The energy balance of Earth’s tectonosphere

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Abstract. Concentrations of K, U, and Th in rocks of the Earth’s crust and upper mantle of
platforms, geosynclines, and oceans have been analyzed. Respective values of radiogenic heat
generation in upper mantle rocks of the aforementioned types of regions are 0.04, 0.06, and
0.08 μW/m². As far as platforms are concerned, heat generation there has been found to
correlate with geological history, heat flow, and deep-seated temperatures. The energy
preservation law in geological processes has been shown to hold.

1. Introduction
Identification of the energy source of any deep-seated processes is an indispensable part of any serious
tectonic hypothesis. The presently available data make it possible to identify the source -- the
radiogenic heat generation (HG) in the Earth’s crust and upper mantle -- and to show, on a quantitative
level, correlation between the energy being released and all known energy-intensive processes
throughout the entire documented geological history (Gordienko, 2012; and others). This is possible in
the advection-polymorphic hypothesis. This problem is unsolvable in the frameworks of other
available hypotheses.

In terms of the advection-polymorphism hypothesis (APH) (Gordienko, 2012; and others), the
energy balance is a sum of heat generation in the crust and mantle, on the one hand, and energy spent
on maintaining the heat flow (HF) through the surface, on the other. HF comprises three components
associated with 1) cooling of a quiescent medium; 2) heat generation therein; and 3) heat and mass
transfer in the tectonosphere, a phenomenon that accompanies active processes. Energy requirements
for other manifestations of active processes (magmatism, upheavals, folding, etc.) are insignificant in
comparison with HF anomalies accompanying active processes.

The adopted parameters of the source need to be monitored. The initial procedure of monitoring the
accuracy of selected heat generation values and assessment of the HF arising as a result of the
tectonosphere’s cooling consists in referencing the total HF with that observed on a quiescent
Precambrian platform, i.e., in a region where no heat and mass transfer occurred in the mantle for a
sufficiently long period of time (hundreds of millions of years). Naturally, the period of time, during
which the value of HG responsible for the formation of contemporary HF, must be long enough to
enable an assessment of the contribution of a large part of the mantle and to take into account
variations of the radiogenic heat generation in the course of time. This paper uses a maximum stretch
of time (4.2 billion years). The second procedure is correlation between the total radiogenic heat
generation over a long period of time and energy carried away over that period of time by conductive
heat flow and anomalous HF during active periods of geological history. We opted for a period of 0 to
3.6 billion years during which it is possible to describe that history fairly well, at any rate for
contemporary shields.
In view of the fact that radiogenic heat generation varies sharply with time, it might be of interest to compare estimated and experimentally derived data characterizing such variations for the energy being “consumed”.

In Boyd’s opinion, mantle rocks of platforms could not have been formed through “clustering” of the oceanic lithosphere. Continental regions outside platforms occupy an intermediate position. It makes sense, therefore, to analyze separately the distribution of HG in the tectonospheres of Precambrian platforms, Phanerozoic geosynclinal belts, and oceans.

2. Heat generation in the Earth’s crust
There is an abundance of data on the content of uranium, thorium, and potassium (and therefore, on contemporary heat generation) in crustal rocks. Determined for the same rocks were P-wave velocities (Vp), as well as their dependence on temperature (T) and pressure. As a result, correlations were established between parameters for rocks of the consolidated crust HG=1.28exp (1.54 [6–Vp]) for the case of 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]) (figure 1) (HG in μW/m³, Vp in km/sec).

![Figure 1](image_url)

**Figure 1.** A is variation of heat generation in crustal rocks of a contemporary platform (1 – sedimentary layer and metapelites and 2 – consolidated crust) as a function of seismic wave velocities. B is variation in HG of crustal rocks in the course of time (Av is the mean value, Σ is composite heat generation over 3.6 billion years in 10¹⁴ J/m²). C is variation of the heat flow due to HG in platform crust over 3.6 billion years (Σ is total transported energy, 10¹⁴ J/m²).

