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Temperatures of the tectonosphere of Ukraine

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In the paper, we propose a three-dimensional thermal model of the tectonosphere of Ukraine. Its basis is a scheme of endogenous regimes. Accordingly, we constructed heat and mass transfer models for each region for the ages of processes that can significantly affect the calculated temperature anomalies. We calculated the anomalies relative to the background temperature (represented by the thermal model of the platform at each depth) for the conditions of typical heat generation of crustal and mantle rocks. The calculated temperatures were compared with values independently established based on various petrological data. The average discrepancy is about 70 °C; it corresponds to the error of each method of about 50 °C and allows us to draw reliable isolines every 150 °C. For the crustal conditions, the isotherm step was 100 °C due to some additional information used. The results are schemes at depths of 10, 25, 35, 50, 75, 100, 150, 200, 300, and 400 km. The obtained thermal model reveals noticeable negative anomalies in the western platform regions with reduced heat generation of rocks (mainly the Ukrainian Shield). In some areas, the temperature was found to be higher than the rocks' solidus at 25 km (the Carpathians, the Scythian Plate, and certain parts of the activated platform, Donbas, and the Lviv Trough), at depths of 50 and 100 km (the Carpathians and the Scythian Plate, slight inclusions on the platform), at 75 km (the melting is much more under the activated platform, in Donbas, and in the Lviv Trough) and at 400 km (under the inactivated platform). (Insufficient geological study of Ukraine's territory, which may significantly increase the error in the results in some areas, has been noted. It applies primarily to the southern part of the Scythian Plate and the western part of the South Ukrainian monocline.)

Key words: heat and mass transfer in the tectonosphere, three-dimensional thermal model.

Introduction. This article discusses a thermal tectonosphere model calculated based on a scheme of heat and mass transfer during deep processes. Such was the order of analysis for almost all endogenous regimes on continents and oceans. Exceptions are some oceanic regions, where there is not enough factual material, and the zone of recent activation on the continents and in the oceans, where the process has not yet manifested itself in full in the phenomena and fields available for observation.

Thus, for Ukraine, work should begin with finding the area of recent activation (RA) and other geological processes. Then we must construct a thermal model, compare it with observed temperatures (*T*), and identify layers of partial melting of matter within it.

Process scheme. The choice of the general nature of the matter's movement during periods of active events in geological history is based on the geological theory used by the authors [Gordienko, 2022, etc.]. It implies advective movement of matter within the tectonosphere. The part of Ukraine covered by the recent activation was clarified in 2024

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[Gordienko et al., 2024]. The applicability of the used heat and mass transfer scheme for interpreting the Earth's thermal and gravitational fields was considered based on the system of deep seismic sounding profiles around the Northern Hemisphere and perfectly passed the test [Gordienko et al., 2023a,b, etc]. Comparing thermal and velocity models of the tectonosphere will demonstrate the advective nature of matter and energy transfer (in contrast to the frequently used concept of convection with a large horizontal branch) for all endogenous regimes of continents and oceans. The result for the case of the recent activation and the youngest geosynclinal zones, island arcs, is the most obvious.

In the first case, a recent single energy transfer allows us to see the balance of the process. In the second case, there are several transfer events, but the results of the initial ones appear at a significant depth, and the heat does not have time to go into the crust and through the surface. It is no longer the case for ordinary Alpides (for example, the Carpathians). See Fig. 1 for relevant data.

Positive and negative velocity anomalies relative to the velocity distribution under the platform fully correspond to the results of advection movement considering adiabatic changes. The lower boundary zones are somewhat incomplete (especially in the case of the arc, for which agreement with the platform data is achieved noticeably deeper). The reason is the uncertainty of the velocity structure of the transition zone from the upper to the lower mantle [Tauzin et al., 2013]. However, this does not change the evident result that energy exchange occurs vertically. The velocity sections of the mantle calculated from the thermal ones agree with the observed ones within the error limits.

In each of the active endogenous regimes represented in the territory of Ukraine, whose influence currently affects the difference between the deep *T* and the platform one, one to three acts of advection heat and mass transfer occurred [Gordienko, 2022, etc.]. Their boundaries are given in the previous publication of the authors [Gordienko et al., 2025a,b]. Their three-dimensional thermal models form the general picture of the temperature distribution in the tectonosphere.

Determination of the calculation error. This parameter is necessary when assessing the calculations' reliability and the actual possible detail, and representing the results. To establish the calculation error, we must compare the calculated *T* values with independently established experimental ones, using information on various variants of endogenous regimes. Not all data of this kind can be found in the territory of Ukraine (Fig. 2).

The error in the calculated temperature with the correct calculation scheme arises due

