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ON ENERGY BALANCE OF THE TECTONOSPHERE

Purpose of this work is to refine and complete the energy balance of the Earth's tectonosphere by thermal modeling. The methodology includes a detailed comprehensive analysis of heat generation in the crust and upper mantle throughout the studied geological history of the Earth for 4.2 billion years. Results. Experimental data on radiogenic heat generation in the Earth's crust and upper mantle are summarized. The need for a separate consideration of the heat balance for regions with different endogenous regimes on platforms, in geosynclines and oceans has been established. The average values of heat generation in the crust are about 0.4–0.5 µW/m^3. In the upper mantle they are 0.04, 0.06, and 0.08 µW/m^3, respectively. When taking into account the thicknesses of the solid crust (about 40 km under the platforms and geosynclines and about 6 km under the oceans) and the upper mantle (430–460 km), almost the same number of sources is found under all regions. They are distributed differently. This leads to different variants of geological history. It can be assumed that there are radiogenic heat sources with an intensity of about 0.02 µW/m^3 in the transition zone to the lower mantle and in the lower mantle up to about 1100 km. At greater depths in the shell (the total mass of the Earth outside the core) and core, there are no sources. The energy balance of the tectonosphere is calculated for the platforms. Over 3.6 billion years (the period over which it is possible to describe the geological history quite accurately), about 73.5·10^{14} J/m^2 has been carried out by the heat flow. The conductive heat flow during this time carried out 59.5·10^{14}J/m^2. The difference corresponds exactly to the needs of all active processes of this period. Originality. The experimental dates of the events also coincide with those calculated by the theory (some of which are for the first time). Practical significance. For the Phanerozoic geosynclines, such control has also been partially performed. The independently determined evolution of the mass flow (which is also of practical importance) in the geological history also agrees with the calculated values.

Key words: radiogenic heat generation, conductive and convective heat transfer, active processes in the tectonosphere, thermal history.

Introduction

The energy balance of the tectonosphere is one of the main elements of the geological theory developed by the author. It controls the implementation of the law of conservation of energy in deep processes. The currently available data allow us to identify the source – the radiogenic heat generation (HG) in the Earth’s crust and upper mantle – and quantitatively show the correspondence of the energy released to all known energy-intensive processes throughout the studied geological history starting from about 4.2 Ga ago [Gordienko, 2012, 2022, etc.]. The energy balance consists of residual heating from accretion and differentiation of the planet, heat generation in the crust and mantle, on the one hand, and the cost of maintaining the heat flow (HF) through the surface, on the other. HF comprises three components associated with 1) cooling of a stationary medium; 2) heat generation in it; and 3) heat and mass transfer in the tectonosphere, a phenomenon that accompanies active processes. The external thermal background of these processes is created by solar radiation and the evolution of the atmosphere. The release and absorption of heat during polymorphic and phase transformations of matter, according to the author, can be considered balanced.

The balance was considered in detail by the author earlier [Gordienko, 2017]. In this article, some additions and clarifications have been made to its brief description.

The individuality in the composition and heat generation of the crust in regions with different endogenous regimes is obvious. Differences in the composition of mantle rocks on platforms and in oceans were recorded even in the works of F. Boyd [Boyd, 1989]. In the opinion of F. Boyd, mantle rocks of platforms could not have been formed through “crowding” of the oceanic lithosphere. The off-platform continental regions occupy an intermediate position [Boyd, 1989]. Therefore, it makes sense to consider the distribution of HG in the tectonospheres of Precambrian platforms, Phanerozoic geosynclinal belts, and oceans separately.

Data on the Earth's radiogenic heat sources

Now sufficient material has already been accumulated to reliably determine the concentrations of uranium, thorium, and potassium in the substance of stone meteorites that formed the Earth, and the processes of their migration in separation from the material of the metallic core have been studied [Crozaz, 1979; Goreva & Burnett, 2001; Handbook…, 1969; Rocholl & Jochum, 1993; White, 2020; etc.]. A general estimate of the radiogenic sources number (for the current level) can be obtained from the HG of chondrites and iron meteorites (Fig. 1).