In all cases we used average values of heat generation in groups of rocks. The mention of this completely normal circumstance is linked to the determination of mantle rocks’ HG (see below). The data on heat generation in the sedimentary layer and in the consolidated crust are shown in figure 1 (A). Two- and three-dimensional forward stationary problems were solved with the help of the aforementioned patterns of HG distribution versus seismic wave velocities. Comparisons with experimentally derived data were performed primarily on platform-type territories of Ukraine (with stable mantle HF) covered by a dense network of deep seismic probing profiles with crustal velocity profiles and HF determinations. A fairly good correlation of HF variations was obtained in all cases including zones of substantially lower heat flows. This type of verification shows absence of any appreciable errors in the data used.

Crustal HG variations versus time have been determined in terms of half-life periods for uranium (4.51·10⁹ years), thorium (13.9·10⁹ years), and potassium 40 (1.3·10⁹ years) and estimates of radioactive isotopes’ contents (figure 1B). The heat flow generated by the platform crust with a typical velocity profile as a result of heat generation in its rock has varied widely over 0-3.6 billion years and averages 28 mW/m² (see figure 1C).

In the Earth’s Phanerozoic geosynclinal zones, crustal thickness matches, on the average, that on platforms. At the top, velocity profiles are also close (the differences not exceeding natural variations; down to 10 km, the velocities are somewhat lower, whereas at the depths of 10-20 km they are somewhat higher than on platforms). At greater depths, the situation is different (figure 2).
The average difference of contemporary heat generation for the entire crust of geosynclines can be assessed (it would be pointless to talk about a precise result) as 0.13 $\mu$W/m$^3$ lower than on the platform.

The total contemporary radiogenic heat generation in the crust beneath platforms ($W_{\text{crust}} = HG \cdot H$, $H$ being the thickness of the layer) is 23 mW/m$^2$; beneath geosynclinal belts, it amounts to 17.5 mW/m$^2$.

**Figure 2.** Comparison between velocity profiles of the crust of shields and Phanerozoic geosynclines.

1 – Mean velocity profile of the Ukrainian, Baltic, Canadian, Indian, Aldan, Arabian, and Australian shields, 2004; and others); 2 -- Mean velocity profile of the Donets Basin, Carpathian Alpides, Crimean Cimmerides, Rheno-Hercynian and Moldanubian zones of Europe’s Hercynides, English Caledonides, Tien-Shan and Urals Hercynides, Kamchatka, Cordilleras, and Andes Alpides and Cimmerides; 3 -- Mean velocity profile of geosynclinal crust adjusted with an allowance for high temperatures.

Beneath oceans with a solid crust 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 $\mu$W/m$^3$, and the composite contemporary energy generation is 3 mW/m$^2$.

### 3. Heat generation in the upper mantle

The HG value in this part of the tectonosphere can be derived from the results of determination of uranium, thorium, and potassium concentrations in xenoliths transported by kimberlite magmas (about two-thirds of the data known to this author) and alkaline basalts (primarily on platforms). There is no perceptible difference between the two groups of xenoliths. Nor is there much difference between the data on xenoliths and more sparse information for areas where mantle rocks emerge onto the surface (in axial troughs of some mid-ocean ridges – MOR). The data on uranium and thorium vary widely, on potassium - less so. The latter, however, accounts for just up to 25 percent of mantle rocks’ HG.

There is a common opinion to the effect that uranium and thorium contents in mantle rocks are insignificant, approximately at the level of maximum peaks on the histograms shown later in this paper, whereas relatively higher contents are caused by contamination with magma material during the xenoliths’ transfer up to the surface. This kind of judgment derives from the concept that the mantle composition changes from primitive toward depleted due to the transportation of its incoherent components into the crust. From the viewpoint of the problem in question both contentions are extremely indeterminate (information on the HG in the initial -- primitive -- magma and the resultant depleted magma are ill-founded and differ from author to author) and can be seriously challenged.