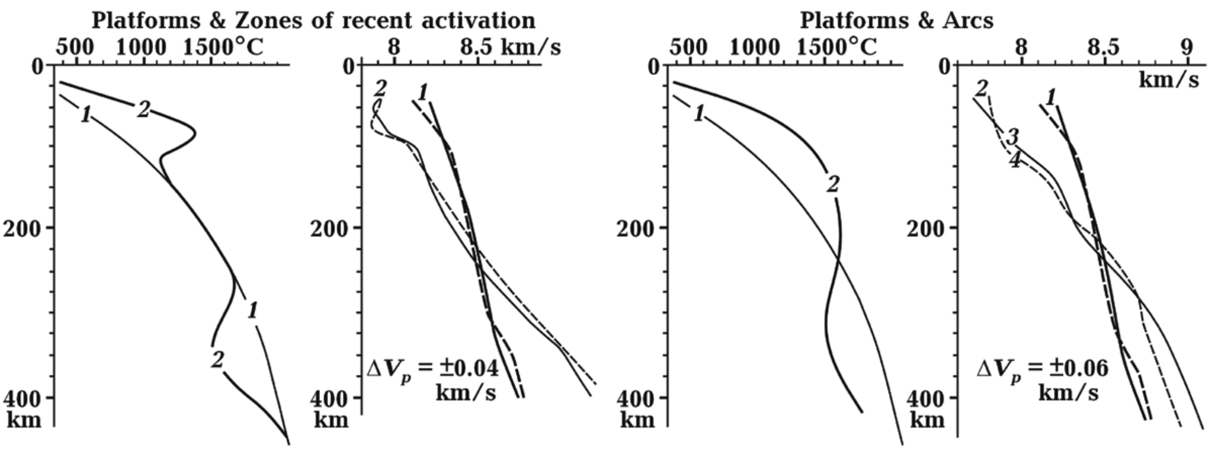


Fig. 1. Comparison of thermal and velocity models of the tectonospheres of the inactive platform and the zone of recent activation and the island arc: *1* — platform models, *2* — models of the arcs and RA zones, *3*, *4* — velocity models (*3* — experimental, *4* — calculated), ΔV_P — average differences between the calculated and experimental models of longitudinal seismic wave velocities [Gordienko, 2022, etc.].

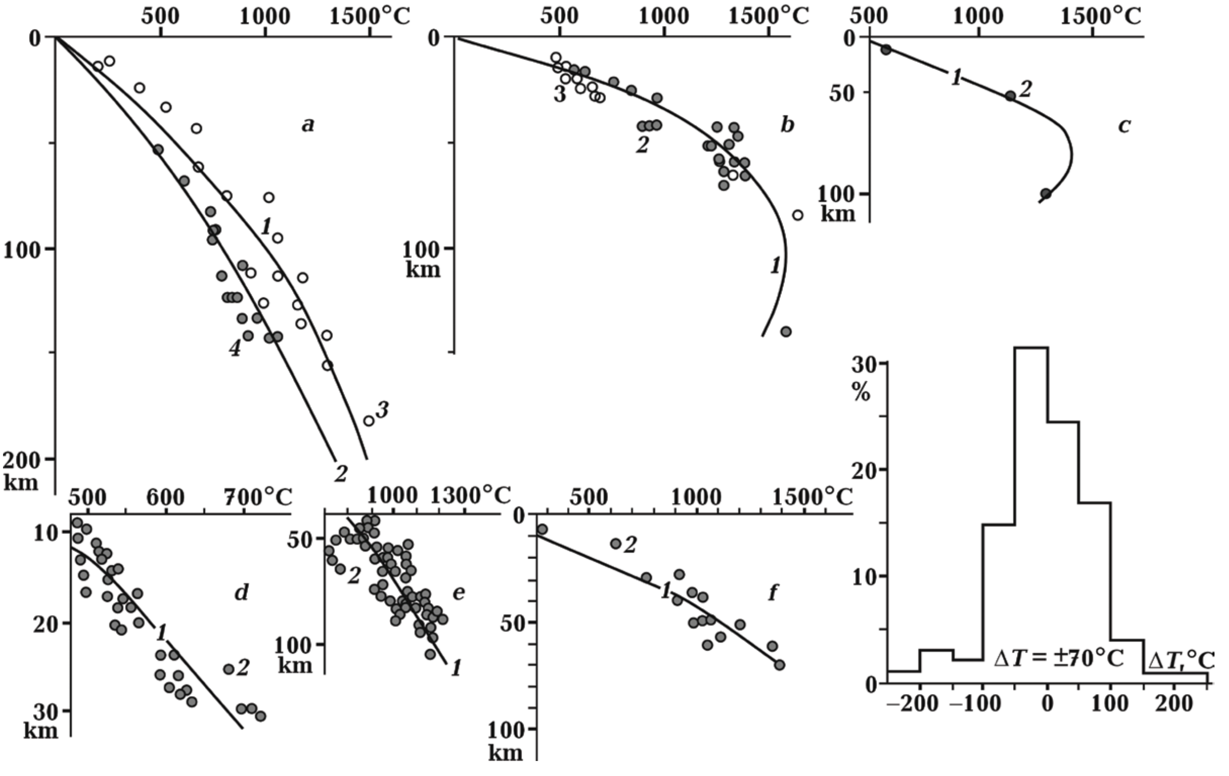
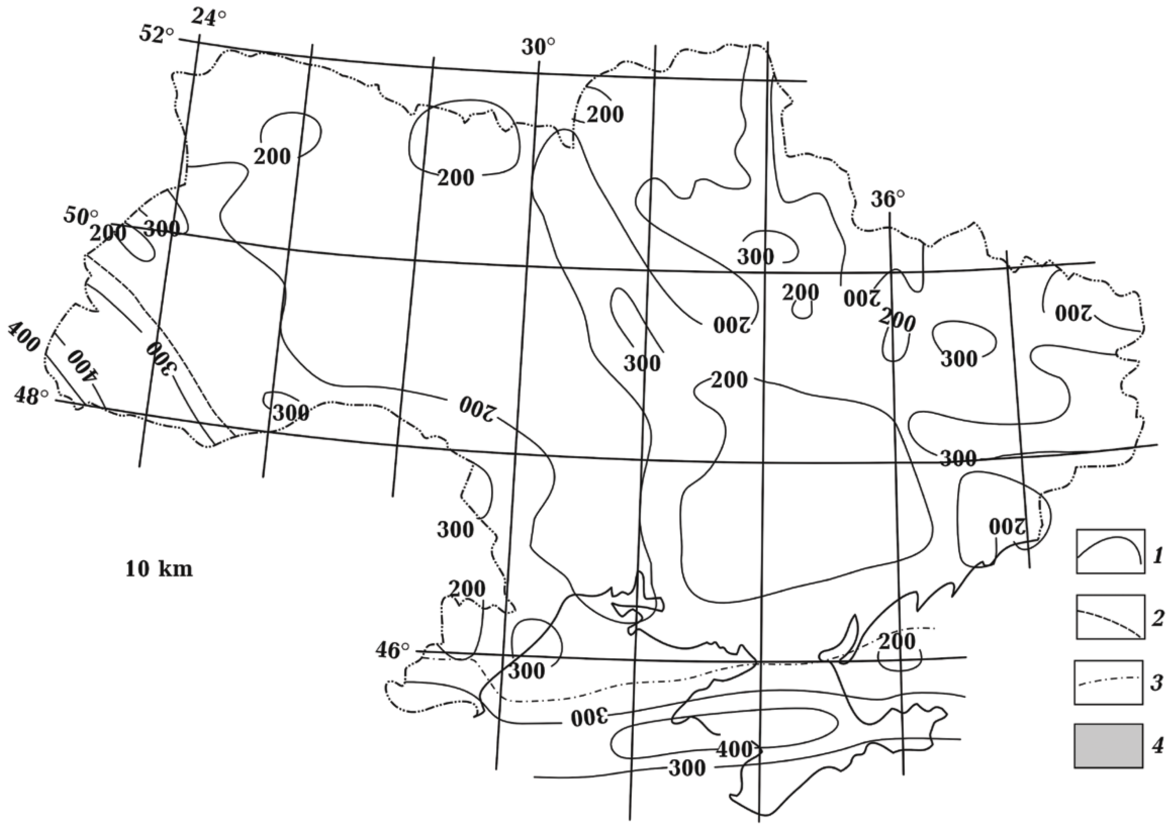


