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Abstract

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ON THE NATURE OF THE LAYERING OF THE EARTH' S CRUST IN THE NORTHEAST OF THE BALTIC CRYSTALLINE SHIELD

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Seismic investigations on the Baltic Shield (⌒1) and in other regions of the USSR have established a subhorizontal layering of the earth' s crust, which cannot be explained by the structural features of geological formations developed at the present-day surface. Therefore, to explain the nature of the layering, various investigators invoke hypotheses either about a change with depth in the petrographic composition of individual "layers," or about the confinement of the layering to the boundaries of structural levels of different ages in ancient metamorphic complexes of pararocks, or hypotheses about partial phase transformations of matter at corresponding values of temperature and pressure, as well as ideas about the existence of special fronts of metamorphism developing under the specific conditions of the earth' s interior ([2-]4). Analysis of the available materials in connection with comprehensive investigations at the Kola geophysical test site (⌒5, ⌒6) makes it possible to put forward a new point of view, according to which the layering established from seismic data is a reflection of actually existing structural, textural, and macrotextural features, and of the pore spaces associated with them, within earth' s crust that is compositionally equally heterogeneous.

Laboratory studies have made it possible to relate the vertical gradient of seismic-wave velocity near the present-day surface only to the closure of micropores (⌒7), i.e., to a decrease in the structural porosity of rocks. In nature, however, textural porosity is also widely developed; porosity associated with jointing of rocks and tectonic fracturing; and pore spaces caused by the occurrence of zones of tectonic disturbances of various orders, including zones of deep faults. According to investigations on the Kola Peninsula, the porosity of unweathered specimens of the granite-gneiss complex (structural and partly textural porosity) may reach 5% and even more. An idea of the role of tectonic disturbances in the formation of pore spaces can be obtained from Fig. 1: despite partial bogging and forest cover of the territory, aerial photographs distinctly trace a large number of disturbances represented at the present-day

Fig. 1

Figure 1: Fig. 1

surface by systems of fractures. The considerable permeability and fragmentation of the crust are indicated by occurrences of gas emission from crystalline rocks in mines, by the increased conductivity of rocks in zones of tectonic disturbances, and also indirectly by gravitational data, which attest to the existence of a vertical gradient of volume weight due to a decrease in the macroporosity of rocks with depth.

Fig. 1. Lines of tectonic disturbances in the Archean granite-gneiss complex according to the interpretation of aerial photographs.

The data presented allow us to suppose that pore spaces in crystalline rocks are not something exceptional and are distributed at much greater depths than was previously assumed. The formation of pore spaces in the Earth' s crust is substantially influenced by the tectonic setting of regions of block movements: the systems of fractures that form serve as the main source for the penetration of waters and gases into the body of the crust down to depths of 5-30 km. A change in the tectonic regime may lead to the sealing of pore spaces and to their subsequent localization into a system of horizontal, rather persistent interlayers. The available geological data, indicating the great plasticity of rocks over time, make it possible to suggest that an even more mobile formation of layering must occur in the conditions of the Earth' s interior in the presence of liquid and gaseous inclusions. Thus, qualitatively new structural and textural forms of matter, different from those observed at the surface, should be formed. The process of formation of layered forms of various orders must apparently proceed differently depending on the physical conditions at particular depths and on the genetic features of the pore spaces; however, we may expect that their most intense manifestation is confined to certain discrete, fairly extended depth intervals.

Seismic data do not contradict the hypothesis under consideration. The established vertical gradient of the velocity of seismic waves in the upper parts of the crust may be caused by the closure of rock macropores and by the gradual attenuation of vertical systems of cracks. The slight influence of other types of pore spaces on the average velocity, beginning at depths of about 5 km, is readily explained by their orientation relative to the direction of propagation of seismic waves. The formation of head waves, or more precisely refracted waves ([8]), should be associated with a sharp anisotropy of the medium due to the subhorizontal orientation of pores and textures. The existence of fairly extended depth intervals in which intensive formation of layering takes place is also confirmed by data from the reflected-wave method ([9]) (see Fig. 2). From consideration of the figure one may also conclude that the reflecting surfaces gradually flatten with increasing depth, and that the character of their distribution is the same in rocks of the Archean granite-gneiss complex and in the basic and ultrabasic

Fig. 2

Figure 2: Fig. 2

rocks of the effusive-sedimentary series of the Proterozoic. The latter is difficult to explain either by peculiarities of the working method and interpretation of the results or by hypotheses of layering, but becomes understandable if one takes into account the fragmentation of ancient Precambrian rock complexes, which repeatedly experienced block movements.

To substantiate the previously expressed views on changes in the material composition of the crust, the results of laboratory studies on rock samples carried out at high temperatures and pressures have been widely invoked. However, these data cannot be accepted unconditionally in substantiating the hypotheses noted, since when large masses of the Earth' s crust are considered (at least masses comparable in cross section with the wavelengths used), the criteria of similarity are violated for measurements on rock samples and in their natural occurrence. It follows from general considerations that the velocity of ultrasound in rock samples is overestimated because the influence of macropore spaces on the specific porosity of the samples is not taken into account, and is underestimated in comparison with the velocity of seismic waves owing to the heterogeneity of the samples relative to the wavelengths used. On the other hand, data from refracted-wave methods under field conditions give an overestimated value of the velocity in the "layers" of the crust for at least three reasons: (a) the nature of the waves recorded (head and refracted waves generally have a velocity greater than the average velocity in the "layer"); (b) anisotropy of the medium, strongly expressed at great depths; (c) the greater homogeneity of the medium, "increa-

"increasing" with increasing investigated depths (wavelengths). Accounting for the similarity parameters of seismo-geological conditions is extremely difficult, and we shall confine ourselves only to an estimate, according to which the velocities of seismic waves may be compared with ultrasonic velocities measured on rock samples (as a rule, erupted rocks), which have values 5-10% lower than seismic ones. It follows from this that there is no need to invoke considerations about changes in the petrographic composition of crustal rocks below the Conrad surface.