According to the advection-polymorphism hypothesis (APH), throughout the Earth’s documented geological history, crustal eclogites descended into the upper mantle in the amount that exceeded half of the mantle’s volume. Many other authors, among them proponents of other tectogene hypotheses also adhere to the opinion about the existence and intensity of this (and naturally, of the reverse) process. The scope 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 differ from the upper portion.

The list of supporting points could be continued further, but even those cited here are sufficient for sharing Ringwood’s opinion to the effect that “… there is every reason to assume that the association of peridotite and eclogite xenoliths and xenocrysts encountered in kimberlites constitutes an average ‘sample’ of the mantle”.

A database collected by this author for about 40 years was used to determine average values of HG.
Figure 3. Histograms of distribution of $K_2O$, $U$, and $Th$ contents in mantle rocks of platforms, geosynclines, oceans, crustal basites and eclogites, as well as meteorites. $n$ is the number of analyses used; $M$ is the median value.

Figure 3 shows histograms of distribution of radioactive elements in rocks of the mantle (and in crustal basites and eclogites) for three types of regions in question. Differences in the numbers of analytical results are wide, and it can be assumed that the result for platforms will hardly change if we add new data (it was the same when we only had 50 percent of the data available now); the same this is also likely for geosynclines. Information on oceans is so far in short supply and it essential that
evidence should be further amassed to make it possible to arrive at a reliable assessment of heat generation. Yet, even available information points to noticeable differences in heat generation for the three types of the Earth’s regions.

The depth of the upper mantle bottom assumed by this author, an interface where, according to the APH, olivine-α starts transforming into olivine-β at contemporary temperatures beneath quiescent Precambrian platforms (about 470 km) does not necessarily conform precisely to the change in heat generation.

Nevertheless, it might be appropriate to point out that the total number of radiogenic heat sources in the crust and upper mantle of all the three types of regions happens to be virtually the same: 42 ± 0.5 mW/m². It is unlikely that the differences exceed the computation error. To put it differently, the same amount of heat is presently generated at any point of the Earth, but its sources are distributed in dissimilar ways, which is due to the formation of one type of crust or another. On continents, the crust of approximately contemporary thickness has existed for billions of years, whereas the situation is not clear regarding oceans; in all likelihood, the way it is now (i.e., with the M. discontinuity’s depth at about 10 km, which may not be an accurate assumption), it is young, and dozens or hundreds of millions of years ago there existed there a crust with a thickness similar to that of continents and possibly basic in composition. This exhausts all the more or less trustworthy information on the history of oceanic crust.

Thus, HG values reflect differences in mantle rocks as established by Boyd (Boyd, 1989). Given the same depth, temperature, and mineral composition, other properties (density, seismic wave velocities, and electrical conductivity) do not reflect the known variations of chemical composition (and all the more so, the trends identified by Boyd) (Gordienko, 2010; and others).

Figure 4 shows variation of HG versus time in mantle rocks of regions in question. Encountered in the crust are HG differences of about 20 percent which is directly manifested in values of the heat flow. It cannot be ruled out that such fluctuations are also characteristic of the mantle. It is therefore possible that 4.2 to 2.5-3 billion years ago, “energy saturation” of the mantle beneath platforms and geosynclines differed within limits of natural variations. This is the level of contemporary HG in the mantle of oceans.

![Figure 4. Heat generation in mantle rocks of platforms (1), geosynclines (2), and oceans (3) versus time. Σ is total heat generation over 3.6 billion years in the upper mantle of platforms, in 10^{14} J/m².](image)

At present, HG in the mantle of platforms amounts to 0.043 μW/m³; this virtually matches Ringwood’s concepts on the composition of mantle pyrolite as “a mixture of three-fourths of Alpine peridotites and one-fourth of Hawaiian tholeiites”. Certainly, while applying such a model for the assessment of HG (rather than of chemical and mineral composition of pyrolite), one needs to be aware of the fact that basic rocks in the mantle are represented by eclogites in which uranium and
thorium contents are much lower than in basalts (according to HG, from 0.47 to 0.11 μW/m³ -- see figure 3).