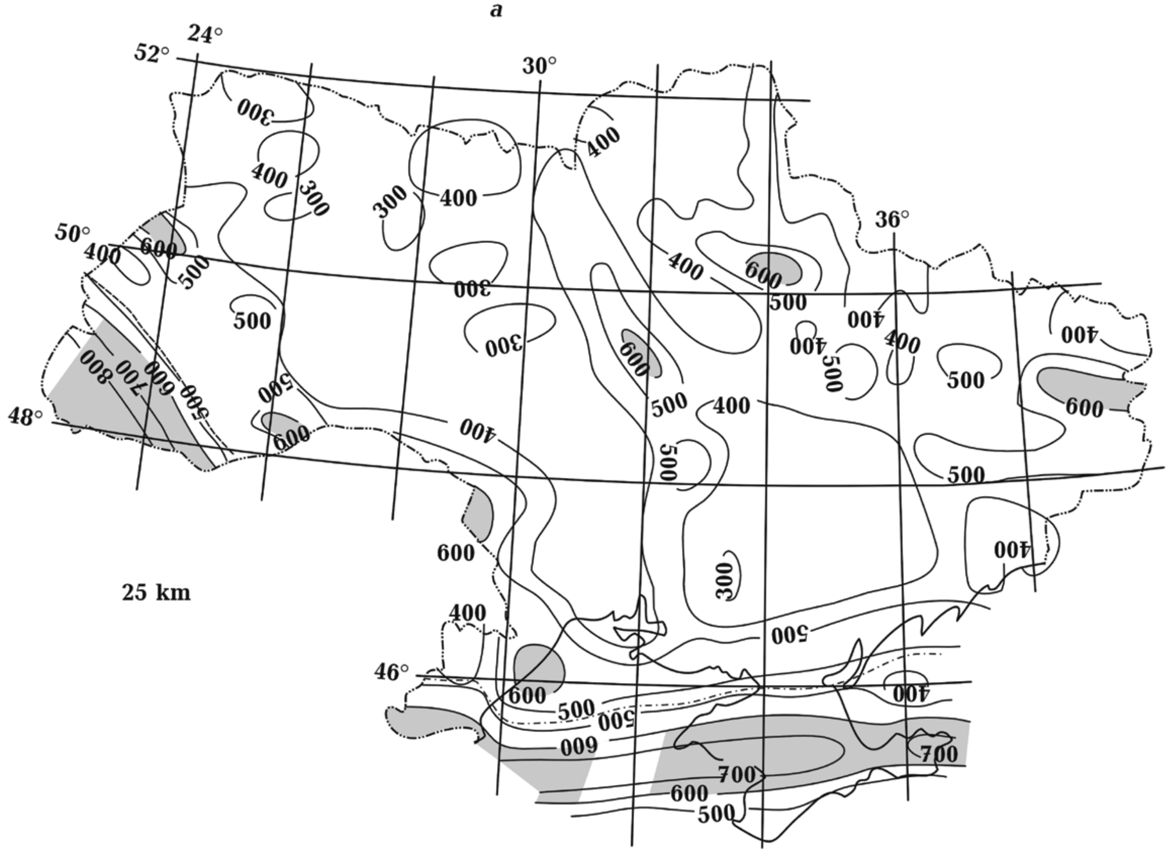
Fig. 2. Comparison of calculated and experimental temperatures in different regions of Ukraine and other countries: *a* — inactivated platform of Ukraine, Siberia, Africa, and Brazil in the Phanerozoic (*1*, *2* — calculated *T*; *3*, *4* — established ones by xenoliths in zones with normal heat generation (HG) of crustal and mantle rocks, including diamond-bearing regions with negative heat flow anomalies (*3*) and reduced one (*4*)); *b* — Alpine geosynclines (*1* — calculated *T*, *2* — Carpathians, *3* — Apennines); *c* — zones of recent activation (*1* — calculated *T* for the process age of 2—5 million years, *2* — temperature data on the Moesian Plate, Cis — Carpathian and Transcarpathian troughs); *d* — Vitim and Aldan zones of recent activation); *e* — the final stage of development of the Paleozoic geosyncline of the Carpathians (*1* — calculated *T*, *2* — experimental ones); *f* — initial zones of rifting or young activation (*1* — calculated *T*, *2* — experimental ones for the Dnieper-Donets Basin, of the Rheno-Libyan Rift and the zone in the Lublin-Lviv Paleozoic Trough). The bibliography is in [Gordienko, 2012, 2017; Gordienko et al., 2005, 2006, 2011, etc.]. The inset shows the distribution histogram of differences between experimental and calculated temperatures.

to insufficient information on the boundaries of various sources and the time of their action. The latter applies, first of all, to recent activation. There are still uncertainties regarding the moment of its onset in various regions of Ukraine, and they will not disappear shortly. Moreover, the ages of individual heat and mass transfer parts are also important. One example is the intrusion of partially molten mantle rocks from a reservoir in the upper horizons of the mantle into the crust. It is separated obviously from the start of activation (inflow of deep superheated matter under the crust) by a noticeable time interval. The sources of possible calculation errors can be further detailed, but there is no point in this. At present, it is possible to use only averaged process parameters. Comparison with experimental results (which, naturally, also contain errors) must confirm the applicability of such an approach.

