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About geological theory

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Science is what we do to keep from lying to ourselves. R. Feynman
A geologist needs the whole Earth. A.P. Karpinsky.

The author's advection-polymorphic hypothesis of deep processes in the tectonosphere is based on V.V. Belousov's system of endogenous regimes, a certain source of energy (radioactive decay in crustal and upper mantle rocks), and the method of energy transfer (advection). Elementary volumes of transported material have been termed «quanta of tectonic action» (QTA) with the diameter of about 50—70 km. The physical reality of such objects is proved. The choice of endogenous regime is related to the type of the preceding thermal model.

The mechanism of the tectonosphere's «heat machine», which relies firmly established facts and quantitatively explains the main events of geological history within the energy conservation law, has been substantiated.

For any period, from the Early Archaean to our time, it is possible to numerically justify the pattern of heat and mass transfer, to select the endogenous regimes, and construct a non-stationary heat model and variation in time of the distribution of physical properties of rocks. By using the findings and solving only direct problems, one can determine the geological manifestations of the process and the anomalies of the physical fields. The results are compared with the observed ones (without fitting), and the discrepancies do not exceed the values due to the observation and calculation errors.

Pursuant to the advection-polymorphic hypothesis, it became possible for the first time to predict: 1. The emergence of quanta of tectonic action. 2. Stability of parameters (depth and temperature) of magma chambers in the mantle in the history of the Earth. 3. Existence of the global asthenosphere (depth about 700—1000 km). 4. Velocity distribution of longitudinal seismic waves in the upper mantle of regions with all types of endogenous regimes. 5. The difference in the nature of earthquakes at various depths in the focal zones. Successful verification of predictions transfers the hypothesis into the rank of theory.

The theory is used to explain the following at the quantitative level: dating of active processes on all platforms of the Earth, temperature distribution in the crust and upper mantle of platforms and active regions, sediment thickness in geosynclines and post-rift depressions, changes in mass flow in geological history, heat flow and gravitational field anomalies.

Several applications of the theory to studies of seismicity and UHP-blocks problems and prospecting for mineral deposits (hydrocarbons, hydrothermal sulfide ores, diamonds, and geothermal energy resources) have been considered.

Key words: advection-polymorphic hypothesis, verification of predictions, geological theory.

Introduction. Various authors, who recognize the existence of the scientific method in question, characterize it in virtually identical terms. The scientific method involves [Wikipedia].

1. Careful observation, applying rigorous skepticism about what is observed, given that cognitive assumptions can distort how one interprets the observation.

2. Formulating conclusions (conjectures), via induction, based on such observations, hypothesis formation.

3. Experimental tests of predictions (previously unknown objects and processes) following from hypotheses and refinement (or elimination) of hypotheses based on experimental results.

An experiment aims to determine whether

observations agree with or conflict with the predictions derived from a hypothesis. A scientific hypothesis must be falsifiable [Popper, 1959], implying that it is possible to identify a possible outcome of an experiment or observation that conflicts with predictions deduced from the hypothesis; otherwise, the hypothesis cannot be meaningfully tested.

4. Depending on how well additional tests match the predictions, the original hypothesis may require refinement, alteration, expansion, or even rejection. If a particular hypothesis becomes very well supported, a general theory may be developed.

About 40 years ago, V.V. Belousov developed the general concept regarding endogenic regimes, that describes, in a single system of terms, events taking place at subsurface (accessible to observation) Earth's depths on continents, in oceans, and transition zones [Belousov, 1975, 1978, 1982, etc.]. The concept generalized and further advanced the knowledge amassed in geological science over the 20th century (van Bemmelen, Yeardley, Cloos, Aubouin, Stille, and others) and supplemented it with ideas on geological formations introduced by Shatsky, Strakhov, and others. At about the same time, with the fast accumulation of data on the geochemistry of crustal and mantle rocks, heat flow anomalies, electrical conductivity, and seismic wave velocities (the gravitational and magnetic fields had been fairly well studied even earlier), there emerged information on energy sources within the body of the planet, as well as on energy requirements for deep-seated processes. It became possible to construct models of tectogenesis in compliance with the law of energy conservation.

Advection-polymorphic hypothesis. The author used these observation results, generalization, and conclusions (paragraphs 1 and 2 of the scientific method) in constructing the advection-polymorphic hypothesis (APH) he has been working on [Gordienko, 1975, 1998, 2007, 2012, 2017 and others].

The hypothesis is based on the V.V. Belousov's system of endogenic regimes (with small additions) and a specific source of energy — radioactive decay in crustal and upper mantle rocks with energy transport through advection. Elementary volumes of transported material have been termed «quanta of tectonic action» — QTA. More or less synchronously ascending QTAs (about 50—70 km in diameter) merge to form large asthenoliths under the entire territory of regions experiencing active processes. The physical reality of such objects has been proven. The choice of endogenous regime was tied to the type of the preceding thermal model. If the temperatures exceeded solidus within a broad range of depths greater than 200 km, the situation was assumed to be suitable for the emergence of convection and a geosyncline process within the tectonosphere. If the asthenosphere was thinner, conditions were considered suitable for the rifting process or for one-act activization (which corresponded to the movement of the material characteristic of the initial stage of rifting). For any period, from the Early Archaean to our time, it is possible to numerically substantiate the pattern of heat and mass transfer, to select the endogenic regimes, to construct a non-stationary heat model and variation in time of the distribution of physical properties of rocks. Using these data and addressing direct problems alone, it is possible to determine geological manifestations of the process and anomalies of physical fields. The results are compared with the observed ones (without selection), and the discrepancies do not exceed observation and calculation errors magnitudes. The scheme of action of the tectonosphere «heat machine» is substantiated, based on firmly established facts and quantitatively explaining the major events of geological history within the framework of the law of conservation of energy. The total present-day number of radiogenic heat sources in the crust and upper mantle of all the varieties of regions turns out to be virtually the same: 42±0.5 mW/m^2. In other words, today, at any point of the Earth, the same amount of heat is generated beneath a unit surface, but its sources are distributed in dissimilar ways due to the formation of the crust of one type or another.

The total value of HF (heat flow) is formed, not only as a result of heat generation in the crust and mantle but also as a consequence of the still ongoing process of cooling of the tectonosphere that started from the solidus temperature, according to the APH, 4.2 billion years ago. Current heat generation in the upper mantle: platforms — 0.04, geosynclines — 0.06, oceans — 0.08 $\mu W/m^3$. Total current radiogenic heat generation in the crust beneath the platform amounts to 23 mW/m^2, and under geosyncline zones, to 17.5 mW/m^2. Beneath oceans, energy generation is 3 mW/m^2.

Integral heat generation in the crust and upper mantle of platforms, over recent 3.6 billion years, amounts to $73.5 \cdot 10^{14}$ J/m^2. Over the said time, the conductive heat flow has carried off $59.5 \cdot 10^{14}$ J/m^2. The difference, $14 \cdot 10^{14}$ J/m^2, must be supplied by heat and mass transfer during active deep-seated processes.

A single geosyncline cycle (3 acts of heat and mass transfer) requires $0.8 \cdot 10^{14}$ J/m^2. This value turns out to be somewhat lower in the case of rifting (3 acts of heat-mass transfer): about $0.6 \cdot 10^{14}$ J/m^2. Approximately the same amount of energy (0.50—$0.55.10^{14}$ J/m^2) is required for a single-episode active process.

Hypothesis control. Hitherto unknown phenomena can be predicted with the help of the advection-polymorphic hypothesis.

1. Quantum of tectonic action. It is difficult to view the physical mechanism of QTA formation in its entirety, primarily due to the shortage of reliable information on the properties of the medium and their changes. As a possible resolving the problem, we can mention Ya.M. Khazan's results and the data of the author slightly different from them. They imply the possibility of a long-term existence of a partial melting layer with a roof depth of 200—250 km and a base depth of 400—450 km. Unstable volumes of the material with a diameter ranging from 50 to 100 km [Khazan, 1999] or 50—80 km [Gordienko, 1998] can form in the upper portion of the layer and ascend over distances from their diameter up to the M discontinuity.

The use of additional information on temperature anomalies (300—5000 °C), a decrease in density (0.03—0.05 g/cm^3), strength (0.02—0.04 GPa) and viscosity (1020 Pa·s), lifting speed and melt segregation conditions [Schmeling, 2000; Anthony et al., 2001; Dimanov et al., 2005; Yanovskaya, 2006; Chen et al., 2007 and others] made it possible to refine the prediction of the diameter of the QTA to 50—70 km.

More or less synchronously ascending QTAs merge to form large asthenoliths beneath the entire territory of regions experiencing active processes. Let us discuss the physical reality of such objects.

Studies of mantle objects with anomalous velocity of seismic wave (and rocks melting) beneath zones of various types of young activization on continents, oceans, and in zones of transition to oceans have revealed their approximate thickness of about 60±10 km. These are the zones of recent activization of all platforms of the world, the alpine geosynclines of the Tethys, island arcs and coastal ridges of the Pacific, the hollows in the northern part of the Pacific.

Obviously, the density of the geological data network in the near-surface zone, characterizing the manifestations of various endogenous regimes, is immeasurably higher than that achieved in the study of mantle objects. Therefore, one should first consider the available information on the geometry of regions of synchronous activity of the same type, although it can only indirectly reflect the size of the sought-for QTA. Because the length of the zones is, as a rule, much larger than their width, it makes sense to focus on the latter parameter (width). It is precisely there that the size of a single quantum can be detected. Broad formations (folded «ovals» median massifs of large geosynclines, and so on) were not incorporated in the study. Aggregations of many QTAs may correspond to these structures. The data quoted below pertain to structures with sufficiently distinct boundaries. In the case of Paleozoic geosynclines, we are talking largely about folded zones of Hercynides and Caledonides bounded by major faults. Zones covered by a young sedimentary cover were not considered (except for the well-studied West Siberian Plate basement). Deep-seated faults edging grabens were assumed to be boundaries of rifts. The widths of deep-water trenches were, as a rule, determined at the level of the depth corresponding to the depth of an adjoining oceanic basin.

The generalization based on published data is not presented as something complete and statistically valid (the eight histograms are based on 600 values of width). Based on its results, it was only necessary to get answers to the questions:

1. Is there a minimum width of structures typical of manifestations of a single type of endogenous regimes?

2. Does it change with age during the Phanerozoic?

3. Does it happen to be the same for dissimilar endogenous regimes?

A generalization for folded uplifts of the Mediterranean belt was reported by [Sholpo, 1991]. According to Sholpo, those widths range between 60 and 150 km. Mainly Alpine structures were studied. In the Pacific belt, Alpids and Cimmerides were analyzed. Structures of North and Central America's Cordilleras, South America's Andes, and the Verkhoyan-Chukotka folded region of northeastern Asia were also analyzed. Approximately the same range of widths as in the Tethys was revealed, although some wider and narrower folded zones were also encountered.

For Paleozoic folded zones (largely Hercynides) in Western Europe and the Appalachians, prevalent widths measured 50—60 km, and no narrower structures were found. The same applies to small folded zones of Paleozoics in Eastern Australia. Caledonides and Hercynides of Taimyr, the basement of the Western Siberian Plate and Altay-Sayan-Mongolian folded region, are represented by folded zones mainly 60±20 km in width.

In fact, the same widths have been detected in the youngest folded zones of volcanic arcs at the periphery of the Pacific Ocean and in the Caribbean basin.

The data on Cenozoic rifts of the Eastern African system, the Baikalian and Moma zones are listed. Cenozoic rifts of continental Western Europe have been studied alongside somewhat older (partly Mesozoic) rifts of the North Sea. The data on the Meso-Paleozoic rift system of the Western Siberian Plate and Paleozoic rifts of the Eastern European Platform have also been listed. In all cases, narrow structures prevail, but trenches less than 40 km wide are almost absent.