4. Elements of heat balance in platform tectonosphere

An analysis of the initial stage of the Earth’s geological history shows that the heat flow from the lower mantle is close to zero. There is pretty much an adiabatic situation between the lower mantle’s top and bottom (judging by the temperatures of melting), and this corresponds to a heat flow of 1.5-2.0 mW/m². According to Ringwood, there is no basaltic component in the lower mantle (as a consequence of the “magma ocean” effect). Therefore, heat generation (which is the same for all the three types of regions) in it is at the level of extreme points on the histograms presented in figure 3: 0.010 μW/m³; the calculation of contemporary HF produces 0.5 mW/m² at the surface, and at the bottom of the upper mantle, mantle (with an account of sphericity) is 1.0-1.5 mW/m². It is only a negligible temperature gradient that could account for the distribution of seismic wave velocities in the lower mantle. Similar results are also obtained with the initial chondritic model of a silicate Earth. Radiogenic heat generation in the iron core is vanishingly small (two or three orders of magnitude lower than in the mantle), and no energy from it is supplied to the tectonosphere.

Heat flow due to heat generation during the period of 0-3.6 billion years ago is shown in figure 5A. In addition to heat generation in the crust and mantle, the total value of heat flow is also formed by the long-term cooling, the continuing stage of which started (according to the APH) from the solidus temperature 4.2 billion years ago. For mantle rocks, 

\[ T_{\text{sol}} = 1.013 + 3.914H - 0.0037H^2, \]

where \( H \) is the depth in km within the depth range of 0-470 km.

The sum of the two estimated components presently equals 20.5 mW/m². It matches the value of the mantle heat flow on platforms (i.e., in the situation of a longstanding period of absence of mass transfer) determined as the difference between observed heat flow and estimated crustal radiogenic HF. This would have been impossible with incorrectly selected heat generation in the upper mantle and in conditions of its cooling. The sum of all the three components of the conductive heat flow presently amounts to 40 mW/m², 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 antecline, in the Dnieper-Donets Depression, on the Ukrainian Shield, on the Volyn-Podolsk plate, and in the South Ukrainian monocline. Not infrequently, HF is higher by approximately 2 mW/m², which may, in a number of areas, be attributed to the presence of a sedimentary layer with a relatively high heat generation, and on the shield – with an abundance of granitoid rocks.

The integral heat generation in the crust and upper mantle over recent 3.6 billion years is 73.5·10¹⁴ J/m². The conductive heat flow during that period of time carried away 59.5·10¹⁴ J/m². The difference must be due to the heat- and mass transfer during active deep-seated processes.

Let us analyze energy requirements for deep-seated processes (\( W_{\text{actv}} \)). We are talking about geosynclines, rifts, and zones of single-episode active processes (according to the APH, there are three
episodes of heat-and mass transfer in the geosynclinal process and two or three episodes in continental 
riifting) that occurred in the geological history of the contemporary platform. Some general data alone 
are considered in this paper. It should be pointed out that, in this author’s publications, the value of 
W actv. varies somewhat. This is due to the difficulty involved in attempts to accurately assess the heat 
flow in relatively young geosynclines or rifts.

In many instances, heat flow values are distorted by the effect of ongoing active processes. The 
W actv. values listed below are somewhat lower than those used in Gordienko due to corrections 
introduced into the values of anomalous HF for individual regions.

The anomalous heat flow in the geosyncline carries away $0.68 \cdot 10^{14} \text{J/m}^2$ (figure 6A); 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 $0.8 \cdot 10^{14} \text{J/m}^2$.

