

ON THE RELATION BETWEEN THE STRUCTURE OF THE EARTH' S CRUST AND THE UPPER MANTLE ACCORDING TO MAG- NETOVARIATIONAL OBSERVATIONS AND OTHER GEOPHYSICAL INVESTIGATIONS

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Abstract

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ON THE RELATION BETWEEN THE STRUCTURE OF THE EARTH' S CRUST AND THE UPPER MANTLE ACCORDING TO MAGNETOVARIAIONAL OBSERVATIONS AND OTHER GEOPHYSICAL INVESTIGATIONS

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It is known that in the upper mantle various physicochemical transformations take place, with the release and absorption of heat, which give rise to tectonic and magmatic processes in the Earth' s crust. In all probability, the sources of tectono-magmatic activity are confined to a strongly heated and partially molten region of the upper mantle (the asthenosphere), characterized by increased electrical conductivity, reduced velocities of propagation of elastic waves, and high values of the absorption coefficient. The aggregate of geophysical, geochemical, and geological data, as well as the results of studies of the physicomachanical properties of rocks at high pressures and temperatures, make it possible to regard this anomalous region of the upper mantle as a region of critical and supercritical transition, in which processes of selective melting of basaltoid magmas of various composition from the peridotitic material of the mantle take place (⁷).

The emergence in the upper mantle of critical and supercritical conditions, with the formation of a substantially molten layer, is chiefly influenced by the thermodynamic setting—above all, the increase of temperature with depth, outstripping the change in pressure—as well as by the heat-insulating properties of the overlying layers of the mantle and the Earth' s crust. The asthenosphere has a planetary distribution. But it is quite obvious that beneath different geostructures of the Earth' s crust, the critical conditions favorable for its formation must appear at different depth intervals. The influence of the asthenosphere on the physical state of the material of the Earth' s crust should be emphasized. Where heated regions of the upper mantle occur at shallow depth, zones of reduced thermodynamic stability may arise in the crust, possessing channel velocities (¹, ¹⁰).

Integrated geophysical investigations—magnetovariational observations, DSS,

measurement of natural radioactivity, etc.—carried out by the Department of Geophysics of Voronezh University within the Voronezh massif, with the use of geophysical materials from other regions of the world, make it possible to express certain fundamental considerations concerning the relation between the structure of the Earth' s crust and the upper mantle in different geostructural zones.

Of great interest is a comparison of the results of deep magnetovariational investigations obtained in different parts of the globe and their correlation with the characteristic features of the structure and development of the Earth' s crust.

In the center of the European part of the USSR (the Voronezh massif, the Ryazan-Saratov depression, the Tokmov arch), synchronous magnetovariational observations have been carried out in recent years (⁹). During the period 1965–1968, variations of the magnetic field were recorded at six stations uniformly distributed over the area. In this work the main attention was given to bay-type disturbances with periods of 0.5–4 hours.

Analysis of the results of magneto-variation studies has shown that the behavior of the vertical component with a period of 0.5–2 hours changes sharply between points located in areas with different structures of the Earth' s crust. This indicates different depths of occurrence of the conducting zone of the upper mantle. Quantitative calculations for determining the depths of occurrence of the asthenosphere from magnetic variations, carried out by various authors, are not sufficiently accurate and at present can be used only for qualitative constructions.

Table 1 gives the depths to the highly conducting layer of the upper mantle (the asthenosphere) and other geological-geophysical criteria for various types of geostructures of the Earth' s crust. It is generally accepted that, despite the equality of surface heat flows, the upper mantle beneath the oceans is more strongly heated than beneath the continents. This is explained by the greater concentration of radioactive elements in the upper mantle of oceanic regions (³). The approach of heated, highly conducting layers of the upper mantle to the daily surface beneath the ocean floor is also confirmed by electromagnetic studies (¹³).