The widths of deep-water trenches of the Pacific Ocean and adjacent water bodies of the Atlantic and Indian oceans are fairly stable, and they largely range from 50 to 100 km, and the greater part of the dataset is represented by minimum values from this range.

In mid-ocean ridges (MOR), it is difficult to discern boundaries of structures that might help assess their widths. The width is most certainly not limited to the narrow (or absent in some ridges) central graben. It would be a largely questionable venture to draw a ridge boundary based on the site where the gradient angle changes. We are talking about very young (at any rate, in the latest manifestations of active processes) formations that could be used to assess the QTA length. If we assume that its length equals the size along the strike of an associated structure, it is impossible to determine it in most bodies studied: Without a detailed analysis, they appear to be uniform along the strike or fragmented as a result of superposed active events. It is only in the youngest formations, such as MOR, with a thin and fragile crust, that the results of action of each QTA, individually displacing the ridge axis, can be discovered.

Consequently, the ridge must be broken into a series of blocks by young faults. Precisely such a structure was discovered in well-studied parts of the worldwide MOR system. In particular, typical sizes of blocks along the strike of the Mid-Atlantic Ridge (MAR) amount to 50±30 km; for the Californian part of the Eastern Pacific Ridge, the relevant sizes are 60±20 km. Close to (or multiple of) those sizes are Paleozoic elements of the Dnieper-Donets Depression (DDB) rift, identified along the strike of the structure.

In connection with recent active processes on the territory of Ukraine, a network of faults, even those outside the boundaries of active zones proper, have synchronously regained activity. Studies of those faults (that have been mobile over recent approximately three million years) have enabled us to trace divisibility arising from a single process [Verkhovtsev, 2006].

The presence of two networks of disturbances is obvious. Histograms of the distribution of cell sizes in each clearly reflect a mixture of datasets with prevailing sizes of 60 and 120 km corresponding to sizes of one or two QTAs.

Thus, near-surface manifestations of various types of activization are characterized by fairly stable minimum sizes of features that never changed during the Phanerozoic. Those sizes are close to 50—70 km.

Direct studies of mantle objects exhibiting anomalous properties beneath zones of various types of young activization have revealed approximately the same minimum widths: 50—60 km. Results of interpretation of heat-flow anomalies, geoelectrical and seismological data were used to identify such formations. The widths of anomalous objects (in km) are as follows: 40—60 beneath activized Alpids in the Greater and Lesser Caucasus; 50—100 beneath the zones of the Pamirs, Tien-Shan, and the Turanian plate; 50—70 beneath Southern Kazakhstan; 60—80 beneath the Kuriles Island Arc; 30—70 beneath the rift of the Tatar Strait; 40—60 beneath activized Alpids in the Coast Range of the North American Cordilleras [Gordienko et al., 1990; Gordienko et al., 1992; Belyavsky, Kulik, 1998; Gordienko, 2001 and others]. It would be appropriate to mention that the width of mantle objects turns out to be somewhat larger (by approximately 10 km) than their surface manifestations, although this difference is hardly reliably diagnosed.

Consequently, the volume of a single QTA must be 120±60 thousand km^3.

2. Parameters of magmatic chambers in the mantle. From the considered scheme of heat and mass transfer during active processes, QTAs occur at identical depths in all cases of endogenous regimes (during Phanerozoic and Precambrian times). They differ in the sequence of their appearance in the top position. In order to explain the composition of rising magmas and the heat flows (HF) at different stages of the process, it is necessary to assume that magma chambers, initially emerging beneath active regions, had their top portions at depths of 200—250 km (prior to the start of the QTA), then at 160, 100, and 40 km and temperatures 1,700, 1,550, 1,350 и 1,150 °C. A result pointing to the invariability of the depths of the chamber roofs throughout geological history also appears to be perfectly natural from the point of view of the APH.

This is a prediction of a previously unknown phenomenon of stability of depths and temperatures of magma chambers within the mantle.

At the current level, the hypothetical scheme already allows for quantitative control by various geological and geophysical methods. The prediction was confirmed on practically global material together with the assumption of the possibility of a small degree of partial dry melting of mantle rocks at the solidus level, noticeably lower than that accepted in many works.

The depth of the roof of the upper melting

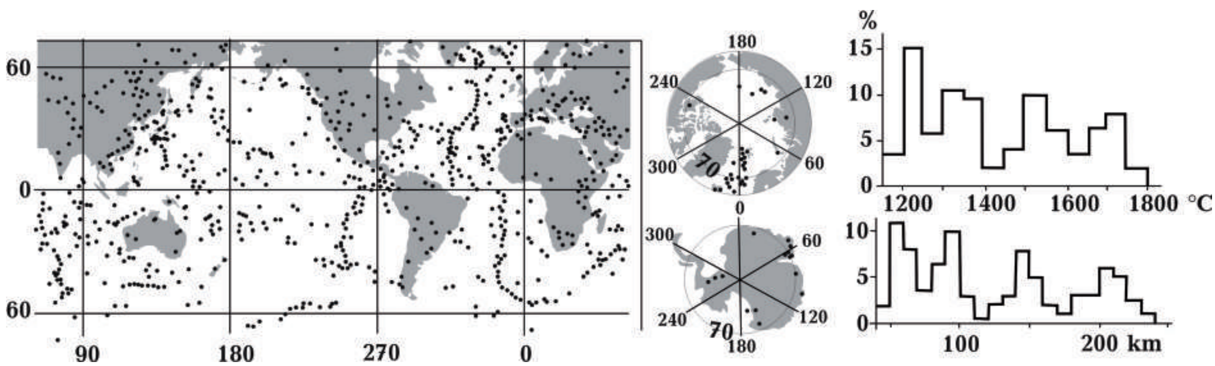


Fig. 1. Sites from which rock samples (about 70,000 analyzes) and histograms of distribution of temperatures and depths of magma chambers in the mantle of the best studied areas of continents and oceans.

zone differs from that predicted. At a depth of 40 km, already five million years following the ascent, the QTA cools down. The mean depth of the solidus' T (1,200 °C) ranges from 50 to 60 km. However, the depth range between about 50 and 100 km is not as free from magma chambers at intermediate depths as is the case between 100 and 150 km or 150 and 200 km.

This may show the influence of 1) sinking of the chamber's roof during the cooling of the object in the upper floor and 2) melting of the eclogitized blocks of the main part of the crust submerged into the mantle.

The depths of magma chambers could also be derived from the data on xenoliths (60, 100, 160, and 210 km) and on seismic boundaries (90, 140, and 210 km) [Gordienko, 2017; and others].

3. Global asthenosphere. Computations performed for the depths beneath the tectonosphere (crust, upper mantle, and transition zone to the lower mantle) have revealed a peculiar situation. Within a depth range of about 700—1,000 km, a layer with insignificant partial melting left by the «magma ocean» has remained intact throughout geological history. From the depths of 200—250 km, the density of the liquid is higher than that of the crystalline material with the same composition, and for that reason, no supernatant asthenoliths take shape in the global asthenosphere. This global asthenosphere is commensurable in volume with the outer core and is larger than the inner core. Presently available velocity models of the mantle do not detect it. There only exist indirect indications of changes in the elastic parameters (minimums of $\Delta V_p/\Delta z$ and V_p/V_s), but geoelectric studies clearly identify the layer [Gordienko, 1998; Gordienko, Logvinov, 2011; Semenov, 1998] (Fig. 2).

Low viscosity causes seismicity to cease in the upper part of the asthenosphere at an approximate depth of 700 km.

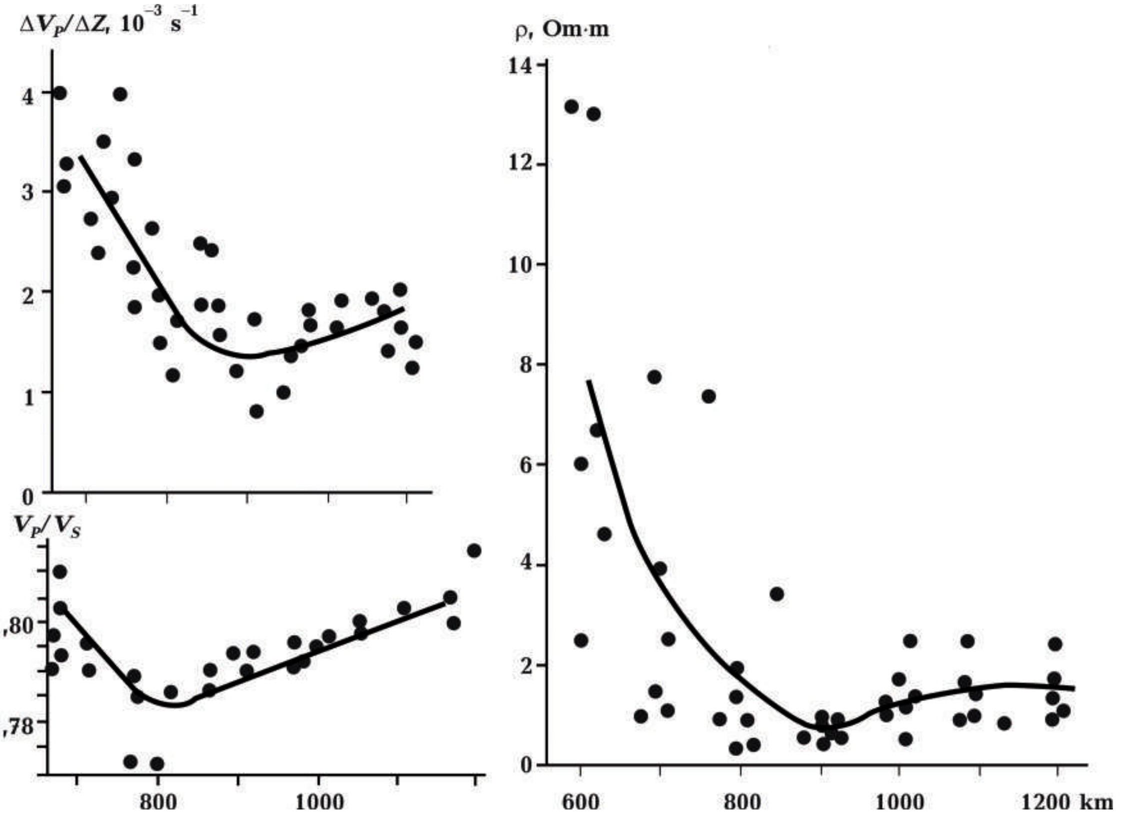


Fig. 2. Variations in the P-wave velocity gradient and in the ratio of P-wave velocities to S-wave velocities within the depth range of the global asthenosphere (PREM, IASP91, SP6, Jeffries-Bullen, Gutenberg, Vinnik) and variation of mantle rocks' ρ with depth at observation points.

4. Velocity of seismic *P*-wave in the upper mantle. Based on the thermal model (in terms of differences between temperatures at different depths and background temperatures beneath the Precambrian platform) and the data on the distribution of velocities in the mantle of the Precambrian platform (in line with the hypothesis and lherzolite composition of mantle rocks), V_p values in the upper mantle of regions of the Earth were calculated. These are predictive models beneath oceanic, continental, and transition regions, such as mid-ocean ridges (MOR), basins, trenches, island arcs, and back-arc trenches (BAT), Atlantic transitional zones, flanking plateaus (FP) of MORs, platforms, geosynclines, rifts, recent activation zones. The models agree with the deep-seated processes in the tectonosphere that correspond to the advection-polymorphic hypothesis. Velocity profiles constructed for some regions have been reported, but that information is often contradictory (the average difference between the two models for the same region is 0.10—0.15 km/sec). Not all earthquakes and seismic stations are located within the region with the studied endogenous regime. The model is limited by a priori concepts, such as the absence of velocity variations relative to the AK135 model [Gudmundsson, Sambridge, 1998] at the depths of the lower half of the upper mantle) etc. Platforms are an exception. Even before hypothetical models were computed, average velocity profiles for the upper mantle that were quite acceptable in terms of accuracy had already been available in publications.