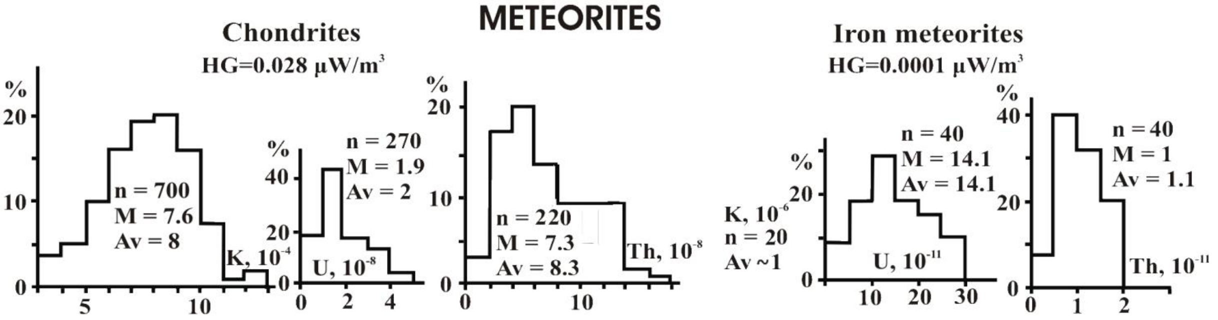

Fig. 1. Histograms of K, U, and Th content distributions in meteorites.
n - is the number of analyzes used, M is the median value, Av is the mean.

The shell volume is $0.9 \cdot 10^{12}$ km^3, i.e. the total power of radiogenic energy sources is $25.2 \cdot 10^{12}$ W. When describing the vertical distribution of heat generation in the Earth's shell, the object predicted by the hypothesis based on the results of thermal modeling and experimentally confirmed is the global asthenosphere (in the depth interval of about 800–1100 km) – zone of partial melting of the lower mantle rocks. This is the preserved lower fragment of the magma ocean. The “ocean” arose during melting, which accompanied the separation of the nucleus, and convection, the transfer of the most fusible and enriched in radioactive elements part of the substance into the upper part of shell. It cooled to solidus temperature, separating the upper mantle and crust in its composition.

Data are abundant on the content of uranium, thorium, and potassium (and therefore, on contemporary heat generation) in crustal rocks. P-wave velocities (Vp), as well as their dependence on temperature (T) and pressure were determined for the same rocks. As a result, correlations were established between parameters for rocks of the consolidated crust HG=1.28exp (1.54 [6-Vp]) at platform-type temperature distribution. Heat generation in rocks with dissimilar degrees of lithification in the sedimentary layer correlates with Vp in the following manner: HG = 1.264 – 0.084exp (0.554 [Vp – 2]) [Gordienko, 2017] (HG in µW/m^3, Vp in km/s).

The average velocity sections of the Earth's crust of platform and geosyncline were constructed for the platform distribution of T. The average HG values in the crust of these regions were 0.55 and 0.42 µW/m^3, respectively. The total contemporary radiogenic heat generation in the crust beneath platforms (Wcrust = HG•H, H being the thickness of the layer) is 23 mW/m^2; beneath geosynclinal belts, it amounts to 17.5 mW/m^2. The thicknesses of the crust are close to each other and are about 42 km. Beneath oceans with a crustal thickness of about 6 km (approximately 0.5 km composed of sedimentary rocks and 5.5 km of basic rocks), the average heat generation in the crust is about 0.5 µW/m^3, and the composite energy generation is 3 mW/m^2.

The exchange of radiogenic energy sources between the crust and the upper mantle occurs in the form of basaltic magmatism and subsidence of eclogites formed in the crust. The volume can be judged by the data in Fig. 2.

The density of gas-saturated basaltic magma allows it to reach the surface. The density of eclogites with pyrope allows subsidence to a depth of about 250 km, with almandine – to the bottom of the upper mantle.

The bibliography and arguments in favor of the reliability of the accepted HG values in the upper mantle rocks are given in [Gordienko, 2017]. According to the theory throughout the Earth’s geological history, crustal eclogites have descended into the upper mantle in an amount that exceeded half of its volume. The scale of the process leaves no doubt that, as far as composition is concerned, the lower portion of the upper mantle (directly from which no xenoliths are transported to the surface) does not noticeably differ from the upper portion. It also contradicts the idea of a general decrease in the concentration of radiogenic sources in the mantle with time due to their removal into the crust.

Distribution histograms of radioactive element content in the mantle rocks (and crustal mafic rocks and eclogites) of the three considering regions varieties are shown in Fig. 3.

Differences in the number of analyzes used are large. It can be assumed that the result for platforms is unlikely to change when new data is added (it was the same with half as many of them). In the case of geosynclines this is also quite likely. There is still little information in the oceans, for a reliable estimate of HG it is necessary to continue its accumulation. However, even with the currently available information, we can state a noticeable difference in the heat generation of mantle rocks in the three region varieties of the Earth.