As follows from Table 1, within the continents the shallowest depth of occurrence of the asthenosphere has been established beneath Alpine folded structures and beneath areas of present-day tectonic activation. Data are given for Transbaikalia, the mountain structures of the western United States, the Andes, the Alps, and southwestern Turkmenia (², ⁴, ¹⁴). It is very noteworthy that in almost all the named regions the Mohorovičić boundary has a reversed form with respect to the roof of the asthenosphere and to the relief of the day surface, forming deep “basaltoid” roots. An exception to this series of structures is the tectonic province of the western orogenic belt of the United States—basins and ranges (Basin and Range), where, with normally low values of the regional gravitational field and high heat flows, there are no roots and the thickness of the

Earth' s crust does not exceed 35 km ⁽¹⁵⁾. At the same time, velocities in the upper mantle have lowered values (7.3–7.6 km/sec). In terms of the activity of tectonic processes, heat-flow magnitude, and territory, this region adjoins the rift zone of the East Pacific Rise. The shallow occurrence of heated layers of the upper mantle may be connected with the existence of a waveguide at the base of the “granitic” layer at depths of 10–15 km, identified beneath the Western Alps by German and French geophysicists ⁽¹⁰⁾.

In the marginal northeastern part of the Canadian Shield, with shallow occurrence of the asthenosphere (Table 1), a zone of increased electrical conductivity is also distinguished in the Earth' s crust from the anomalous behavior of magnetic variations; this zone may prove to be thermodynamically unstable (corresponding to the waveguide layer). These regions of the shield were tectonically activated in the most recent time and intensively granitized in the Upper Proterozoic ⁽⁹⁾. Apparently, physical inhomogeneities in the Earth' s crust and upper mantle may be detected in areas of modern arch uplifts and contrasting tectonic movements of other intensively granitized ancient shields (the waters of the Gulf of Bothnia of the Baltic Shield, the East African rift province, etc.).

The deep structure of the interiors of ancient massifs, weakly granitized and occupying a central position within Precambrian platforms, differs noticeably from tectonically activated ancient shields that have been intensively reworked by alkaline metasomatism. Thus, for example, the depth to the heated, highly conducting layers of the upper mantle beneath the Voronezh Massif is estimated at 150–200 km. In addition to the features of the structure of the Earth' s crust noted in Table 1, structures analogous to the Voronezh Massif and the Ukrainian Shield are characterized by weakened tectono-magmatic activity throughout the entire geological

Table 1

Types of geostrophes of the Earth's crust	Depth to the asthenosphere according to magnetotelluric studies, km	Earth's crust thickness, km: "granite" layer	Earth's crust thickness, km: "basalt" layer	Mean heat flows Q , $\mu\text{cal}/\text{cm}^2 \cdot \text{sec}$	Content of radioactive elements in basalts and hyperbasites, $10^{-4}\%$	Averaged gravitational field, Bouguer	Note
I. Continental structures	I. Continental structures	I. Continental structures	I. Continental structures	I. Continental structures	I. Continental structures	I. Continental structures	I. Continental structures
Areas of Alpine orogeny and present-day tectonic activation	70–100L. Vanyan (1967)M. N. Berdichevskii (1967)	20–25R. M. Demit-skaya (1967)	35–40	> 2.0W. H. K. Lee (1966)	3.5V. L. Ma-saitis et al. (1966)	Deep depressions	High seismicity, contrast of the present-day relief with elevation differences up to 6–7 km

Types of geostrophes of the Earth's crust	Depth to the asthenosphere according to magnetotelluric studies, km	Earth's crust thickness, km: "granite" layer	Earth's crust thickness, km: "basalt" layer	Mean heat flows Q , $\mu\text{cal}/\text{cm}^2 \cdot \text{sec}$	Content of radioactive elements in basalts and hyperbasites, $10^{-4}\%$	Averaged gravitational field, Bouguer	Note
Areas of Paleozoic orogeny	100–200W. Kertr (1964)H. Wirse (1965)	10–15N. I. Khalevin et al. (1966)	35–40	1.23–1.4H. Creutzburg (1964)W. H. K. Lee (1966)	–	Close to normal	Weak seismicity, moderate contrast of present-day relief forms
Stable areas of plateforms (ancient plates)	300–400A. Kovtun (1967)U. Schmucker (1964)	up to 10R. M. De-menit-skaya (1967)	25–30	1.1–1.2R. Roy (1963)	–	Zero	Aseismicity, plain forms of relief