The situation may be rectified with the help of velocity models constructed for the upper mantle regions, known for their often elevated seismicity and equipped with a rather extensive earthquake monitoring system (Fig. 3). Even the construction of one-dimensional P-wave velocity (V_p) distribution with depth, although not reflecting sufficient detail, could enable us to gain insight into the main patterns of heat-and-mass transfer in the upper mantle.

Prediction is confirmed. The experimental and estimated (APH) velocity profiles differ by

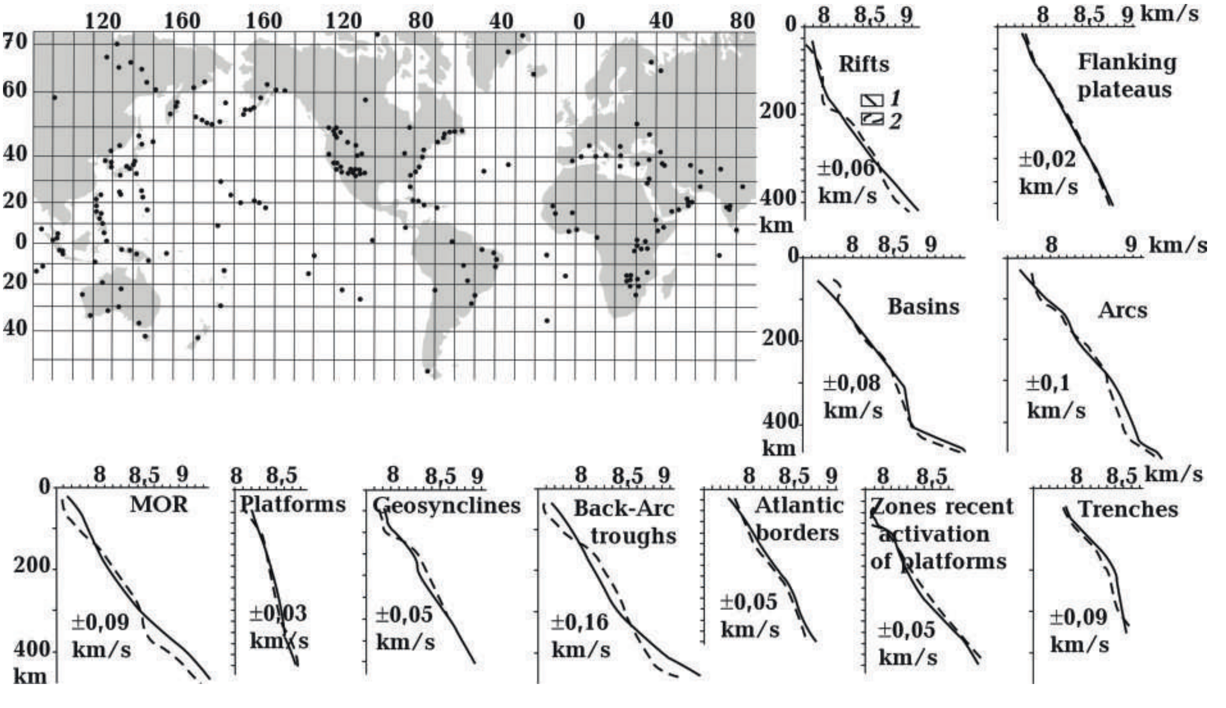


Fig. 3. Seismic stations whose data were used for plotting traveltime graphs (about 200 station, about 40,000 earthquakes) and experimental (*1*) and estimated (in accordance with APH) (*2*) velocity models for the upper mantle beneath regions with different endogenous regimes.

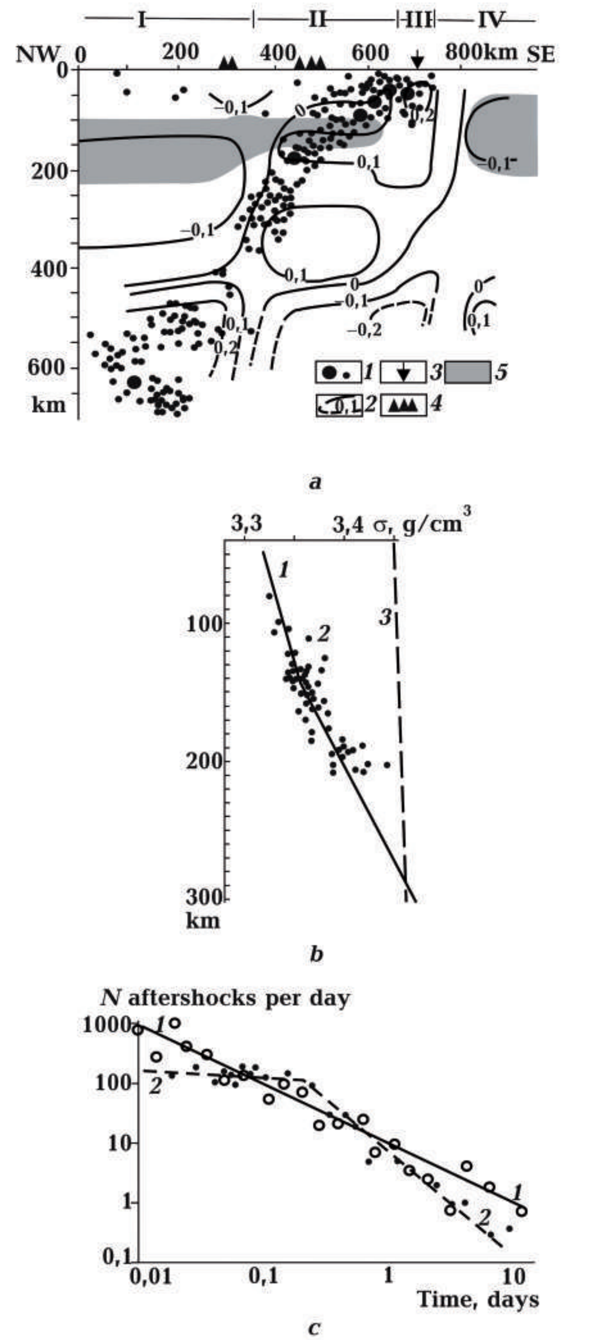


Fig. 4. *a* — Distribution of anomalous velocities (deviations from the mean value at each depth) in the upper mantle of the transition zone beneath southern Kamchatka and adjoining water bodies [Gordienko, Gordienko, 2018; and others] and earthquake hypocenters: *1* — Earthquakes of various energy categories; *2* — *P*-wave velocity anomalies in km/sec; *3* — axis of the deep-water trench; *4* — Kamchatka volcanoes; *5* — area of mantle rocks' partial melting; I — Activated epi-Cimmerian plate beneath the Sea of Okhotsk and Western Kamchatka, II — island arc (activated Alpine geosyncline) in eastern Kamchatka, III — deep-water trench, IV — northwestern plate of the Pacific Ocean. Shown in the lower section of the velocity profile (dashed contours), are velocity anomalies estimated in terms of the APH, since available data were insufficient to enable us to continue the construction of the profile with the help of the selected technique down to depths larger than 450—500 km. *b* — Comparison of the density of mantle and eclogite rocks [James et al., 2004]. *c* — Correlation between temporal distributions of aftershocks from an earthquake in upper mantle levels in Japan [Enescu et al., 2009] and the deep-focus earthquake in the Sea of Okhotsk. Graphs for the earthquakes: *1* — in Japan, *2* — in the Sea of Okhotsk.

an average of ±0.07 km/sec. This corresponds to the 0.05 km/sec error value typical for each technique. In the case of back-arc trenches, the differences can be up to 2 times larger. Additional research for those regions is required.

Advective transport of the upper mantle material occurs within cells whose centers occur at depths of about 220—230 kilometers. Here T and V_p are unchanged, and exceptions are trenches, Atlantic-type margins, and flanking plateaus. In these regions, T is created by lateral influences. The average V_p for the remaining experimental models is 8.37±0,07 km/sec, as in the reference models of the upper mantle AK135 or IASP91. There is also coordination at a depth of 400 km — about 9 km/sec.

5. A hypothesis must be falsifiable. The opinion regarding the immersion of the lithospheric plate in the «subduction zone» (down to 700 km) is widespread [Gordienko, 2017 and others]. It is one of the main elements in the plate tectonics hypothesis. The immersion manifests itself in earthquakes within focal zones between continents and oceans. By suggesting a common source, one assumes the same mechanism of earthquakes at all depths. In terms of the advection-polymorphic hypothesis (APH), however, the mechanisms within the mantle at depths down to about 300 and more than 400 km are different.

The profile shown (Fig. 4, *a*) in the diagram illustrates the lack of agreement between the genuine structure of the upper mantle and seismicity on the one hand and plate tectonics postulates on the other.

1. The oceanic plate approaching the «subduction zone» does not appear cold, dense, or capable of submerging under the low-density continental edge. It transpires from the evidence of magmatism, heat flow, and heat and velocity models that a shallow asthenosphere is developed here and that the plate density is much lower than the density of the block of rocks in the trench.

2. According to [Tercot, Schubert, 1985], the submerging plate cannot bend elastically to fit the outer slope of the trench. The required bending must be accompanied by the formation of a constantly restorable fault system, something that should lead to intensive seismicity. However, there is little or no seismicity at the external margin of the trench.

3. The location of a part of the focal zone with a maximum cluster of earthquakes cannot match the surface of a plate that starts plunging in front of the trench: The zone is 100—150 km closer to the continent. Identical results were obtained for other areas of Pacific-type transition zones [International…, 2014] (Fig. 4, *a*).

4. The «window» in the focal zone cannot be accounted for in terms of the movement of a solid plate whose lower edge has reached the upper-to-lower mantle transition zone.

5. Some maximum-depth earthquake zones run across island arcs, which contradicts concepts of their origin in plate tectonics. One portion of the descending plate generates earthquakes in the upper-to-lower mantle transition zone, while the other does not.

6. For the plate to advance by 5—10 cm per year, the energy requirement beneath a unit of surface is three orders of magnitude larger than the heat flow. Clearly, it would be pointless to search for such an object, as no known natural processes can create such powerful energy sources. Frictional heating over one million years will reach 4—5 thousand degrees.

The list of mismatches could be continued. Nevertheless, even those pointed out above are sufficient to conclude that patterns of anomalous velocities and earthquakes are at variance with concepts of plate tectonics.

In the upper mantle of regions with a continental type of crust (in accordance with APH), down to depths of about 300 km, the majority of earthquakes during the active period are associated with the submergence of compacted eclogite (omphacite+pyrope) blocks that formed within the crust (Fig. 4, *b*. In the transition zone to the lower mantle, changes in the density of both signs with changes in temperature, pressure, and transformation of minerals in mantle rocks are accompanied by seismicity.

The distribution of aftershocks in time may be indicative, to a certain extent, of the type of the mechanism [Guglielmi, 2017]. In this sense, the significance of the data on the Okhotsk earthquake in 2013 cannot be overestimated. This is the first earthquake with aftershocks at a depth of more than 600 km [Chebrov et al., 2013]. It has long been common knowledge that the distribution of aftershocks from more shallow earthquakes obeys the Omori law, and this fits a strike-slip mechanism. The Omori law does not support the case under study (Fig. 4, *c*), at least not for the initial time-related aftershock sequence. The descending branch on the graph for the earthquake in the Sea of Okhotsk comes about after a rather strong earthquake (after 9 hours) with a magnitude of 6.8.