![Figure 6](image)

**Figure 6.** A refers to the HF anomaly in the geosyncline and B -- to the HF anomaly in the rift.

For the rifting process, this value turns out to be somewhat lower: about $0.610^{14} \text{J/m}^2$ (figure 6B). 
Approximately as much energy ($0.50-0.55 \cdot 10^{14} \text{J/m}^2$) is required for a single episode of activation. In 
the latter case, it is impossible to construct an experimental heat-flow anomaly, and so a value 
estimated in accordance with the APH was used for determining W actv. The anomaly reaches 
maximum of about 20mW/m², just like in the rift.

5. Heat and mass transfer in the tectonosphere

Here is how we performed the calculation of thermal models reflecting the aftermath of heat and mass 
transfer. The initial distribution of temperature (T) in the mantle (the distribution of solidus down to 
the depths of 1,000-1,100 km 4.2 billion years ago) changes under the effect of heat generation and 
heat transfer through the surface. Consequential effects of the advective transport of material in each 
active episode of the region’s history were superposed on the result. A study of the composition of 
magmatic rocks in the Ukrainian and other shields showed that, in the course of active processes in the 
Precambrian, the depths of the top portion of the asthenosphere varied in exactly the same manner as 
in Phanerozoic geosynclines and rifts. It is precisely the reason why the ancient processes were labeled 
“geosyncline” or “rift,” whereas their tectonic impacts could differ from those of Phanerozoic ones.

The choice of the type of active process was linked to the type of the antecedent thermal model. If 
the temperatures were higher than solidus within a broad range of depths larger than 200 km, the 
situation was considered suitable for the emergence of an intra-asthenospheric convection and 
geosyncline. At the same time, the presence of a superadiabatic gradient in the asthenosphere or in its 
part was taken into account. Such specific part of the asthenosphere was viewed as suitable for 
convective intermixing of the material and for shaping an ascending asthenolith. With a thinner 
asthenosphere, conditions were defined as favorable for rifting or for a single-episode activation 
characterized by 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 from 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. To simplify the calculations, the diameter of a 
unit quantum of tectonic action (QTA – a minimum volume of transportable material) was in all cases
assumed to be 50 km. The displacement of three QTA units corresponded to each geosynclinal or rifting event. 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 conditions, so that it would enable us to simulate an activation or extend the period of “tectonic quiescence” in order 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 estimated episodes of heat and mass transfer.

**Table 1.** Comparison between rock dating results (in millions of years) for the Ukrainian Shield based on models (M) and experimental data (USh).

| Year (M) | Year (USh) | Year (M) | Year (USh) | Year (M) | Year (USh) | Year (M) | Year (USh) | Year (M) | Year (USh) |
|---------|------------|---------|------------|---------|------------|---------|------------|---------|------------|
| 3680    | 3680       | 3370    | 3370       | 3040    | 3040       | 2700    | 2700       | 2200    | 2200       |
| 3650    | 3650       | 3330    | 3330       | 3010    | 3010       | 2650    | 2650       | 2150    | 2150       |
| 3620    | 3620       | 3310    | 3310       | 2980    | 2980       | 2600    | 2600       | 2120    | 2110       |
| 3590    | 3590       | 3270    | 3270       | 2940    | 2920       | 2550    | 2550       | 2060    | 2060       |
| 3560    | 3560       | 3250    | 3250       | 2900    | 2900       | 2500    | 2500       | 2000    | 2000       |
| 3530    | 3530       | 3200    | 3190       | 2860    | 2860       | 2400    | 2430       | 1850    | 1880       |
| 3500    | 3500       | 3170    | 3170       | 2820    | 2820       | 2350    | 2340       | 1800    | 1800       |
| 3470    | 3470       | 3140    | 3140       | 2780    | 2790       | 2280    | 2290       | 1750    | 1750       |
| 3440    | 3440       | 3100    | 3100       | 2740    | 2740       | 2240    | 2240       | 1480    | 1460       |
| 3410    | 3410       | 3070    | 3070       |  &nbsp; |  &nbsp;     |  &nbsp; |  &nbsp;     |  &nbsp; |  &nbsp;     |