The spectrum of endogenous regimes with the compared temperatures is reasonably complete for Ukraine. There are non-activated platforms with standard and low heat generation in the tectonosphere, zones of recent activation of different ages superimposed on platforms, and Phanerozoic geosynclines, the initial stage of rifting (coinciding in content with a single-act activation), geosynclines of different ages proper. The sampling depth is limited by the depths of magma sources that


52°
24°
30°
36°
50°
48°
46°
200
300
400
10 km
1
2
3
4

a


52°
24°
30°
36°
50°
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46°
300
400
500
600
700
800
25 km

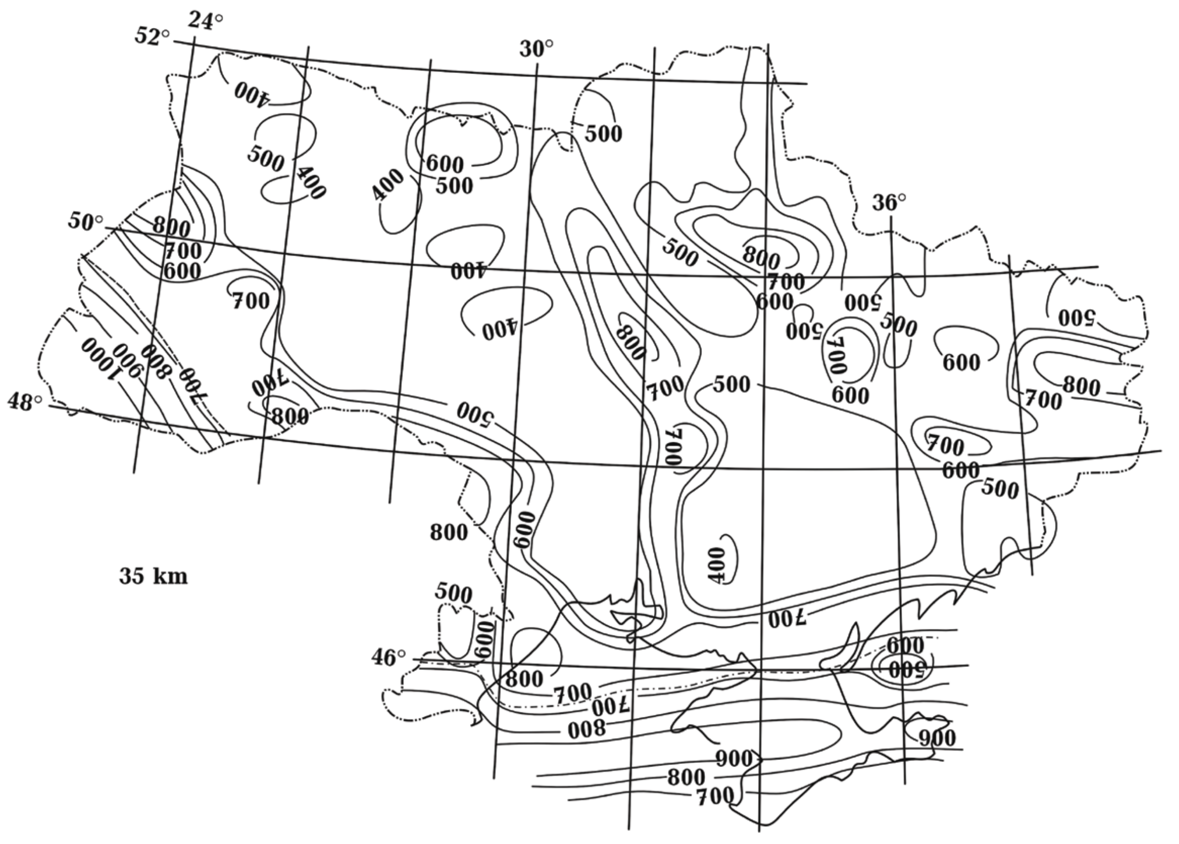
b

carried out xenoliths or by their composition, determining the pressure-temperature conditions in the source (in reality, no more than 200 km).

The results for the mantles of industrial diamond-bearing areas on different continents are interesting. They fit clearly into the model of zones with reduced heat generation. It indicates the possibility of a wide distribution of noticeable variations in heat generation on Earth. This type of deviation came into view due to their confinement to areas of detailed studies. One may miss others because they are of no practical interest. It is quite possible that there are also platform regions where tectonosphere heat generation is higher than average. By the theory, this assumption makes it possible to explain the manifestations of rifting on platforms, specifically in the Riphean and Hercynian times in the Dnieper-Donets Basin.