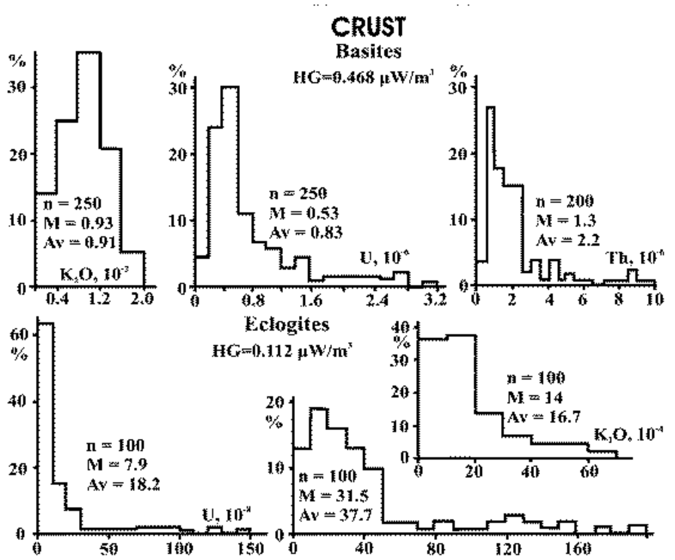

Fig. 2. Histograms of K, U, and Th content distributions in basalts and eclogites.

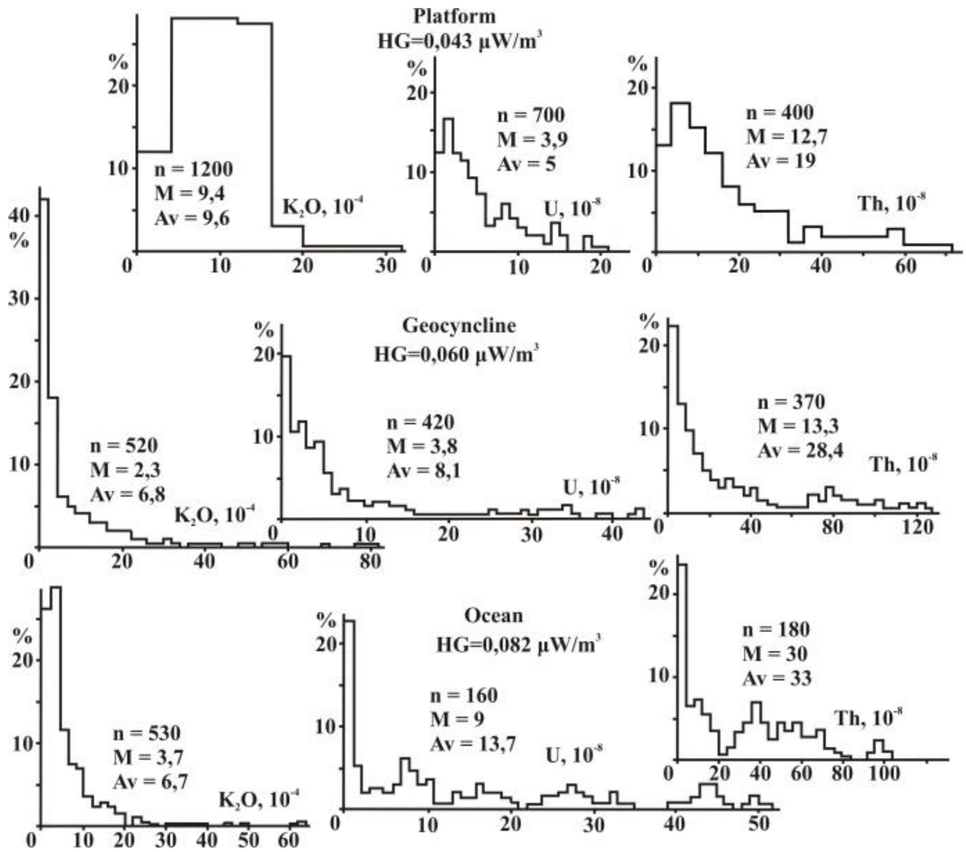

Fig. 3. Histograms of K_2O, U, and Th content distributions in the mantle rocks of platforms, geosynclines, and oceans.
n is the number of analyzes used, M is the median value, Av is the mean.