**Table 1** is an example of comparison between estimated and experimentally established dating of active processes for a considerable stretch of the Ukrainian Shield’s geological history. A detailed review of modeling and comparison between estimated ages of active events and those derived experimentally for shield rocks on all continents. The comparison is impeded by the fact that active processes in the Late Archean and Proterozoic do not simultaneously engulf the entire territory. Small differences in mantle rocks’ heat generation cause a certain shift in activation ages of different shield blocks, whereas calculations pertain to a single block. Yet, it is possible to reliably identify dating results suitable for comparison with those derived from models. “Skipped” experimental dating results (table 1) could be due to incomplete information on the shield (recent studies have in many cases filled in the gaps) or to insufficient information available to this author. On the whole, however, agreement between estimated and experimental data is beyond doubt. Their accidental match is out of the question.

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 1). They include three geosynclinal, 11 rifting, 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 output of about $14 \times 10^{14}$ 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 tectono-magmatic activity consumes about 20 percent of the heat flow energy being released (30 percent of radiogenic energy). Radiogenic heat generation in the tectonosphere is perfectly sufficient to account for deep-seated processes, and there is no need to resort to other data, in particular, to those pertaining to depths on which no information is available (the core-mantle interface, and so on).
Variations of heat generation in the crust and upper mantle of platforms versus energy spent on active processes over recent 3.6 billion years are shown in figure 7. Changes in the activity with time match evolution of heat generation in the mantle rather than in the crust. This is understandable: Crustal energy is mainly spent on maintaining the heat flow. Figure 7 shows that a decrease in the tectono-magmatic activity is exclusively associated with the reduction of the concentration of radioactive elements in proportion to their decay. No mantle rock depletion in terms of heat generation takes place – otherwise experimental points would have been plotted below the curve based on estimated data.

Figure 7. Relative variation of heat generation in the crust (1) and mantle (2) of platforms and average energy requirements for active processes for stretches of time of 0.6 billion years (3).

The data of geothermometry, reflecting PT conditions of rock formation or transformation from Early Precambrian to present time also testify in favor of the assumed level of heat generation in the crust and mantle (figures 8 and 9). This information is supplied by xenoliths transported upwards by kimberlites and alkaline basalts in platform regions. A greater amount of data for the crust was obtained from surface rocks of blocks with dissimilar sizes of erosional truncation.

Figure 8. Comparison between estimated (1) temperatures (T) for periods of activation and experimentally derived (2) data on PT conditions under which Precambrian platform rocks formed; 3 – T distribution in platform crust in the Phanerozoic; 4 -- solidus temperatures of rocks of the amphibolite and granulite facies of metamorphism. 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.
Agreement between estimated and experimentally obtained temperatures (T) is almost complete. It has to be mentioned that maximum temperatures reached in the crust during activation remain largely unchanged provided that there is no further heating. In the mantle, in the absence of activation, temperatures are higher than in the crust, and that promotes changes in mineralogy – its “adaptation” to platform conditions. Geothermometric data shift from those corresponding to maximum heating toward lower temperatures (figures 8 and 9).

Figure 9. Comparison between estimated anomalous temperatures (1) and geothermometry results (2) in the mantle

6. 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.

Figure 10. Variation of mass flow versus time (1), according to Azbel and of the number of heat and mass transfer episodes (2) over every 0.6 billion years.

There is one more independent technique to verify the likelihood of such variation. It is based on a simulation study of isotopic-geochronometric systems. The modeling is expected to solve the problem of correlation between K, U, Sr, as well as 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 changing with time. Variation of the mass flow with time adopted by the authors is shown in figure 10.

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 activation events over 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 advection-polymorphism hypothesis (APH), in the case of the platform version of heat generation (HG), material equivalent to 7-8 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 45 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 35 percent of the Earth’s surface, and assuming that platforms and geosynclinal 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 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.