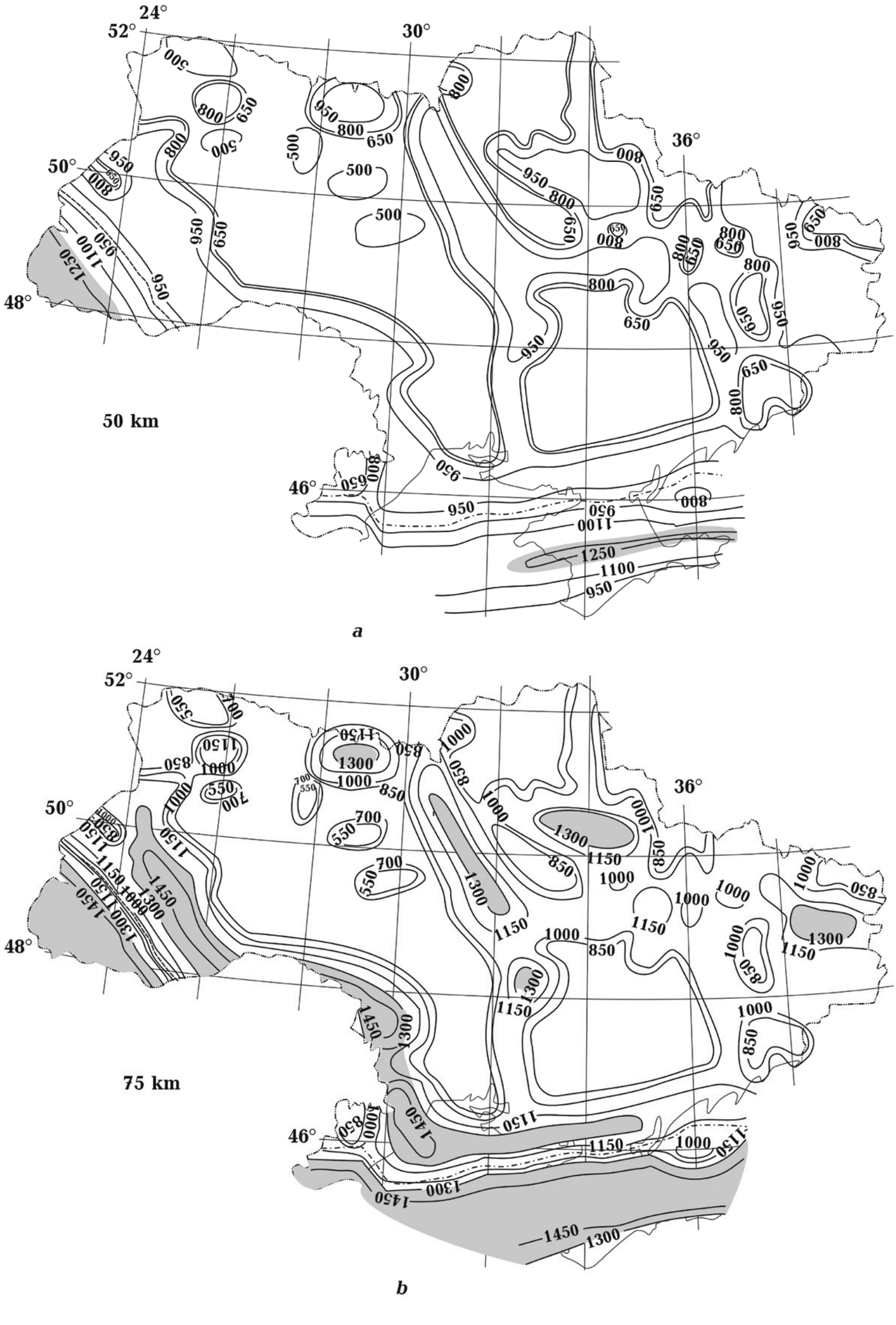
The comparison was for only about 180 samples. The average discrepancy in the data is about 70 °C. According to [Shcherbakov, 2005, etc.], the error in determining the temperature by petrological methods is about 50 °C. Accordingly, the error while calculating the temperature is the same, and the reliable isolines' step can be 150 °C. In fact, in the crust, it is possible to refine the isolines' pattern since the observed heat flow directly indicates the passage of intracrustal advection, one of the elements of the process of recent activation. Therefore, the authors deemed an isoline step of 100 °C for the crustal depth interval permissible. It is impossible to justify strictly this value; however, it allows us to highlight some details of the overall picture that seem necessary (see below).

Temperature calculation results. The distribution of deep T constructed by the authors (Figs. 3—5) is, of course, regional in



c

Fig. 3. Temperature distribution at depths of 10, 25, and 35 km: *1* — temperature isolines, *2* — the boundary of the Carpathian geosyncline, *3* — the boundary of the Scythian plate, *4* — partial melting zones.