The depth of the upper mantle base assumed by the author (the boundary at which, according to theory, the transformation of olivine-α into olivine-β begins at present-day temperature under the inactivated Precambrian platforms is about 470 km) does not necessarily exactly correspond to the change in heat generation. Nevertheless, it is interesting to note that the total amount of radiogenic heat sources in the crust and upper mantle of all three types of regions turns out to be almost the same – 41±1 mW/m^2. The revealed differences hardly exceed the calculation error. I.e., at present, at any point on the Earth, the same amount of heat is released under a unit of surface, but its sources are distributed differently, which is associated with the crust formation of one or another type. On the continents the crust of approximately modern thickness has existed for billions of years, on the oceans the situation is unclear, most likely, in the present form (i.e. with a Moho depth of about 10 km, which is not necessarily true) it is young. Tens or first hundreds of millions of years ago there was a crust of comparable thickness to the continents, perhaps more basic. At this point, any reliable information about the history of the oceanic crust is exhausted.

Considering the HG of the crust and upper mantle to be known (see below), let us determine their share in this heat release. For continents and oceans, the total number of sources in the crust and upper mantle practically coincides. Table 1 presents continental data (average for geosynclines and platforms). This is natural, since according to the theory, at the beginning of oceanization, the conditions were the same as on the present continents. Then the sources from the crust were mostly transferred to the upper mantle (which corresponds to the experimental data.

Table 1

Distribution of radiogenic energy sources in the Earth's shell

Layer	Depth, km	V, 10^{12} km^3	HG, W/km^3	E, 10^{12} W
Crust	0-42	0.021	500	10,5
Upper mantle	42-470	0.201	50	10,0
Transition zone	470-800	0.130	19	2.5
Global asthenosphere	800-1100	0,116	19	2,2

E – energy

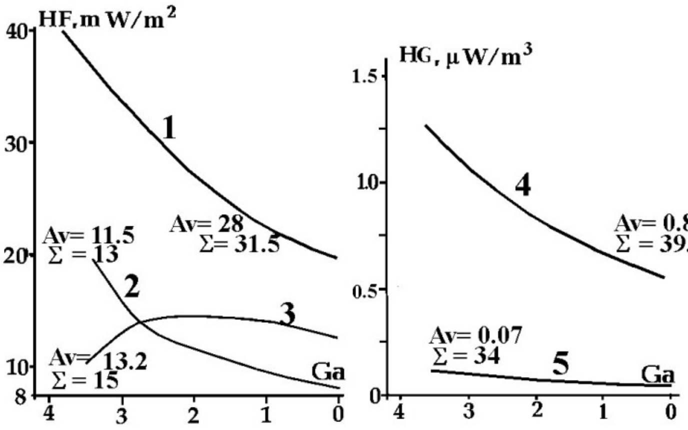

Fig. 4. Change in time of heat flow (1, 2, 3) and radiogenic heat generation (4, 5) on the platform.
1, 2 – radiogenic heat flow from the crust (1), upper mantle (2) and 3 – associated with the cooling of the tectonosphere. 4, 5 – heat generation in the crust (4) and upper mantle (5). Av are the average values, Σ are the total values of the produced and removed energy over 3.6 billion years (in 10^{14} J/m^2).

It can be assumed that there are some radiogenic energy sources in vanishingly low concentrations throughout the lower mantle and transition zone. But it seems more logical to consider the persistence of appreciable content in the lower part of the former magma ocean. This very option is presented in Table. 1, and most of the mantle and core are devoid of radiogenic heat sources. From the above data, the definition of the Earth's tectonosphere as a depth interval where energy is available to support deep processes is clear. This is definitely the crust and upper mantle and, possibly, the underlying layer to the bottom of the global asthenosphere.

Heat balance on the example of platforms. Calculations and results

On the shields of the platforms in areas of prolonged absence of active processes accompanied by convective heat and mass transfer in the mantle, it is possible to collect detailed information on the geological history and compare the observed and calculated parameters of the Earth's thermal field. For this purpose, a time interval of 0–3.6 billion years ago was chosen, for which the necessary information is available on all continents.

The above data and an analysis of the initial stage of the Earth's geological history show that the heat flow from the lower mantle is close to zero [Gordienko, 2012].

Heat flow and heat generation in the period 0-3.6 billion years ago in the crust and upper mantle are shown in Fig. 4.

In addition to heat generation in the mantle, the total value of heat flow is also formed by long-term cooling, the continuing stage of which started (according to the theory) from the solidus temperature 4.2 billion years ago. For mantle rocks, $Tsol = 1{,}013+3.914H - 0.0037H^2$, where H is the depth in km within the 0-470 km range.