Applicability of theory. In addition to the aforementioned examples of control, geological theory should explain the widest possible range of known facts.

a. Show that it is possible to reconstruct the geological history of regions with dissimilar types of endogenous regimes. A process mechanism must enable the calculation of rates and amplitudes of uplifting and subsidence, sedimentation, the time of emergence, and the depth of magma chambers for various stages of the region's evolution, the distribution of zones of lithogenesis and metamorphism in crustal rocks, etc. Models are compared with experimental data.

b. Demonstrate quantitative consistency between estimated and observed geophysical data for the region. Velocity and geoelectric models for the region as estimated based on the adopted process are compared to those derived from experimental evidence. Estimated gravitational and magnetic fields and heat flow distribution (HF) are directly compared against observed ones.

c. An important element is the lack of selection. The parameters must coincide within the limits of the previously agreed calculation and experimental errors. If the limits are excessively wide (i.e., if they allow matching fields and models for fundamentally dissimilar process mechanisms), then a comparison employing this method for deep geophysical studies is considered inconclusive and must be excluded from the list of control criteria.

d. If an unfinished recent activization process is analyzed, when there is no complete clarity in the type of the endogenous regime and, accordingly, in the choice of the deep process variant, such comparison can be performed using a selection of some of the parameters according to the observed data. In this particular case, determining the type of endogenous regimes is precisely the goal of the study.

e. It goes without saying that the relevance of different control methods can vary with the type of endogenous regimes and the age of the process.

The use of geophysical data is only possible when the impacts of the processes give rise to significant anomalies in the physical properties of crustal or upper mantle material, anomalies predictable with sufficient accuracy. Those impacts are caused by changes in the rock composition and deep temperatures (*T*). Changes in composition can be studied in terms of geophysical data provided that, within a considerable depth interval, the current composition has been determined, and the composition that had existed prior to the onset of the process is known. It is certainly far from always that such a problem can be solved quantitatively. In some cases, the data on the structure and thickness of the Earth's crust and its individual layers as supplied by deep seismic probing constitute an exception. Temperature anomalies that took shape in the Earth's interior during the onset of the process and somewhat abated by now can be quite accurately described. The resulting disturbances in the physical properties (and physical fields) can be recorded, provided they are large enough, but their magnitudes are maintained solely for Alpine and post-Alpine processes.

The composition of magmatic and sedimentary rocks presently lying at the surface and the extent of their lithogenetic variations and other geological data, have changed much less than temperature anomalies. Therefore, in many cases, the use of the former in the analysis of pre-Alpine processes is to be preferred.

1. The ages of rocks on the world's shields. A detailed analysis of the evolution of the upper mantle of shields and comparison between the estimated age of periods of activization and that established experimentally for shield rocks of all continents were published in [Gordienko, 2017 and others]. The comparison was encumbered by the fact that starting from the Late Archaean and Proterozoic, activizations never spread simultaneously over the entire territory. Insignificant differences in mantle rocks' heat generation have caused a certain shift in the ages of activizations within different shield blocks, whereas evaluations were performed for just a single block. It is nevertheless possible to reliably identify dating results suitable for comparison with model ones on the Canadian, Baltic, Ukrainian, and Indian shields, as well as on the Siberian, Sino-Korean, African, South American, Australian, and Antarctic platforms (Fig. 5 and Table 1).

A small number (on average, four out of 51 except for Antarctica) of «skipped» experimental dating results by comparison with the model ones could be due to insufficient knowledge about the shields and insufficient information available to this author. Cases of «skipped» results are much more numerous for Antarctica, a poorly studied continent, as the greater part of its surface is covered by ice. On the whole, the agreement between estimated and experimental data is beyond doubt, and it would be preposterous to suggest that it was a random coincidence.

In areas of the world's shields and plat-

Fig. 5. Studied shields and platforms. Folding age: *1* — Archaean, *2* — Proterozoic, *3* — Riphean, *4* — Phanerozoic.

Table 1. Comparison between simulated (M) and experimental dating results for the Canadian Shield (CSh), Baltic Shield (BSh) and Ukrainian Shield (USh) Precambrian rocks (in brackets — the amount of averaged data)

M	CSh	M	CSh	M	CSh
3,800	3,800±0(2)	3,140	3,150	2,240	2,240±10(3)
3,770		3,100		2,200	2,190±0(3)
3,740		3,070	3,080±0(3)	2,150	2,160±10(3)
3,710	3,700±0(2)	3,040	3,040	2,120	2,110±10(3)
3,680		3,010	3,000±0(2)	2,060	2,060±10(4)
3,650		2,980	2,980±10(2)	2,000	2,000±10(8)
3,620	3,620	2,940	2,940±10(2)		1,910±20(5)
3,590	3,590±10(2)	2,900	2,910±10(2)	1,850	1,850±20(20)
3,560	3,550	2,860	2,850±10(2)	1,800	1,800±10(12)
3,530		2,820	2,820±10(3)	1,750	1,750±20(20)
3,500	3,500±10(4)	2,780	2,780±10(3)		1,650±20(15)
3,470		2,740	2,740±10(7)		1,560±20(13)
3,440		2,700	2,700±10(11)	1,480	1,470±20(13)
3,410	3,410±0(2)	2,650	2,650±10(10)	1,350	1,330±20(8)
3,370		2,600	2,600 ±10(9)	1,250	1,260±20(9)
3,330	3,350	2,550	2,550±10(10)		1,180±20(11)
3,300	3,300±0(3)	2,500	2,480±20(8)	1,100	1,080±20(19)
3,270	3,250	2,400	2,420±20(14)	950	960±20(8)

Continuation of the Table

3,230	3,220	2,350	2,350±10(4)	790	770
3,200	3,200±0(2)	2,280	2,290±10(5)		670±20(4)
3,170				600	600±20(4)

M	BSh	M	BSh	M	BSh
3,710	3,700	3,070		2,200	2,210±0 (5)
3,680		3,040	3,030	2,150	2,160
3,650		3,010	3,010±10 (2)	2,120	2,120±10 (6)
3,620		2,980	2,980±10 (4)	2,060	2,050±10 (9)
3,590		2,940	2,940±10 (11)	2,000	1,990±10 (7)
3,560		2,900	2,900±10 (5)		1,940±10 (18)
3,530	3,530	2,860	2,860±10 (27)	1,850	1,860±20 (15)
3,500	3,510±10 (3)	2,820	2,820±10 (25)	1,800	1,790±20 (8)
3,470	3,470	2,780	2,780±10 (34)	1,750	1,740±10 (4)
3,440	3,440±10 (2)	2,740	2,740±10 (23)		1,610±20(14)
3,410	3,410±0 (3)	2,700	2,700±10 (48)		1,550±20 (6)
3,370		2,650	2,650±10 (25)	1,480	1,480±20 (5)
3,330	3,330±10 (4)	2,600	2,590±10 (7)	1,350	1,330±20 (3)
3,300		2,550	2,540±10 (5)	1,250	1,230±20 (7)
3,270	3,250±10 (3)	2,500	2,490±10 (15)	1,100	1,120±20 (8)
3,230	3,230±10 (6)		2,440±10 (15)		1,060±20 (5)
3,200	3,210±0 (5)	2,400	2,400±10 (4)	950	960±20 (20)
3,170	3,160±10 (2)	2,350	2,350±10 (4)		850±10 (6)
3,140	3,140±10 (2)	2,280	2,280±10 (3)	790	780±20 (3)
3,100	3,100±0 (3)	2,240	2,240±10 (2)	600	600±20 (6)

M	USh	M	USh	M	USh
3,680	3,680±0(2)	3,070	3,070±0(5)	2,200	2,200±0(3)
3,650	3,650±0(5)	3,040	3,040±10(5)	2,150	2,150±10(10)
3,620	3,620±10(3)	3,010	3,010±10(6)	2,120	2,110±10(9)
3,590	3,600±0(3)	2,980	2,980±10(5)	2,060	2,060±10(15)
3,560	3,560	2,940	2,920	2,000	2,000±10(18)
3,530		2,900	2,900±10(9)		1,950±20(12)
3,500	3,500±0(3)	2,860	2,860±10(4)	1,850	1,880±20(4)
3,470		2,820	2,820±10(12)	1,800	1,800±0(7)
3,440	3,450±10(3)	2,780	2,790±10(7)	1,750	1,750±10(7)
3,410	3,400±0(3)	2,740	2,740±10(3)		1,690±10(2)
3,370	3,370±20(3)	2,700	2,700±10(10)		1,580±20(5)
3,330		2,650	2,660±10(6)	1,480	1,460±20(5)
3,300	3,310 ±10(10)	2,600	2,600±0(9)	1,350	1,350±20(3)
3,270	3,270±10(4)	2,550	2,550	1,250	1,230±20(4)
3,230	3,250	2,500	2,500	1,100	1,100±0(2)
3,200	3,190±10(3)	2,400	2,430±10(4)	950	900±0(2)
3,170	3,170±10(4)	2,350	2,340±20(5)	790	770
3,140	3,140±10(7)	2,280	2,290±10(5)	600	650
3,100	3,100±0(7)	2,240	2,240±0(2)		

forms, where traces of active processes over 3.6 billion years can be observed, 23 active events have taken place. They include three geosynclinal processes, 11 cases of rifting, and nine activizations (recent activizations are not listed here because they have not yet occurred on the greater part of platforms). The evaluations that have been conducted are, in fact, about a physical substantiation of Stille's canon [Stille, 1924]. The result (energy expenditure of about $14 \cdot 10^{14}$ J/m^2) corresponds to the difference between radiogenic heat generation in the crust and upper mantle, on the one hand, and conductive flow from the tectonosphere, on the other. Therefore, if we compare the derived $14 \cdot 10^{14}$ J/m^2 with the entire energy discharged, it accounts for 20 percent of the total energy, whereas if the comparison is with radiogenic energy alone, the corresponding value will amount to 30 percent. Radiogenic heat generation in the tectonosphere is perfectly sufficient for explaining deep-seated processes, and there is no sense in resorting to other data, especially regarding deep-seated processes for which there is no information (the core/mantle interface, and so on) [Ivanov, 2010].

Fig. 6 illustrates the variation in heat generation in the crust and upper mantle of platforms versus energy spent on active processes over the recent 3.6 billion years.

The evolution of the activity versus time matches heat generation variations in the mantle better than in the crust. This is natural since crustal energy is largely spent maintaining the heat flow. Fig. 5 shows that the drop in the tectonomagmatic activity is due solely to a lower concentration of radioactive elements in the course of their decay. No other depletion of heat generation is observed in mantle rocks; otherwise, the experimental points would be below the curve.

2. Mass flow evolution in geological history. Not only do the data presented above indicate compliance with the energy preservation law, but they also illustrate a five-fold reduction in the incidence of active processes over the period in question due to a reduction in the concentration of radioactive elements in the course of their decay.