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.

7. Heat generation in the upper mantle and active processes in oceanic Phanerozoic folded zones

It is obvious that in those regions during the period following “all-encompassing” active events (less than 2.5 billion years ago) episodes of mantle heat and mass transfer must have been more frequent than on platforms.

Let us determine maximum frequency of such events. There are no sufficient 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 ordinary advection episode (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 are corroborated by results of some independent studies.

It would be logical to expect 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 active events exceed 30 million years. 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. In Phanerozoic geosynclines, episodes 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 episodes 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 similar to that in the mantle of Phanerozoic geosynclines. Later, the difference in HG increases at a fast rate and the time interval between activation events on the platform (geosynclinal cycles are absent) grows to 180 million years by the end of the Precambrian. This particular period may hold the key to finding differences in the activity of the two types of regions.

To enable a comparison, it is necessary to select portions of Phanerozoic geosynclinal belts of relatively small dimensions for which dating of active events is known within a considerable time interval. It is a complicated procedure. Instead of one area, three were used for which there were no offsets between close dating results (only accurate results were admitted): the Sangilena block in Tyva, the southern part of the Yenisey range, and the Bashkirian block of the Urals.

In the Archean and Early Proterozoic, experimentally derived ages match up with estimated ones. 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 active processes (including contemporary ones) are similar to those on platforms. It is possible that heat generation in regions under study is somewhat less intensive than is typical of Phanerozoic folded belts.

In all likelihood, there are no distinct boundaries between parts of the Earth with dissimilar heat generation in the mantle. There is still a possibility that, after geosynclinal development ceases completely on main platforms, it may still continue for a certain period of time in their vicinity. The greater the distance from the main platforms, the longer the geosynclinal development will be. Thus, the available concepts account for the Eardly principle in terms of energy parameters. Geological evidence, however, shows that this principle cannot be applied across the board. The Eardly principle is applicable to North America and North Eurasia and, to some extent, also to South America and the Antarctic. In the area of the Tethys’ southern boundary, it definitely does not hold.

Energy generation in the mantle beneath platforms gradually decreased and, 1.5 to 2.0 billion years ago, it turned out to be insufficient for triggering a geosynclinals process. The territories of simultaneously produced geosynclines on continents dwindled (figure 11), and this type of endogenous conditions became confined to geosynclinal belts.

![Figure 11. Variation of absolute and relative areas of geosynclines on continents.](image)

Geological history of oceanic mantle rocks might be instrumental for verifying the hypothesis of higher heat generation in them, but only a very short period of that history has been studied.

In various parts of the Mid-Atlantic Ridge (MAR) active events may occur with a certain shift in time (due to small fluctuations in heat generation), and this may cause an impression as though their number exceeds that obtained through calculations. In fact, the dating results were obtained on the MAR’s limited stretch of about 300 km. Their number testifies to a much greater energy generation in the tectonosphere (including in the Precambrian) than that used in the simulation procedure. In geologically recent past, active events with minimum age differences are found to have occurred on relatively small blocks of oceanic regions.

One gets an impression that there also exist regions with intermediate values of heat generation between Phanerozoic geosynclinal belts and oceans. We are talking about backarc and intercontinental water bodies, as well as median massifs with sharply thinned out and in many cases basified crust. There also exists information on similar, not fully reworked, crust-mantle blocks in all oceans.

On the whole, the available information is sufficient for endorsement of the hypothesis regarding elevated heat generation in the mantle beneath oceans and the resulting high tectono-magmatic activity there. This issue should be considered on the basis of more factual evidence.

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Additional information on the subject of the lecture and the bibliography in V V Gordienko *Thermal processes, geodinamics, mineral deposits*. 2017. [https://ivangord2000.wixsite.com/tectonos](https://ivangord2000.wixsite.com/tectonos)