24°
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50 km
a
24°
52°
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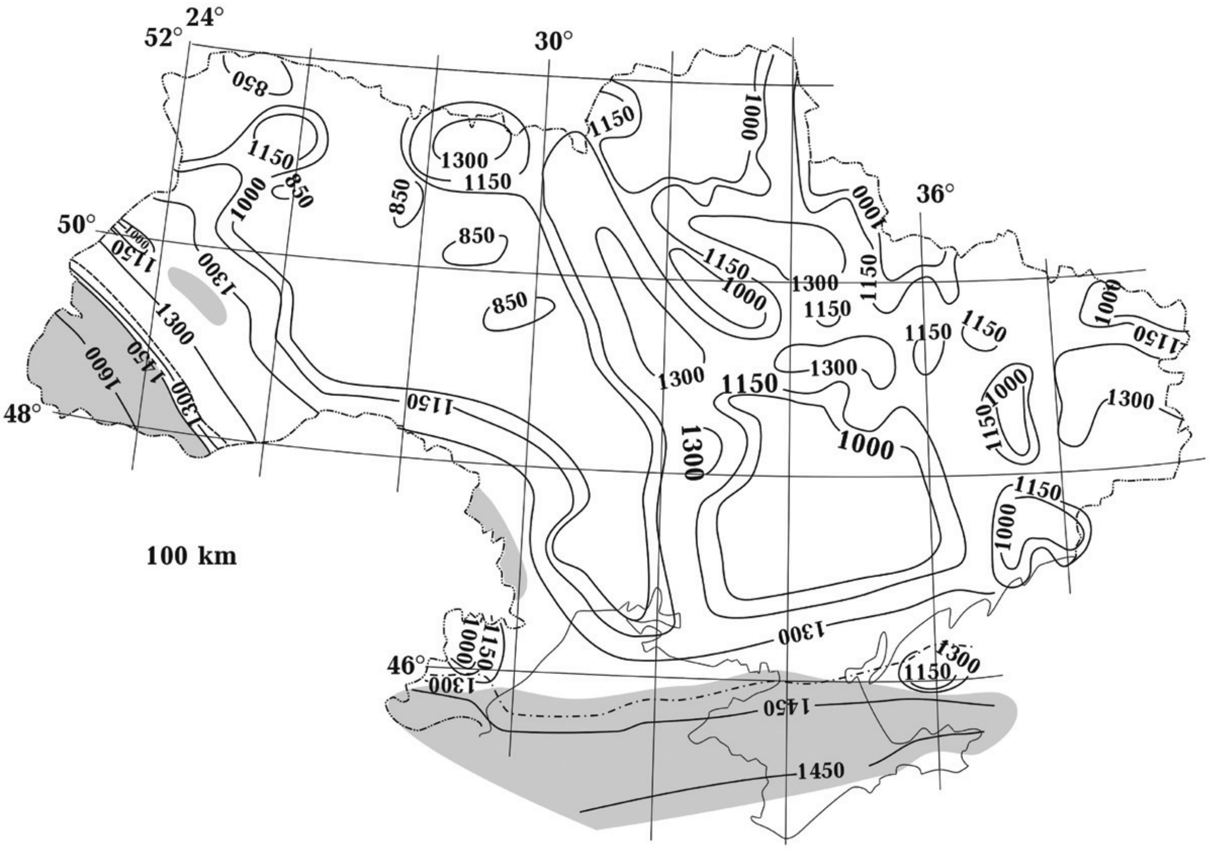
36°
50°
48°
46°
75 km
b



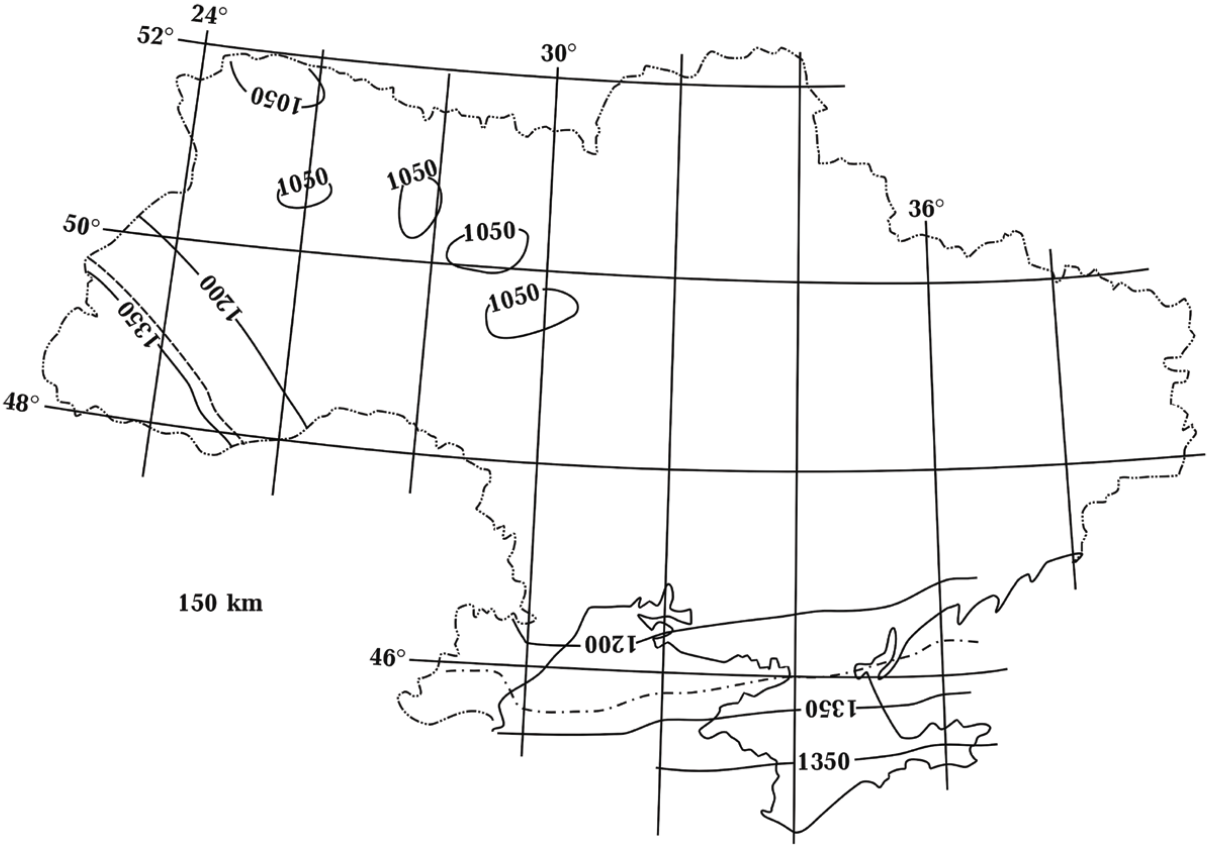
c

Fig. 4. Temperature distribution at depths of 50, 75, and 100 km. For the legend of the figure, see Fig. 3.

nature. Thermal models of the tectonosphere for regions of Ukraine (at least for the upper horizons of the mantle and crust) have been repeatedly published by the authors [Gordienko et al., 2005, 2006, 2011,2015, 2017; Gordienko, 2017, etc.]. In this article, changes have been made that correspond to the results of additional studies. Primarily, they concern the boundary of the RA zone and anomalous temperature values within the platform. Several revision and *T* on the borders of the Carpathians and Scythian Plate with the platform. Within the Phanerozoic geosynclinal regions themselves, changes are minimal. Temperatures in the crust of Ukraine are shown in Fig. 3.