There is one more independent technique to verify the likelihood of such variation. It is based on a simulation study of isotopic-geochronometric systems [Azbel, Tolstikhin, 1988; and others]. The modeling is expected to solve the correlation between K, U, Sr, and isotopes of He, Ar, Ne, Xe, and other inert gases in the mantle, crustal basalts, and atmosphere. The recorded inconsistency can be eliminated if we get on board with the concept of mass flow from the mantle to the crust and back, the intensity of the process

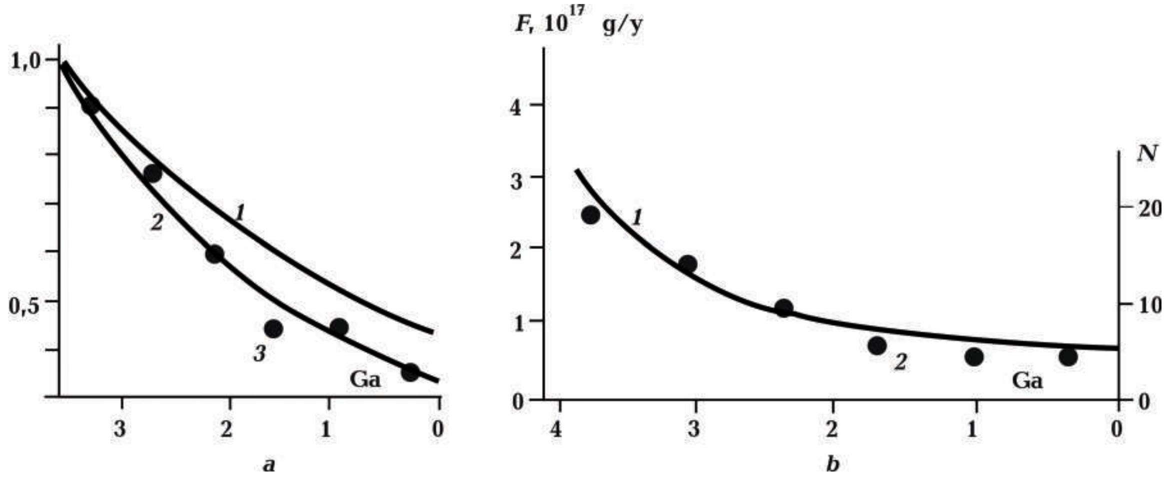


Fig. 6. Relative variations of heat generation in the crust (*1*) and mantle (*2*) of platforms and of average energy requirements for active processes within stretches of time of 0.6 billion years (*3*) (*a*) and variation of mass flow versus time (*1*), according to [Azbel, Tolstikhin,1988], and of the number of heat and flow transfer episodes (*2*) over every 0.6 billion years (*b*).

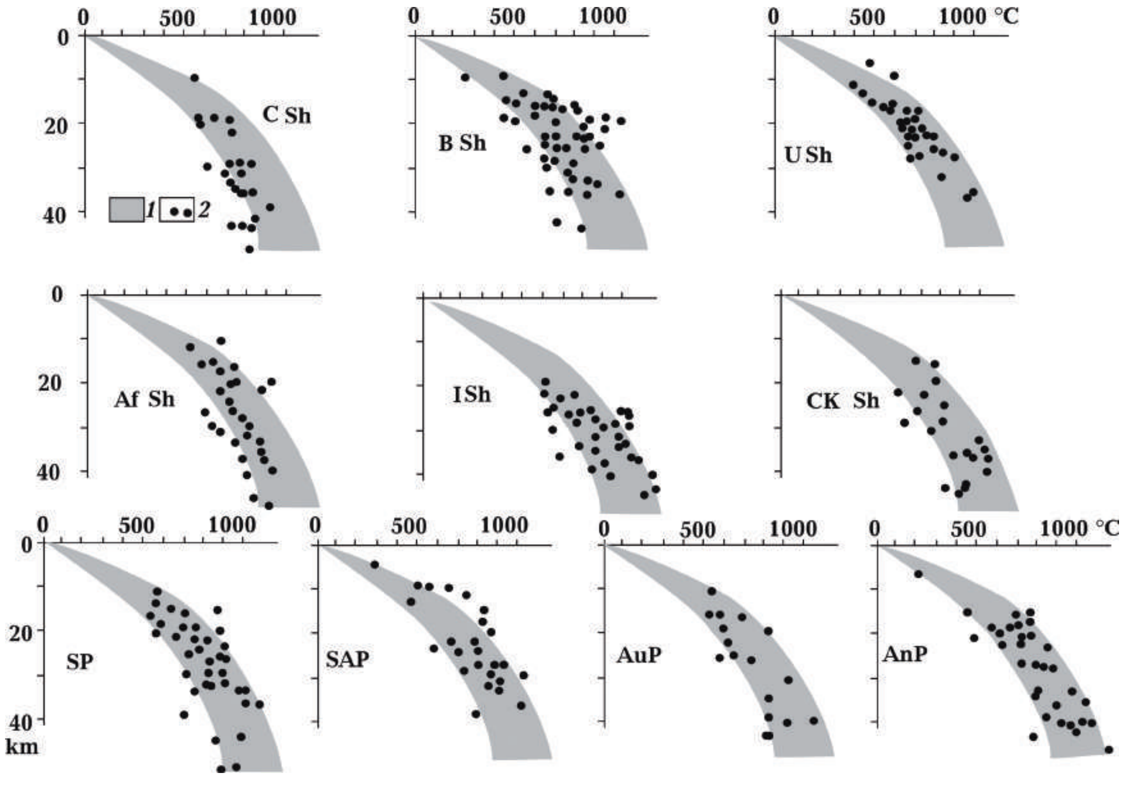


Fig. 7. Comparison between estimated (*1*) temperatures (*T*) for periods of activation and experimentally derived (*2*) data on *PT* conditions under which Precambrian platform rocks formed. Symbols used to designate various shields: CnSh — Canadian Shield, BSh — Baltic Shield, UkrSh — Ukrainian Shield, and IndSh — Indian Shield; Platforms: AfrP — African, SAm — South American, AuP — Australian, AntP — Antarctic.

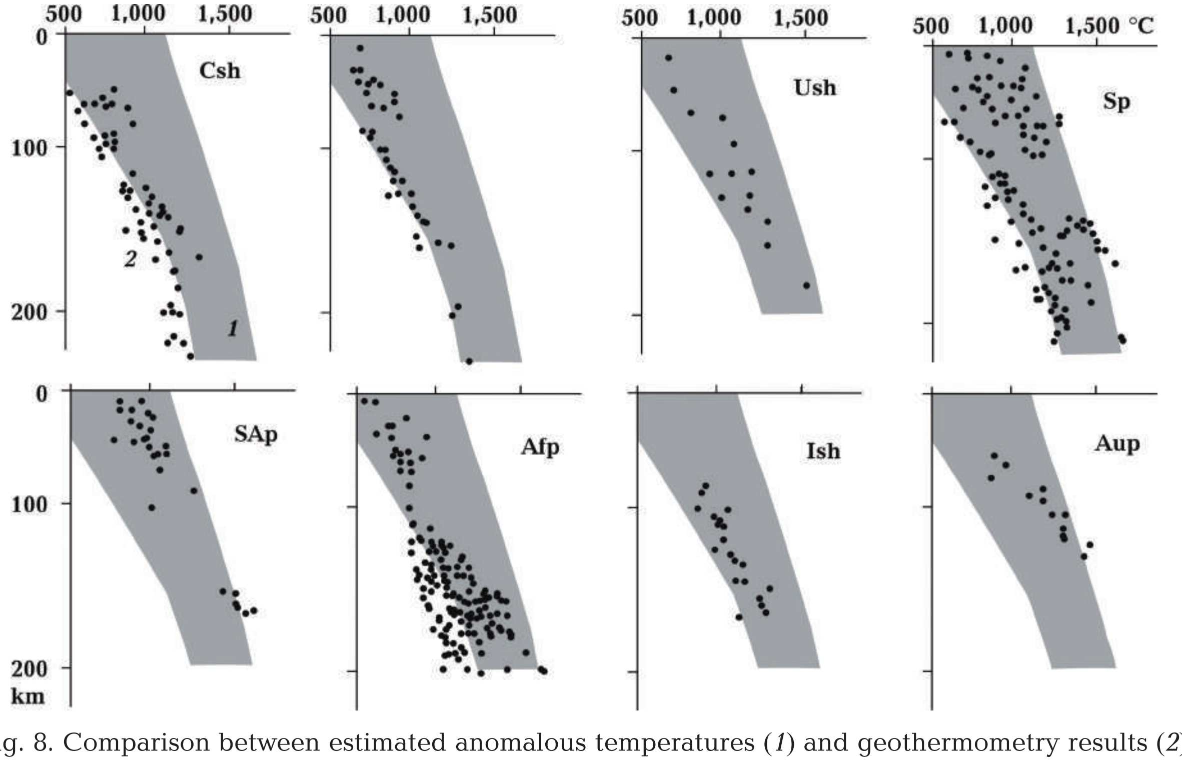


Fig. 8. Comparison between estimated anomalous temperatures (*1*) and geothermometry results (*2*) in the mantle.

changing with time. Variation of the mass flow with time adopted by the authors is shown in Fig. 6, *b*.

It conforms to the relative variation in the number of heat and mass transfer episodes in the platform mantle within a unit of time, something that can be considered as yet another validation of the adopted parameters for the tectonosphere energy balance.

The resulting parity makes it possible to calculate the size of the mass flow corresponding to one of the 23 platform activization events over the recent 3.6 billion years. This matches removal from the mantle of the material equivalent to a 13—13.5 km thick layer. In terms of the theory of the platform version of heat generation (HG), material equivalent to a 7—8 km thick layer is removed from the mantle during each active event. In the case of geosyncline belts, HG is 1.5 times greater, and beneath oceans, it is twice that for platforms. It would be logical to assume that in regions of these types, there should be 34—35 and 45 events, respectively. Since dry land, the shelf, and part of the continental slope, where the crust still differs from the oceanic crust, occupy 35 percent of the Earth's surface and assuming that platforms and geosyncline belts occupy areas of similar size, we obtain the removal of the material equivalent to a 13-km-thick layer, on the average, at the Earth's surface for each active

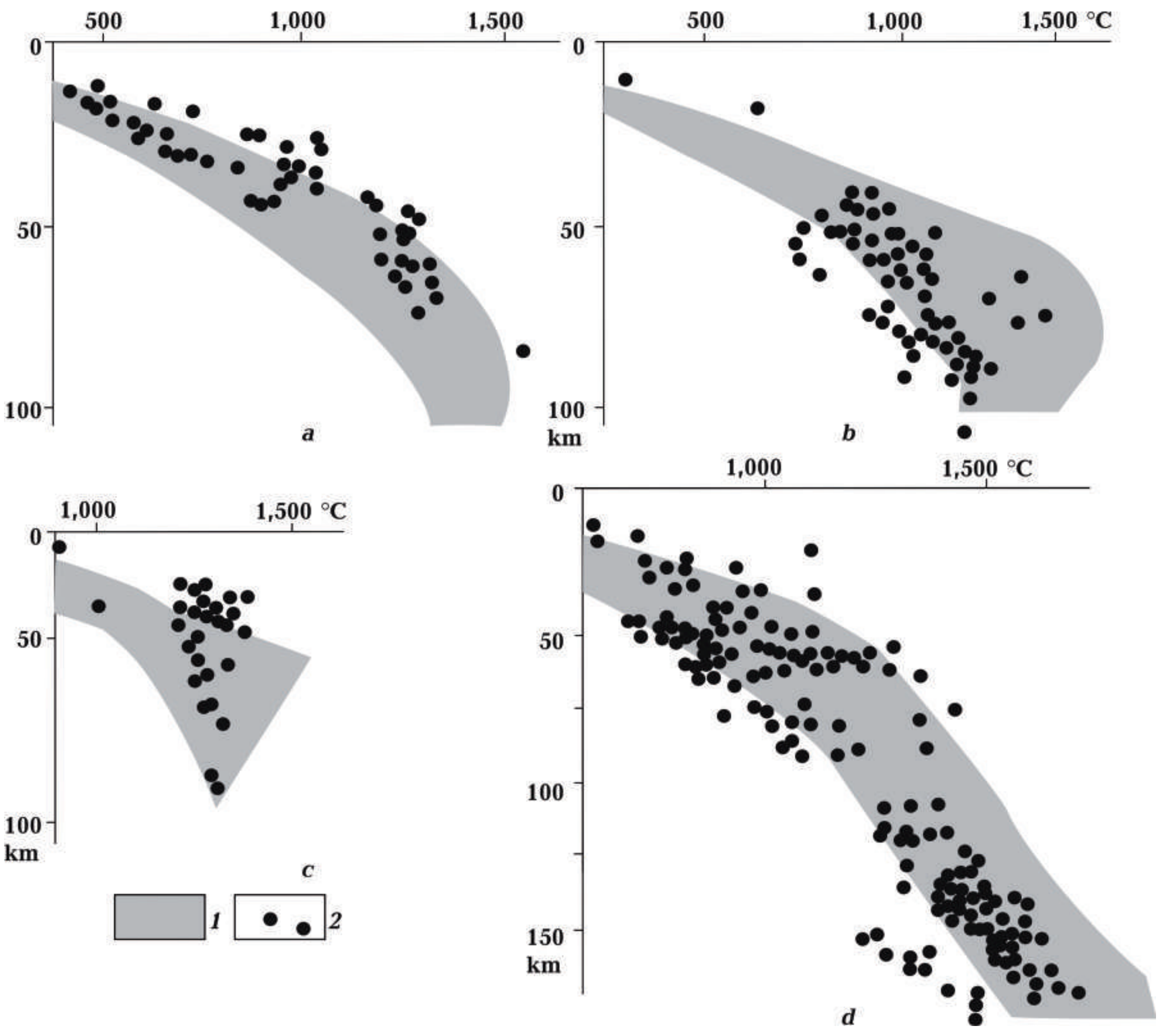


Fig. 9. The calculated *T* (*1*) and geothermometer data (*2*) in the areas of recent and current activity. *a* — Tethys geosynclines and island arcs of the west of the Pacific Ocean; *b* — Zones of recent activation of Eurasia; *c* — back-arc depressions; *d* — rifts of North. America, Eurasia and Africa.

event on the platform. To put it differently, the energy balance is also in conformity with the level of mass flow required for the observed outgassing of the Earth.