The hypothesis also explains well the slight fluctuation of seismic boundaries in areas of intense block movements. The nature of this phenomenon may be represented as follows.

Fig. 2. Seismo-geological sections according to G. N. Shablinsky. **a** –western contact of the Khibiny alkaline pluton; –northern contact of the Lovozero pluton; –graphs of the variation with depth of the number of reflecting areas n (calculated for a 1 km interval); **1** –seismic profiles, **2** –reflecting areas, **3** –contacts according to gravimetric data, **4** –contacts according to seismic data,

5 –inferred fault.

Block movements of the crust, leading to an increase in pressure or to its decrease, substantially affect the position of seismic boundaries. Thus, uplift of a block, if it entails the development of steeply dipping systems of fractures and faults, leads to a partial unsealing of previously isolated pore spaces; in this case, near the ground surface V_{cp}, determined from hodographs of direct waves or by parametric soundings, decreases, while boundaries of the same type in V_{rp} with neighboring blocks "sink," so that the general position of the seismic boundary may remain the same. An analogous picture should also be observed at greater depths. Therefore, it should be considered that the disagreement, established in a number of cases, in the positions of intermediate seismic boundaries relative to one another probably reflects the sum of multiple mutually leveling, oppositely directed processes of the dynamic development of the Earth' s crust. This same mechanism well explains the established fact that manifestations of boundaries of layering are absent at the ground surface.

The nature of the layering of the deep horizons of the crust is apparently different. Although here, too, one may assume the presence of micropore spaces filled with liquid and gaseous solutions (10^{-13}), their origin is most likely endogenous; along with micropores, macropore spaces may also arise within the crust as a result of stratification of the crust under conditions of sharply heterogeneous block movements. These pore spaces may also play a role in the formation of crustal layering, but the dominant processes are probably those of stepwise formation of new structural and textural forms, manifested in changes in the orientation and packing of minerals, their aggregates, and textures; processes of change in the physical state and partial transformation of the petrographic composition of matter under the specific physicochemical conditions of the Earth' s interior (14). The available data do not contradict the viewpoint set forth,

therefore, as an extreme interpretation of this question, one may put forward the proposition that the entire Earth' s crust, including the Moho boundary, is composed of rocks of uniform composition. Apparently, the nonparallelism of seismic boundaries observed at these depths testifies to real physical conditions in the Earth' s interior, among which pressure and temperature occupy the principal place.

The hypothesis set forth concerning the physical nature of the layering of the Earth' s crust can at present be tested by comprehensive investigations. Among such investigations, it is first of all necessary to organize stationary hydro- and gas-geochemical observations of variations in the composition of deep solutions in areas with different types of block movements, and periodic observations of modern movements of the Earth' s crust. The program of work should include detailed seismic studies by different methods, using different types, kinds, and wavelengths; gravimetric, electromagnetic, geothermal, and other investigations; and the drilling of an ultradeep borehole. In the latter case, since the borehole is planned in an "anomalous" area (in the sense of the composition and structure of the rocks of the Pechenga region), the possibility of erroneous conclusions about the nature of seismic boundaries cannot be excluded. It would be advisable to combine the program of work with investigations at the Kola geophysical polygon.

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REFERENCES

1. I. V. Litvinenko, *Transactions of the Leningrad Mining Institute*, **46**, issue 2, 3 (1963).

2. I. A. Rezanov, *MOIP Bulletin, Geological Section*, **37**, 1, 25 (1962).

3. G. D. Afanas' ev, *Proceedings of the Academy of Sciences of the USSR, Geological Series*, No. 10, 3 (1962).

4. Yu. V. Ryabichenko, I. P. Kosminskaya, *Doklady of the Academy of Sciences*, **153**, No. 2, 323 (1963).

5. Yu. D. Bulanzhe, *Collection: Modern Movements of the Earth' s Crust*, 2, Tartu, 1965.

6. V. I. Bogdanov, ibid.

7. M. P. Volarovich, E. I. Bayuk, N. E. Galdin, *Proceedings of the Academy of Sciences of the USSR, Physics of the Earth Series*, 1, 112 (1965).

8. I. V. Pomerantseva, *Applied Geophysics*, **41**, 53 (1965).

9. G. N. Shablinsky, *Transactions of the Leningrad Mining Institute*, **46**, issue 2, 28 (1963).

10. V. F. Dërrgol' ts, *Proceedings of the Academy of Sciences of the USSR, Geological Series*, 11, 18 (1962).

11. S. V. Obruchev, *Collection: Absolute Age of Precambrian Rocks of the USSR*, Moscow-Leningrad, 1965.

12. K. I. Neuvonen, *Bulletin de la Commission géologique de Finlande*, **196** (1961).

13. V. V. Belousov, *The Earth' s Crust and Upper Mantle*, Moscow, 1966.

14. G. S. Yoder, K. E. Tilley, *The Origin of Basaltic Magmas*, Moscow, 1965.

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