The sum of the two calculated components for the present equals 20.5 mW/m^2. It matches the value of the mantle heat flow on platforms determined as the difference between observed heat flow and estimated crustal radiogenic HF [Gordienko, 2012 etc]. This would have been impossible with incorrectly selected heat generation in the upper mantle and in conditions of its cooling. The sum of all three components of the conductive heat flow presently amounts to 43 mW/m^2, which is very close to the heat flow observed on the platform unaffected by anomalies associated with deep-seated heat- and mass transfer. Such heat flow on the territory of Ukraine covered by detailed studies was recorded at the slope of the Voronezh anteclise, in the Dnieper-Donets Depression, on the Ukrainian Shield, on the Volyn-Podolsk plate, and in the South Ukrainian monocline. The integral heat generation in the crust and upper mantle over the recent 3.6 billion years is $73.5 \bullet 10^{14}$ J/m^2. The conductive heat flow during that period carried away $59.5 \bullet 10^{14}$ J/m^2. The difference must be due to the heat- and mass transfer during active deep-seated processes.

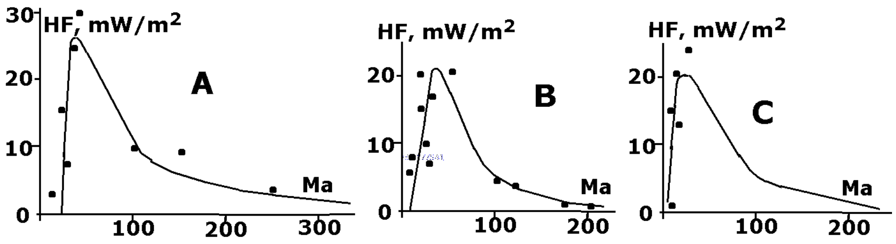

Fig. 5. A refers to the HF anomaly in the geosyncline and B – to the HF anomaly in the rift, C – in the recent activisation zone.

Let us analyze energy requirements for deep-seated processes (W_{actv}). We are talking about geosynclines, rifts, and zones of single-episode activation that occurred in the geological history of the contemporary platform (Fig. 5). (According to the theory, there are three episodes of heat- and mass transfer in the geosynclinal process and two or three episodes in continental rifting.) The anomalous heat flow in the geosyncline carries away $0.68 \cdot 10^{14}$ J/m^2 (Fig. 5A); with an allowance for the energy spent on non-thermal processes in the near-surface zone (primarily, the ascent of a crustal block and upper horizons of the mantle), energy spent on a single geosynclinal cycle increases to $0.8 \cdot 10^{14}$ J/m^2.

For the rifting process, this value turns out to be somewhat lower: about $0.6 \cdot 10^{14}$ J/m^2 (Fig. 5B). Approximately as much energy ($0.50\text{-}0.55 \cdot 10^{14}$ J/m^2) is required for a single episode of activation. In the latter case, it is not possible to completely construct the experimental anomaly of the heat flow, and so a value estimated following the theory was used for determining W_{actv}. The anomaly reaches maximum of about 20mW/m^2, just like in the rift.

The choice of the type of active process was linked to the type of the antecedent thermal model. If the temperatures exceeded solidus within a broad range of depths larger than 200 km, the situation was considered suitable for the emergence of intra-asthenospheric convection and geosyncline. At the same time, the presence of a superadiabatic gradient in the asthenosphere or its part was taken into account. Such a specific part of the asthenosphere was viewed as suitable for the convective intermixing of the material and for shaping an ascending asthenolith. With a thinner asthenosphere, conditions were defined as favorable for rifting or a single-episode activation characterized by the transport of material like at the initial stage of rifting. As a rule, in that case the transport of material occurred from the asthenosphere or its portion about 100 km, less commonly 50 km thick. In the absence of the asthenosphere or its small (less than 50 km) thickness, the situation was considered unsuitable for the onset of an active process, and the computations (implying solely the evolution of background and smoothing of earlier temperature anomalies) were continued until the necessary conditions were achieved. In calculations of thermal effects resulting from the displacement of the material, whenever necessary, the limited length and width of the arising heat sources were accounted for.

The modeling by no means reflects the only possible sequence of active processes in the shield's tectonosphere. We analyzed several versions of the process with different thermal properties of the medium and different characteristics of the process for instants when the thermal model did not make it possible to pinpoint a specific type of endogenous regime, so that it would enable to start an activation or extend the period of "tectonic quiescence" to obtain better "maturation" of conditions for a subsequent heat and mass transfer. In all cases we observed largely the same picture. There is nothing that could be added to the calculated episodes of heat and mass transfer.

