these quantities reach the maximum (6750 m/sec), as well as serpentinites and palobasalts, where they are the minimum and are 4350 - 4550 m/sec for the first and 4950 m/sec (average) for the second. Reduced rate of ultrasound spread in the serpentinites is due to their composition, and primarily the crystalline structure of the serpentine. Differences in serpentinites and the original rocks in ratio of ultrasound spread rate can be used in seismic exploration.

Analysis of the material presented above allows us to draw the following conclusions:

1. Rocks in the crystalline foundation are sharply differentiated in the ratio of parameters of physical properties (density, magnetic susceptibility, residual magnetization induced by polarization, and rate of ultrasound spread).

2. The physical properties of the rocks are closely related to their substance composition and genesis.

3. The petrographic properties of the rocks often make it possible to unequivocally solve the question of affiliation of the rock to a certain complex.

4. Study of the physical properties, including study of magnetic properties in strong fields needs to be done only in close relationship to the petrographic, chemical, x-ray and other methods of study.

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