3. The data of geothermometry reflecting pressure and temperature (PT) conditions under which rock formation or transformation took place during the periods from the Early Precambrian to the present also corroborate the adopted level of heat generation in the crust and mantle. This information is supplied by xenoliths transported by kimberlites and alkaline basalts in platform regions. The greater part of crustal data was derived from near-surface rocks making up blocks with dissimilar sizes of erosional cut. Mineralogical characteristics of those formations and xenoliths from the greater part of the crust retain traces of maximum temperatures. In the mantle, under the extreme PT conditions, rocks largely «managed to adjust» to platform conditions, but the estimated and experimentally obtained temperatures match fairly well.

4. Mentioned above was an agreement between temperatures of the crust and upper mantle on platforms as estimated, on the one hand, and experimental data, on the other. **Results of a similar matching** could also be presented **for Phanerozoic geosynclines, rifts, and zones of single-episode active processes on continents and in oceans** (Fig. 9).

It is obvious that estimated and experimental data are in fairly good agreement. Numerical characteristics of the degree of their congruence are represented by two parameters: differences between estimated and experimental temperatures and differences between temperatures of magmas at the same depth. Modal values of both divergences amount to about 50 °C, i.e., the dissimilarity between experimental and estimated data could be due to an error in the experiment.

5. An obvious method for controlling the heat and mass transfer process scheme is the **comparison of the region's thermal model and the heat flow (HF) distribution.**

The agreement achieved in different regions of Earth is almost complete. In complicated cases, it is necessary to resort to data averaging to eliminate disturbances of unclear nature.

The agreement (observed and calculated

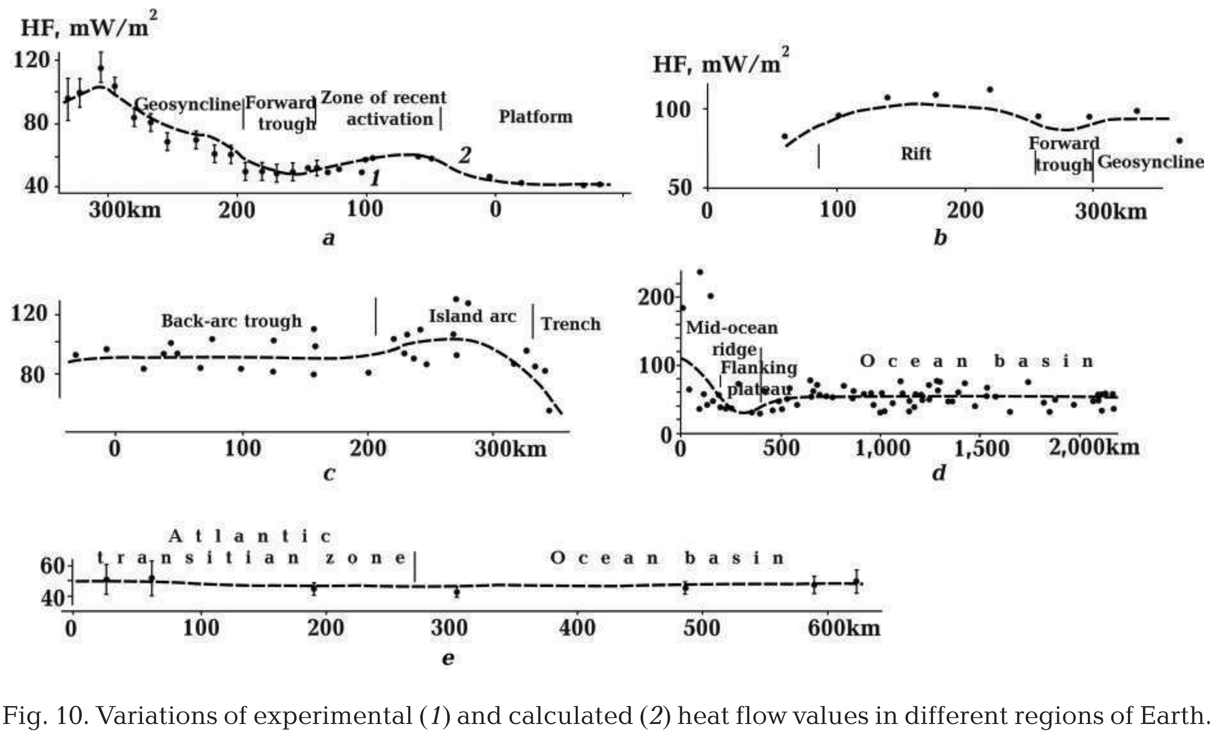


Fig. 10. Variations of experimental (*1*) and calculated (*2*) heat flow values in different regions of Earth. Regions: *a* — Carpathian, Volyn-Podolian plate, Ukrainian Shield; *b* — Central massive France, West Alps; *c* — South-Okhotsk depression, Kuril arc, Kuril-Kamchatka trench; *d* — Angola-Brazil profile; *e* — Contact between N. America continent and Atlantic ocean.

HF values) was also reached in other regions of the Earth: the Rhine graben, the Czech Massif, the Apennines, Dinarides, the Stavropol Uplift, the Greater Caucasus, the Urals, Turanian Plate, Kopetdag, Tyan-Shan, Pamir, Afghan-Tajik Depression, Baikal, Sikhote-Alin, Sakhalin, Sea of Japan and Okhotsk, Hokkaido, Kamchatka, Basins and Ridges region, Appalachian mountains.

6. A thickening of the sedimentary layer was viewed as equivalent to its subsidence. This assumption was tested on an example of the Ukrainian Shield and surrounding depressions. The volume of rocks supplied into them fairly well matches the size of the erosional cut on the shield over the period from the Riphean to the present time.

Subsidence (and upheaval) were assumed to be associated with temperature anomalies, polymorphic transformations, and changes in crustal composition and thickness. The latter factor, for example, played a major role in the formation of the Black Sea's western basin. It is located within an extended strip — from the Mesian Plate to the Turanian Plate — an abnormally basic ancient crust. The transformation of basaltoids into eclogites during young active processes imparted an ocean-

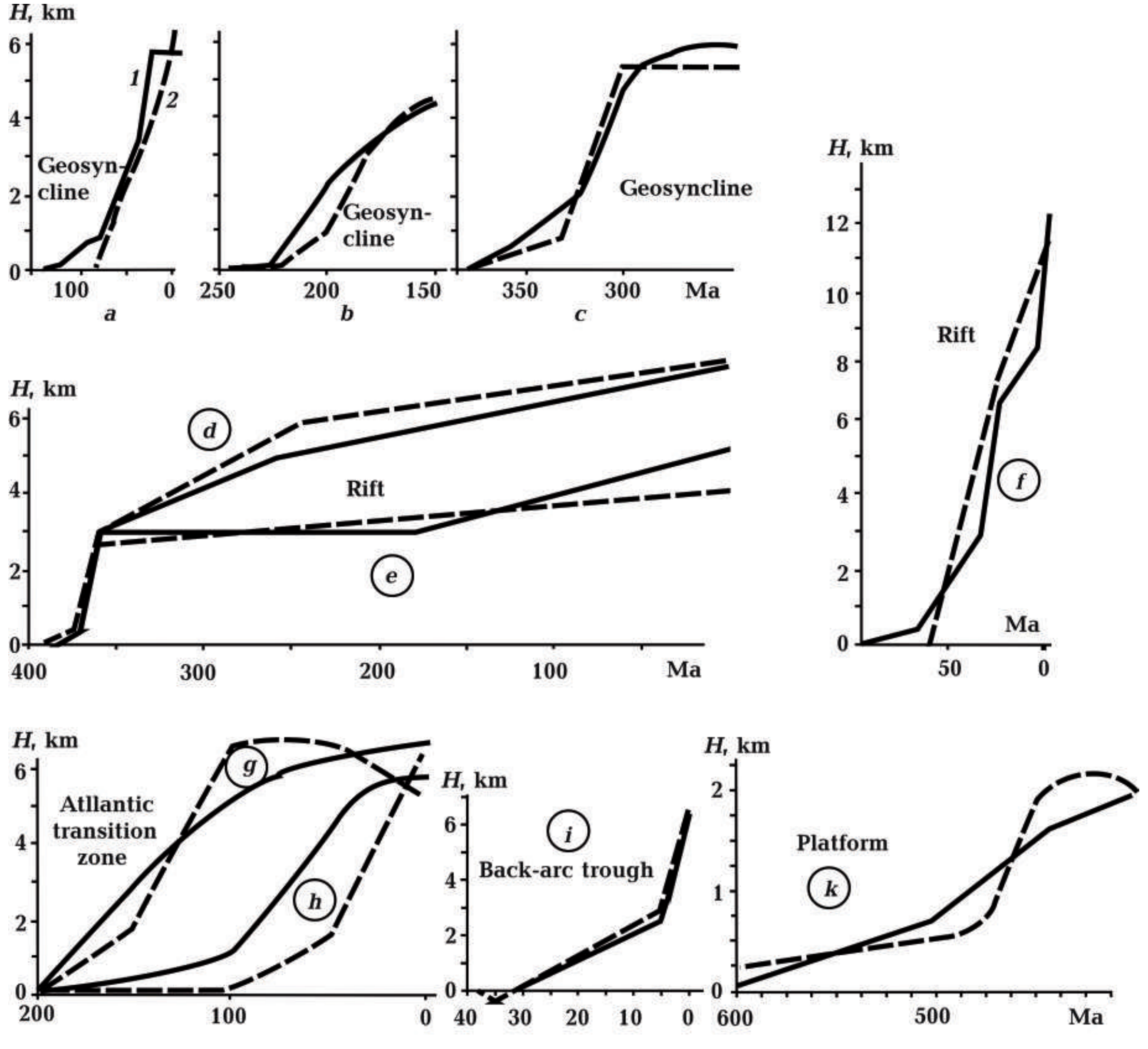
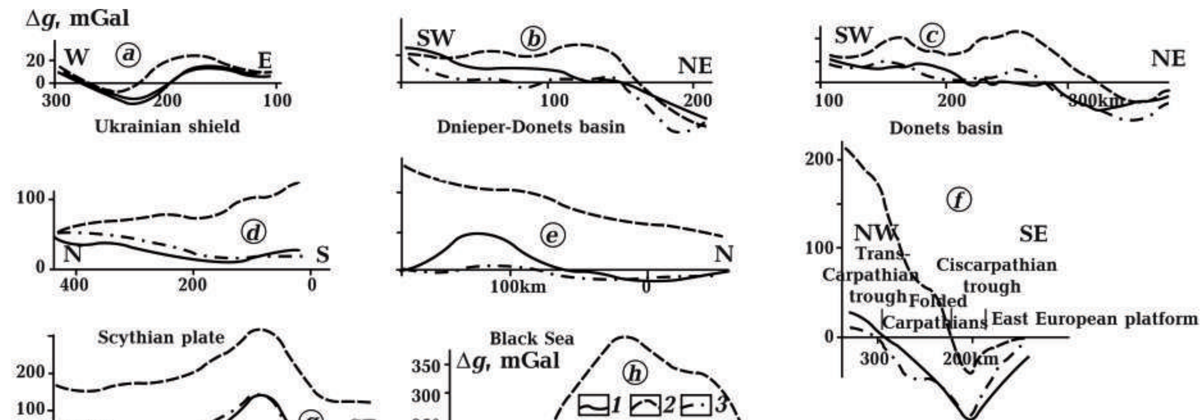


Fig. 11. Experimental (*1*) and estimated (*2*) variations of the sedimentary layer thickness in Folded Carpathians (*a*), on the Scythian Plate (*b*), in the Donets Basin (*c*), in the Dnieper-Donets Depression (*d*), in the Pripyat trough (*e*), in the Western Black Sea trench (*f*), in the inner (*g*) and outer (*h*) depressions of the North American cis-Atlantic trough, in South Okhotsk depression (*i*), in Volyn-Podolian plate (*k*).

ized appearance to the trench.