In areas of the world's shields and platforms, where traces of active processes can be seen, 23 active events took place over 3.6 billion years (Table 2). They include three geosynclinal, 11 rift, and nine activation processes (contemporary activation is not on this list because it has not yet occurred on the greater part of the territory of platforms). The calculations that have been performed are in fact a physical verification of the Stille's canon.

The result (energy consumption of about $14\bullet10^{14}J/m^2$) corresponds to the difference between radiogenic heat generation in the crust and upper mantle and conductive flow from the tectonosphere. In other words, mass transfer responsible for the tectonic-magmatic activity consumes about 20 % of the heat flow energy being released, i.e. 30 % of radiogenic energy. Radiogenic heat generation in the tectonosphere is perfectly sufficient to account for deep-seated processes, and there is no need to involve others, especially those located at depths on which no information is available (the core-mantle interface, and so on).

Table 2

Comparison of model (M) and experimental dates for rocks of the Ukrainian Shield (USh) (million years) [Shcherbak et al., 2005, 2008, Shcherbakov, 2005].

M	Ush	M	USh	M	USh	M	USh	M	USh	M	USh
3800	3790	3500	3500	3170	3170	2820	2820	2280	2290	1480	1460
3770		3470	3490	3140	3140	2780	2790	2240	2240	1350	1350
3740	3750	3440	3450	3100	3100	2740	2740	2200	2200	1250	1230
3710	3730	3410	3400	3070	3070	2700	2700	2150	2150	1100	1100
3680	3680	3370	3370	3040	3040	2650	2660	2120	2110	950	900
3650	3650	3330	3330	3010	3010	2600	2600	2060	2060	790	770
3620	3620	3300	3310	2980	2980	2550	2550	2000	2000	600	650
3590	3600	3270	3270	2940	2920	2500	2500	1850	1880	400	390
3560	3560	3230	3250	2900	2900	2400	2430	1800	1800	200	280
3530		3200	3190	2860	2860	2350	2340	1750	1750	0	5

Heat balance on the example of Phanerozoic geosynclines

Calculation of heat and mass transfer acts for geosynclines is carried out according to the same scheme as for platforms, but with a different HG of mantle rocks. The results obtained indicate the existence of a minimum time separating these events. Probably, it is determined by the time of asthenolith floating.

There are no sufficient reliable data on the degree of deconsolidation during heating as a result of radiogenic heat generation, on the path length, on the rocks' strength and viscosity, and so on to enable us to accurately evaluate the duration of an individual ordinary act of advection (even in its most simplified form in accordance with the Stokes' law). It can be assumed that rates of displacement in the upper portion of the tectonosphere are higher due to the reduction in density during partial melting. Rates of motions amounting to 0.5 to 1.0 cm per year and the cycle duration of 20-30 million years appear to be plausible. The accuracy of such assessments is not certain, but they find some support from independent data.

It would be logical to expect the maximum incidence of active events during the Hadean period (3.9–4.0 to 4.2–4.3 billion years ago) of maximum heat generation. Yet, intervals between activations slightly exceed 30 million years [Balashov, 2009]. In recent years much information has been published on vertical displacements of large rock blocks by 50–200 km at the rates of 0.1-2.0 cm/year [Board et al., 2005; Romer & Roetzler, 2001; Gordienko, 2022]. In Phanerozoic geosynclines, acts of heat and mass transfer within the cycle are often divided by the same time gaps of 30 million years.

Judging by the data for platforms, intervals between activation acts over the period of 3.8–2.0 billion years increase (for a single block) slowly enough: from 35-30 million years to 55-60 million years. During the same period, heat generation is comparable to that in the mantle of Phanerozoic geosynclines. Later, the difference in HG increases at a fast rate and the time interval between activation acts on the platform (geosynclinal cycles are absent) grows to 180 million years by the end of the Precambrian. This period seems promising to look for differences in the activity of the two types of regions. The calculation confirms this estimate. During the period from 0 to 2 billion years, 1 riftogenesis and 9 single-act activations occur under the platform with a typical HG.There are 22 active events under the geosyncline, 3 of which are geosynclinal, 7 are rift, and 12 are single-act events.

To enable a comparison, it is necessary to select portions of Phanerozoic geosynclinal belts of relatively small dimensions for which the dating of active events is known within a considerable time interval. This is proving difficult. Instead of one area, three areas were used in the Ural-Mongolian fold belt, for which the absence of offsets in close datings was shown (only those due to accuracy were allowed): the Sangilena block in Tyva, the southern part of the Yenisey ridge, and the Bashkirian block of the Urals [Anisimova et al., 2012; Bibikova et al., 1993; Kratz & Zapolnov, 1982; Nozhkin et al., 1989, 2012; Pronin, 1965; Khain, 1977 et al.]. In Table 3, the ages matched for the three districts are shown in brackets. Their number and location on the timeline suggest that there is no “extra” data in the resulting list.