Types of geostrophes of the Earth's crust	Depth to the asthenosphere according to magnetotelluric studies, km	Earth's crust thickness, km: "granite" layer	Earth's crust thickness, km: "basalt" layer	Mean heat flows Q , $\mu\text{cal}/\text{cm}^2 \cdot \text{sec}$	Content of radioactive elements in basalts and hyperbasites, $10^{-4}\%$	Averaged gravitational field, Bouguer Note
Areas of ancient shields, intensely granitized with strongly manifested alkaline metasomatism	50–70L. Lew (1963) North-eastern Canadian Shield, Queen Elizabeth Islands	15R. M. De-nit-skaya (1967)	20	1.25–1.4Sass, Mustonen (1967)	0.6–0.9Masaitis et al. (1966) Rogers (1963)	NegativeIncreased seismicity, mountainous forms of relief, fjords in marginal parts of ancient shields. Modern domal uplifts up to 1 cm per year

Types of geostructures of the Earth's crust	Depth to the asthenosphere according to magnetotelluric studies, km	Earth's crust thickness, km: "granite" layer	Earth's crust thickness, km: "basalt" layer	Mean heat flows Q , $\mu\text{cal}/\text{cm}^2 \cdot \text{sec}$	Content of radioactive elements in basalts and hyperbasites, $10^{-4}\%$	Averaged gravitational field, Bouguer	Note
Areas of ancient shields, weakly granitized massifs	150–200 V. M. Maksimov (1967)	10–15 B. I. Sollogub (1967) "Spetsgeofizika," VGU (1967)	35–40	0.7–0.9 E. A. Lyubimova (1964) S. R. Hart et al. (1967)	0.15 V. I. Gonshakova et al. (1966), VTU, VNIYaI (1968)	Positive	Aseismicity, smoothed relief forms. Presence of basaltic roots
II. Oceanic structures	II. Oceanic structures	II. Oceanic structures	II. Oceanic structures	II. Oceanic structures	II. Oceanic structures	II. Oceanic structures	II. Oceanic structures
Oceanic plains	—	absent G. U. Menard (1966)	5–6	1.28 W. H. K. Lee (1966)	—	Intensely positive	Alkaline derivatives of basaltic magma (carbonatites, kimberlites)

Types of geos- tructures of the Earth's crust	Depth to the astheno- sphere accord- ing to magne- to varia- tional studies, km	Earth' s-crust thick- ness, km: "gran- ite" layer	Earth' s-crust thick- ness, km: "basalt" layer	Mean heat flows Q , $\mu\text{cal}/\text{cm}^2 \cdot$ sec	Content of radioac- tive ele- ments in basalts and hyperb- asites, $10^{-4}\%$	Averaged gravi- ta- tional field, Bouguer Note
Oceanic ridges with rift struc- tures	—	absent G. U. Menard (1966)	up to 3	1.8 (to 7.0) W. H. K. Lee (1966)	0.6 Heier, Rogers (1963)	Depressions in a posi- tive field Zones with anoma- lously low values of seis- mic veloci- ties in the upper man- tle (7.3— 7.6 km/sec)

history, by the absence of magmatic facies of carbonatites and kimberlites, which are the end products of differentiation of basaltic magma formed during periods of domal uplifts in tectonically activated platform areas.

Beneath the negative structures of ancient platforms (the Moscow syncline, the Texas basin, etc.), heated mantle regions, according to magnetic-variation studies, occur at depths of 300–400 km (^{7,14}). In these regions, boundary velocities in the upper mantle have anomalously high values of 8.4–8.5 km/sec (¹⁵).

Thus, materials from magnetic-variation studies, together with seismic velocities, heat flows, and other geological-geophysical criteria, provide additional information for identifying and studying physical inhomogeneities in the tectonosphere. When identifying inhomogeneities in the Earth's crust (a zone of reduced thermodynamic stability, increased electrical conductivity, and channel velocities),

it is necessary to pay attention to the intensity and depth of granitization and especially to the degree of alteration of the original rocks under the influence of alkaline metasomatism. According to laboratory studies, alkaline igneous rocks under conditions of elevated pressures and temperatures have an electrical conductivity three orders of magnitude higher than that of basic igneous rocks ⁽⁵⁾.

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