The distribution of *T* in the crust of Ukraine, constructed in the described manner, does not reveal unexpected anomalies. The map of deep heat flow can predict almost all features of the resulting picture. Questions arise only in the diagnostics of partial rock melting zones. The solidus temperature (T_s) for crustal formations significantly depends on the degree of metamorphism, changing noticeably both with depth and horizontally.

At a depth of 10 km, the solidus temperature of amphibolite (and lower) facies metamorphic rocks is 600—650 °C caused by a noticeable amount of water; it practically does not depend on the rock composition. Under the conditions of Ukraine at this depth, there are no such temperatures. At a depth of 25 km, amphibolite facies rocks are widespread, and in some areas, solidus temperatures have been reached. In the western part of the Carpathian region (Fig. 3, *b*), longitudinal seismic wave velocities exceed 6.8 km/s. They are in an environment where the temperature is undoubtedly higher than typical for the platform. The rocks' metamorphism reaches that of granulites. Therefore, 600 °C is not enough for melting. In this area, partial melting seems unlikely. It is achievable


24°
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1200
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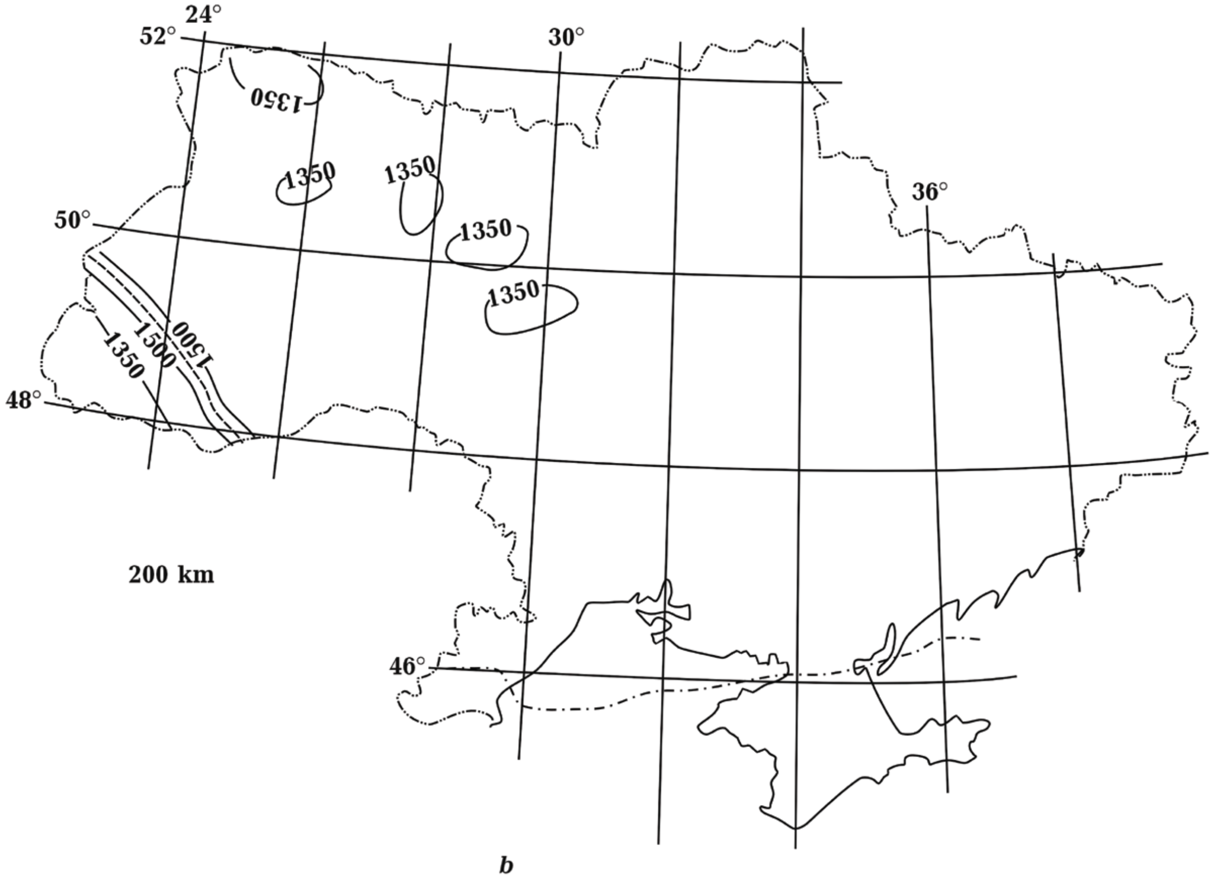
1350
1350