Table 3

Ages of rocks of the Bashkirian block of the Urals, Yenisei Ridge, and Sangilen (BYeS) in comparison with the model ones (M)

M	BES	M	BES	M	BES	M	BES	M	BES
3300	3310	2860		2200	**(2210)**	1480	1470	700	700
3270	3270	2820		2150		1400	1400	650	670
3230		2780	2790	2110	2100	1350		600	**(620)**
3200		2740	(2730)	2060	2050	1250	(1250)	550	520
3170		2700	2700	2000		1150	1150	500	470
3140		2650	2670	1950	1970	1100	1120	450	**(440)**
3100		2600	2600	1920	1930	1050	1050	400	400
3070		2550	2550	1880	1900	950		350	350
3040		2500		1850	(1830)	900	900	300	310
3010		2400	(2400)	1800	1780	850	870	250	280
2980		2350		1750	1750	800	810	200	220
2940		2280	2260	1650	(1640)	760	**780**	100	130
2900		2240		1550	(1580)	730	(750)	20	30

In the Archean and Early Proterozoic, the experimental ages correspond to those calculated for the platforms. It is interesting to note that the experimental dates also agree. The average differences do not exceed the errors (10 million years) (see Tables 2 and 3). For the ages below two billion years observed dating results are more numerous, and this supports the assumption that higher activity is due to more vigorous heat generation. However, after Caledonian-Hercynian events, the geosynclinal process never recurred, and activations, including contemporary ones, are similar to those on platforms.

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 et al., 1988 etc]. The modeling is expected to solve the problem of concentration ratios of K, U, Sr, as well as isotopes of He, Ar, Ne, Xe and other noble gases in the mantle, crustal basalts, and atmosphere. The recorded contradictions 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 changing with time. Variation of the mass flow with time adopted by the authors is shown in Fig. 6.

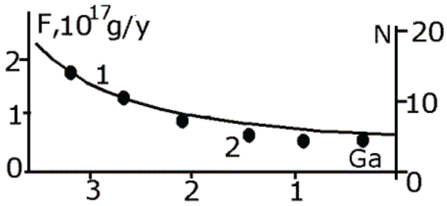

Fig. 6. Variation of mass flow versus time (1), according to [Azbel et al.,1988], and of the number of heat and flow transfer episodes (2) over every 0.6 billion years.

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 obtained correspondence makes it possible to calculate the size of the mass flow corresponding to one of the 23 platform activation events over the recent 3.6 billion years. This matches removal from the mantle of the material equivalent to a 13 km thick layer. In terms of theory in the case of the platform version of heat generation (HG), material equivalent to an 8 km thick layer is removed from the mantle during each active event. In the case of geosynclinal 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 46 events, respectively. In view of the fact that dry land, the shelf, and part of the continental slope, where the crust still differs from the oceanic crust, occupy about 35 percent of the Earth's surface, and assuming that platforms and geosynclinal belts occupy areas of similar size, we obtain on average over the Earth's surface for each event on the platform the removal of matter equivalent to a 13-km thick layer. 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.

The assessment that has been performed is but a formal one. However, simulation of deep-seated processes pertaining to recent 3.6 billion years of the Earth's history for geosynclinal belts and oceans presents no particular interest until it becomes geologically meaningful. For that results of such modeling should be correlated with a still poorly studied geological history of those regions. For geosynclines, this estimate seems quite realistic to the author at present. Extending these data to the entire surface of the Earth except for the platforms, we obtain 11.5 km. The endogenous oceanization regime implies a greater mass flow than the geosynclinal one; the total value must be greater. However, most likely, the ocean has existed only for the last 200 million years [Bluman, 2008]. Nevertheless, it can be stated that the calculated mass flow turned out to be close to that established by [Azbel et al., 1988].

The calculated value of the mass flow can be somewhat refined without claiming the accuracy of the introduced additives.

1. It is very likely that about half of the Earth's surface is covered by the process of recent activation, which is accompanied by a transfer equivalent to the appearance of a deep material layer in the crust with a thickness of 8 km. In the above calculation, these objects were not taken into account.