In most cases, Fig. 11 shows the average thicknesses of the sedimentary layer for different basins. The agreement is fairly good, and it is only in the Atlantic-type troughs of the transition zone that the differences grow significantly. The deep-seated process for this type of zone has not been developed as reliably as for continents. An analysis of events in intercontinental and back-arc seas suggests that the area underwent oceanization. Matching it is the heat and mass transfer in the mantle, similar to that in rifts but more intensive. As a result, we should recognize the need to supplement Cloos' triad [Cloos, 1939] for cases of rifting on a basite crust. A syneclise with a thick layer of sedimentary rocks took shape in the Carboniferous-Permian above the rift structure of the Dnieper-Donets Depression, whose crust had been basificated by Riphean processes. In the Black Sea rift that emerged on a basitic crust block, a suboceanic structure formed during the Cretaceous-Cenozoic. In many cases, this kind of structure on the vast expanses of contemporary oceans is not filled with thick sediments simply because their sources are too distant.

7. Values of the mantle gravity anomaly are estimated as the difference between the observed field and the crustal effect. The latter is derived from the density section established on the basis of the velocity section. Used in practice are densities anomalous with regard to those in the upper part of the



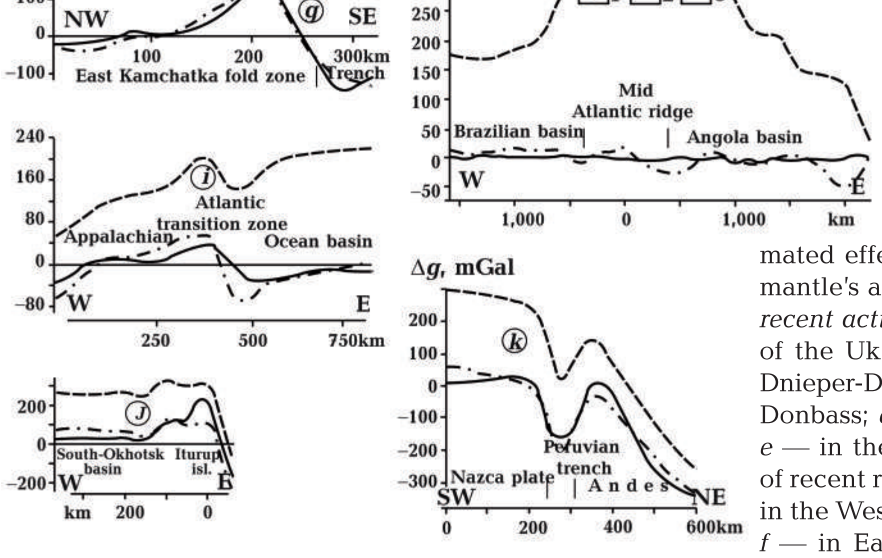


Fig. 12. Mantle gravity anomaly in some areas of active processes. *1* — observed field (the Bouguer anomaly), *2* — estimated effects of the crust and normal mantle, *3* — estimated effect with an account for the mantle's anomalous density. *Zones of recent activization*: *a* — in the center of the Ukrainian Shield; *b* — in the Dnieper-Donets Depression; *c* — in the Donbass; *d* — on the Scythian Plate; *e* — in the marginal part of the area of recent rifting and crust basification in the Western Black Sea Depression; *f* — in Eastern Carpathians; *g* — in Eastern Kamchatka, Kurile-Kamchatka Trench, and in the North-Western plate of the Pacific Ocean; *h* — Angola-Brazil geotraverse running across the Mid-Atlantic Ridge (MAR) and adjoining basins; *i* — Inner and Outer depressions of the North American Cis-Atlantic trough and adjacent part of North America with the Appalachian zone of active processes; *j* — South Okhotsk backarc trough; *k* — Transition zone from the Andes to the Nazca Plate.

mantle (3.32 g/cm^3). On parts of the platform, where activization has been clearly absent for a long time (and the mantle density is normal, background), the crustal effect of minus 870 mGl corresponds to zero of the observed field (Bouguer anomaly). The crustal effect is distributed in reference to this norm, and its deviation from the observed field is used to assess the mantle anomaly. Even with high-quality velocity profiles, the error is at least 10 mGl. An anomaly of 20 mGl, which in many cases corresponds to recent activization on the platform, was viewed as significant. In Alpine geosynclines and rifts (including those on the territory on which current activization is taking place in addition to the main process), anomalies are much greater (Fig. 12). On average, the difference between the estimated and observed fields when the anomalous effect of the mantle is taken into account becomes less than ±17 mGl, a value explainable by errors.

Consent (of the observed and calculated Δg values) was also achieved in other regions of the Earth: Armorican massif, Alps, Provence, Apennines, Tyrrhenian and Adriatic seas, Sudetenland, Baltic shield, Caledonides of Scandinavia, Voronezh massif, Moscow syneclise, Urals, Timan ridge, Pechora depression, Small Caucasus, Big Caucasus, Kurin Depression, Karpinsky Val, Caspian Depression, Mangyshlak, Ustyurt, Turan Plate, Kopetdag, Baikal, Sikhote Alin, Sakhalin, Kuril Islands, Hokkaido.

8. UHP blocks. There are known crustal rocks «…which could form only at very high pressures, the maximum of which can correspond to depths of more than 120 km. So far, such anomalous phenomena have no explanation in terms of physics. … We do not know a mechanism that would enable large masses of continental crust sink into the upper mantle down to a depth of at least 120 km and then bring them back to the daylight surface» [Perchuk, 1997, p. 72]. Rock blocks with such tectonic-metamorphic history, when pressures at the highest point of metamorphism reached the field of coesite stability, are termed ultrahigh-pressure metamorphic terrains (UHP terrains).

Known at present (in Eurasia, North America, and Australia) are about 20 metamorphic complexes incorporating coesite [Liou et al., 2004; Shirey et al., 2013a,b] or quartz pseudomorphs based on coesite.

Conditions that prevailed during the formation of UHP complexes can be conveniently analyzed on an example of the Kokchetav Block in Central Kazakhstan — one of the best-explored complexes. According to recent data [Buslov et al., 2015], the depth to which its rocks subsided — 150—200 km — is larger than that of known bodies of similar type.

It is so far impossible to describe the geological history of the Kokchetav Block, which is part of the Central Asia folded belt, in substantial detail. Literature, however, contains information enabling a reconstruction of the history of the region's development during the period when diamond-bearing rocks formed [Buslov et al., 2015; Khain, 1977; Zhimulev, 2007; and others]. However, some points in the reconstructed history remain at the level of likely assumptions because much of the massif's Riphean sedimentary-volcanic section was destroyed by erosion.

It can be maintained that two consecutive stages of geosynclinal development took place in the region: Late Grenvillian (Early Lufilian?) and Early Caledonian (Late Baikalian?). Each stage started with basic-ultrabasic magmatism and ended with acidic magmatism and folding, and those processes ended 850 and 450 million years ago, respectively. Territorial overlapping of geosynclines did exist, but it is impossible to determine its extent.

A thermal model of the tectonosphere was constructed for the said period of the massif's development involving heat generation in the geosynclinal upper mantle. It is shown that the time between the two events was sufficient to accumulate the required energy. About 550 million years ago, initial magmatism could trigger the Caledonian geosynclinal process. The start of the UHP terrain exhumation dates back precisely to that time interval. Information on the procedure of its immersion is unavailable. Apparently, it happened long before the beginning of the Caledonian cycle.

Rocks making up the UHP complex within the Caledonian stratum exhibit clear traces of their formation from rocks of the sedimentary-volcanogenic (upper) crustal layer of the Lufilian geosyncline. It can be assumed that precisely those formations, complemented by rocks of the lower crust, were involved in creating the block that rose to the surface in the Caledonian time. This author [Gordienko, 2017] analyzed the mechanism of formation of crustal blocks capable of changing position within the crust and sinking into the mantle. We are talking about intracrustal advection. In the lower portion of the geosyncline's sedimentary layer, during its immersion and heating, there formed rocks whose density was higher (by 0.1—0.15 g/cm^3) than the density of rocks in the upper part of the heated consolidated crust. After subsiding by several kilometers, they entered the eclogitization zone. The composition of the resulting mixture [Zhimulev, 2007; and others] makes it possible to estimate the density of the block after it dipped into the mantle and the metamorphic transformations of its components (quartz into coesite, amphibole into omphacite, and so on). The density anomaly enables us to estimate the depth to which the block sank as two-thirds of the depth to which pure eclogite subsided (see above). The depth where the block halted would amount to about 170 km. This independently derived estimate matches the data of [Buslov et al., 2015]. The transformation of submerged rocks, including siderite, pyrite, and graphite, is favorable for the formation of diamonds within them. In this sense, the process is fundamentally different from the removal of diamonds by kimberlites, which were in the rocks above the magma chamber.

It might be logical to associate the rise of the complex that remained in the medium with platform-type temperature all the way toward the surface (Fig. 13) with the start of initial magmatism. Perhaps, the rocks within it were only slightly heated compared with conditions that prevailed prior to the onset of the Caledonian process. Publications [Buslov et al., 2015; Zhimulev, 2017] mention traces of insignificant partial melting of rocks within the complex. At temperatures of 1,100—1,200 °C reached at a depth of about 150—170 km, solely preserved micro-inclusions of amphibole and phlogopite (biotite?) could have undergone melting. As a result, there emerges a minimal negative density anomaly measuring a hundredth of a fraction of g/cm^3.