2. Considering the area of the oceans covered by a series of geosynclines the entire estimated period, except for the last 200 million years, can be assumed that oceanization has replaced one geosynclinal cycle. In this process, material corresponding to a layer with a thickness of 8 km would be transferred. The restructuring of the crust from continental to oceanic (actual oceanization) led to a change in composition in a layer about 37 km thick.

Accounting for such additions would result to the thickness of the conditional transported layer among those formed under the platform at about 12.5 km.

Conclusion

To control the reliability of the analysis of the energy balance of the Earth's tectonosphere, the author used independently established (by geothermometers) temperature distributions in the crust and upper mantle, information about the depths and temperatures of the roof of magmatism chambers, the distribution of longitudinal seismic wave velocities in the upper mantle, and other information. But to demonstrate the solution to the problem posed in this article – some clarification and addition to the energy balance scheme – the information provided is sufficient.

The generalization of data on radiogenic heat generation in the rocks of the Earth's shell using the concepts of geological theory allowed:

1. To establish the absence of energy sources in the core and (presumably) in the lower mantle at depths greater than 1100 km.
2. To refine the heat generation power in different crustal types and to reveal three levels of HG value (and possibly existence of intermediate ones) confined to continental Precambrian platforms, geosynclinal belts and oceans, namely, about 0.04, 0.06 and 0.08 μW/m^3, respectively.
3. To find the coincidence of the total modern heat release in the crust and upper mantle of three region types with a significant difference in the depth distribution of sources.
4. To assume the presence of low-intensity energy sources in the transition zone between the upper and lower mantle and the global asthenosphere. This may stimulate the study of specific geodynamic processes at great depths.
5. To show that for platform regions the heat flow and all deep processes in the tectonosphere during the studied history of the Earth can be quantitatively explained with radiogenic heat generation.
6. To estimate mass transfer intensity in the Earth's history, consistent with that established from degassing studies.

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ПРО ЕНЕРГЕТИЧНИЙ БАЛАНС ТЕКТОНОСФЕРИ

Мета роботи – уточнення та доповнення енергетичного балансу тектоносфери Землі шляхом теплового моделювання. Методика включає детальний комплексний аналіз теплогенерації в корі та верхній мантії впродовж усієї вивченої геологічної історії Землі за 4,2 млрд років. Результати. Узагальнено експериментальні дані про радіогенну теплогенерацію в корі та верхній мантії Землі. Встановлено необхідність окремого розгляду теплового балансу для регіонів з різними ендогенними режимами на платформах, геосинкліналях та океанах. Середні величини теплогенерації у корі становлять близько 0.4–0.5 мкВт/м^3, у верхній мантії – 0.04, 0.06 та 0.08 мкВт/м^3 відповідно. При врахуванні потужності твердої кори (близько 40 км під платформами та геосинкліналями та близько 6 км під океанами) та верхньої мантії (430-460 км) виявляється практичний збіг кількості джерел під усіма регіонами. Розподілені вони по-різному. Це веде до різних варіантів геологічної історії. Можна припустити, що радіогенні джерела тепла інтенсивністю близько 0.02 мкВт/м^3 є у перехідній зоні до нижньої мантії та в нижній мантії приблизно до 1100 км. На більшій глибині в оболонці (всієї маси Землі за межами ядра) та ядрі джерела відсутні. Для платформ розрахований енергетичний баланс тектоносфери. За 3.6 млрд. років (період, протягом якого можна досить точно описати геологічну історію), тепловим потоком винесено близько $73.5 \cdot 10^{14}$ Дж/м^2. Кондуктивний тепловий потік за цей час виніс $59.5 \cdot 10^{14}$ Дж/м^2. Різниця точно відповідає потребам усіх активних процесів цього періоду. Збігаються й експериментальні дати подій із розрахованими за теорією (частина з яких – уперше). Для фанерозойських геосинкліналей такий контроль також частково виконано. Незалежно визначена еволюція масового потоку (що також має практичне значення) в геологічній історії узгоджується з розрахунковими значеннями. Наукова новизна. Для контролю достовірності аналізу енергетичного балансу тектоносфери Землі автором залучалися незалежно встановлені (за геотермометрами) розподіли температур у корі та верхній мантії, відомості про глибини і температури покрівлі вогнищ магматизму, про розподіл швидкостей поздовжніх сейсмічних хвиль у верхній мантії та інші відомості. Практична значущість. Результати досліджень дадуть можливість надійніше оцінювати рівень та особливості сейсмічної небезпеки для фанерозойських сейсмоактивних зон України.

Ключові слова: радіогенна теплогенерація, кондуктивний і конвективний теплообмін, активні процеси в тектоносфері, термічна історія.

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