The rate at which the complex ascends inside the mantle is 50 times lower than that of the kimberlite magma (130 km over 2—5 million years). The difference in the density anomaly could provide slowing down the upward motion by one half of the order of magnitude. An additional order of magnitude is most likely due to the smaller size of the

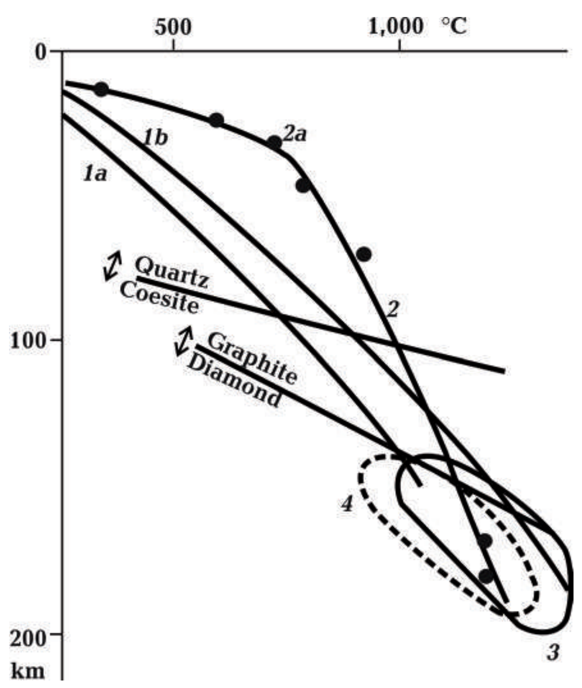


Fig. 13. Comparison of the temperature distribution within the cold upper half of the upper mantle with the graphite-diamond and quartz-coesite transformation conditions *1a* — temperatures beneath the platform; *1b* — temperatures prior to the initial magmatism; *2* — *PT* conditions of eclogite exhumation from the Kokchetav Block (*2a* — at individual points of the exhumation trajectory, according to [Buslov et al., 2015; Zhimulev, 2007]); *3*, *4* — parameters of the medium proceeding from the data on central inclusions in diamonds [Bobrov, 2009] for eclogitic (*3*) and peridotitic (*4*) parageneses.

body. The relevant thicknesses are not appreciable (about 1 km). The authors of the studies [Buslov et al., 2015; Zhigulev, 2007; and others] believe that the body split into several sheets that changed position separately within the crust. The total thickness could not be determined, but it may well have been one-third of the QTA dimension. This explains the estimated rate of upward movement within the mantle. Calculations show that precisely when the thickness was 20 km, during the uplift, the change in T with depth is formed, which is close to those shown in Fig. 13.

The rate of the object's upward motion within the crust is lower by an order of magnitude, which agrees with the increase in viscosity. More likely, however, is the effect of a different mechanism responsible for the block's fragmentation. We may deal with the involvement of the massif in advective folding with the formation of overthrust sheets [Gerya, 2010].

The process of formation of UHP terrains, as viewed by proponents of plate tectonics [Buslov et al., 2015; Malusa et al., 2015; Shirey et al., 2013a,b; and others], lacks consistency, is devoid of substantiation in terms of energy, and actually represents, for some vague reasons, a series of block translocations.

The list of procedures for verifying the constructed models could be continued, although the rest of the examples would hardly add more credibility to the result. On the whole, it is good enough. No other hypothesis would make it possible, without selecting parameters of the model, to obtain such quantitative agreement, the divergences being within acceptable limits of error.

9. Possible mechanism of earthquakes in the crust of Alpids. The articles [Gordienko, 2017; Gordienko, Gordienko, 2018] discussed the application of the theory to seismicity.

It was suggested that earthquakes could be triggered within the upper crust of Alpine geosynclines at the stage of recent activization at interfaces between layers with dissimilar extents of sedimentary rock transformation [Gordienko et al., 2021].

In many Alpids, the young sedimentary layer with the age of folding ranging from 10 to 30 million years is underlain by layers Hercynian (250—300), Caledonian (500—600), Baikalian (900), or Gothian (1,200 million years). The total thickness of the upper series of layers reaches 10—15 km. The level of their transformation during recent activation (about 0—7 million years) is dia- and catagenic. The lower series experienced the stage of metamorphism, including granitization, and became part of the crystalline basement. There formed a zone of density (σ) inversion. It may have triggered the crustal material displacement and seismicity. Parameters of the zone were described, in particular, for the Carpathians [Gordienko, Logvinov, 2011]. No velocity inversion of longitudinal seismic waves (V_p) could be recorded within the same depth range (approximately six to18 km). This can be accounted for by the fact that the types of relationship between σ and V_p are not the same for the sedimentary layer and basement rocks. Density inversion zones are not widespread. They may be totally absent beneath the entire region of folding or its larger areas in regions with intensive basification (typical of Pacific areas). It might be interesting to analyze the crustal material's displacements in greater detail and correlate between predicted and observed events. However, some synchronous crustal seismicity of a different nature may distort the results of such a correlation. In the case of Alpine geosynclines that experienced recent activization, there may also be, in addition to the aforementioned types of earthquakes, others, such as 1) Those associated with processes of folding during which the youngest series of rocks (at depths between zero and 6 km) had slipped down from the basement uplift; 2) Magmatic earthquakes (with major crustal foci occurring at depths of 25—30 km and on the path of magma ascent to the site of eruption at 0—25 km); 3) Earthquakes triggered by movements of plunging eclogitized bodies in the lower crust and the mantle (below 25 km) [Gordienko, 2017]. However, an analysis of large amounts of evidence may reveal the concentration of hypocenters at predicted depths.

Hypocenters were studied down to the depths of 40 km in 2006—2018. In some cases,

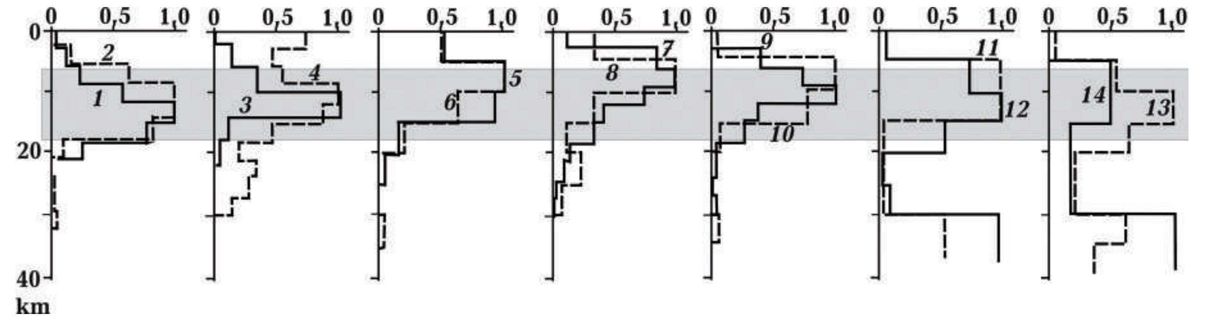


Fig. 14. Earthquake depth distribution patterns for the Tethys belt. The estimated depth range is shown in gray. Region numbers: *1* — the Pyrenees, *2* — the Alps, *3* — the Apennines, *4* — the Carpathians, *5* — the Balkans, *6* — the Pontids, *7* — Dagestan, *8* — Elburs, *9* — Kopet-Dag, *10* — Zagros, *11* — Hindu Kush, *12* — the Himalayas, *13* — Burma, *14* — Sumatra.

there was quoted evidence from already available generalizations made by other authors for different periods. In most cases, the selected interval for graphs showing the distribution of hypocenters versus depth amounted to 5 km, which was due to a potential error of at least 3 km. The number of earthquakes differs widely from region to region. Therefore, the distributions were constructed in the form of values referred to as the maximum (Fig. 14).

The predicted earthquakes have been registered within all Alpids. Seismic events at other depths have been reported less frequently for the Tethys, or else they were separated by depth intervals with smaller clusters of hypocenters. The above hypothesis has been verified. Notwithstanding the fact that in regions other than Alpids, earthquakes at similar depths could be triggered by other mechanisms. One of them might well be vertical motions of crustal blocks with cracking during recent activization.

The derived result corroborates the forecast partially based on a geological theory. Models of deep-seated processes within geosynclines and zones of recent activization have been constructed in terms of theory. However, we focused in our prediction of the data regarding the effect of PT conditions on the physical properties of rocks with a different composition formed as a result of such processes. The said information has also been corroborated. Yet, we cannot claim that our version is final, and evaluations of possible parameters of the medium can be worked disputable. Approaches based on our work and the number of regions covered can be expanded.

Several applications of the theory to studies of seismicity and prospecting for mineral deposits (hydrocarbons, hydrothermal sulphide ores, diamonds, and geothermal energy resources) have been considered. They contribute, with various degrees of significance, to the available knowledge for each of the aforementioned areas of interest. Yet, they do not explicitly explain how mineral deposits formed. Their formation is associated with collateral phenomena of heat and mass transfer in tectogenesis. The main value of such applications is perhaps the fact that tried and tested methods for analyzing geological and geophysical information can be applied to new targets. But there also are important new features that may well prove useful as additional tools in the arsenal at the disposal of experts researching the processes listed above.

Conclusion. Presented information in this article shows that the geological theory complying with formulated requirements is realistic. The article, offered to the readers' attention, is the result of long studies by the author. He could not be satisfied with the concept of plate tectonics, which dominated in recent decades in geology. Other currently existing points of view on the causes of tectogenesis and its evolution in the history of the Earth do not correspond to the requirements that it is logical to present to the contemporary geological theory. First of all, it concerns the energy source for deep processes. It seems to the author that only with the introduction of an energy source and implementation of the law of conservation of energy in the construction of schemes of deep processes, a solid foundation for a general theory of the development of the Earth has arisen. Each result obtained with its help allows for quantitative control on many parameters. Such control has already been carried out over a wide range of geological phenomena and physical fields. It is likely that the work performed is imperfect, but the author is sure that the significant steps have been taken in the right direction.

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Щодо геологічної теорії

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Авторська адвекційно-поліморфна гіпотеза глибинних процесів у тектоносфері спирається на систему ендогенних режимів В.В. Білоусова, певне джерело енергії — радіоактивний розпад у породах кори і верхньої мантії, спосіб перенесення енергії — адвекція. Елементарні обсяги переміщеної речовини названі квантами тектонічного дії діаметром близько 50—70 км. Доведено фізичну реальність таких об'єктів. Вибір ендогенного режиму пов'язаний з видом попередньої теплової моделі.

Обґрунтовано схему дії «теплової машини» тектоносфери, яка спирається на твердо встановлені факти і кількісно пояснює основні події геологічної історії в рамках закону збереження енергії. Для будь-якого періоду від раннього архею до наших днів може бути кількісно обґрунтована схема тепломасоперенесення, обраний ендогенний режим, побудована нестаціонарна теплова модель і змінний в часі розподіл фізичних властивостей порід. Використання отриманих даних і розв'язання тільки прямих задач дають можливіть визначити геологічні прояви процесу і аномалії фізичних полів. Їх порівнюють зі спостереженими даними (без підбору), розбіжності не перевищують величин, зумовлених похибками спостереження і розрахунку.

Спираючись на адвекційно-поліморфну гіпотезу, вперше стало можливим прогнозувати: 1) утворення квантів тектонічної дії; 2) стабільність параметрів (глибини і температури) магматичних вогнищ у мантії в історії Землі; 3) існування глобальної астеносфери (глибина приблизно 700—1000 км); 4) розподіл швидкості поширення поздовжніх сейсмічних хвиль у верхній мантії регіонів з усіма типами ендогенних режимів; 5) відмінність природи землетрусів на різній глибині у фокальних зонах. Успішна перевірка прогнозів переводить гіпотезу в ранг теорії.

Теорію використано для пояснення на кількісному рівні: датувань активних процесів на всіх платформах Землі, розподілу температур у корі і верхній мантії платформ і активних регіонів, товщини осадів у геосинкліналях і пострифтових западинах, зміни масопотоків у геологічній історії, аномалій теплового потоку, гравітаційного поля.

Розглянуто кілька застосувань теорії до вивчення проблеми сейсмічності, UHP-блоків і пошуків родовищ корисних копалин (вуглеводнів, гідротермальних сульфідних руд, алмазів, ресурсів геотермальної енергії).

Ключові слова: адвекційно-поліморфна гіпотеза, контроль прогнозів, геологічна теорія.