a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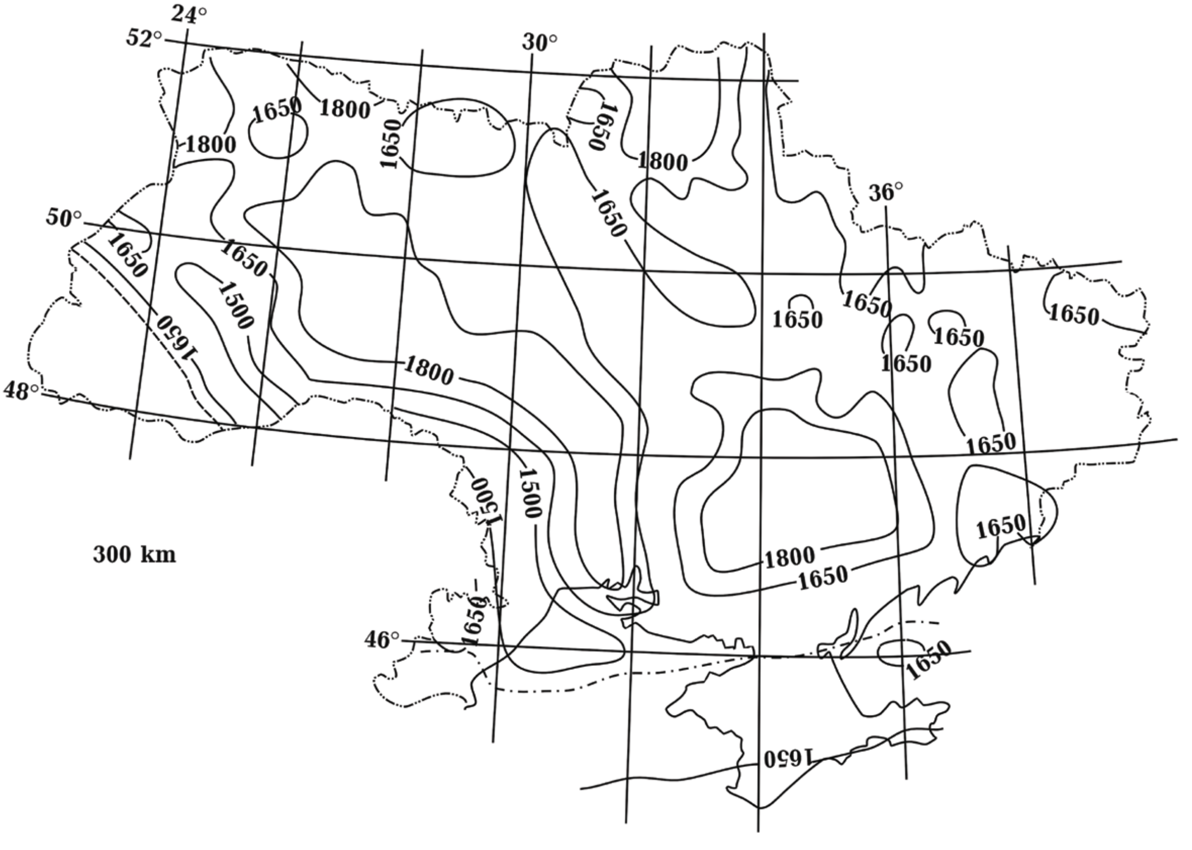
1500
1500
1350
200 km

b



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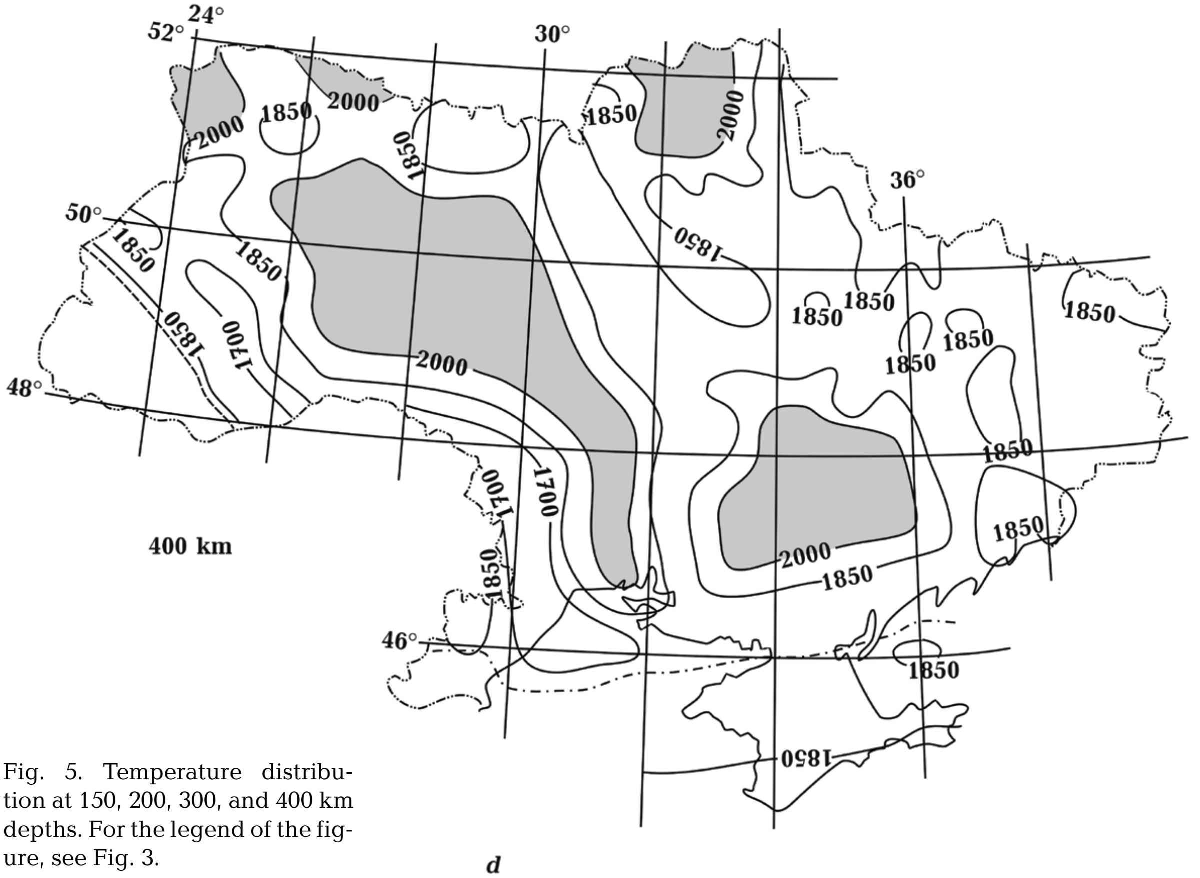

d

Fig. 5. Temperature distribution at 150, 200, 300, and 400 km depths. For the legend of the figure, see Fig. 3.

slightly more to the east in the Carpathians and in several other activated zones.

Granulite facies metamorphism is widespread from a depth of about 30 km. At 3—40 km depths, the solidus temperature increases from 950 to 1050 °C. Within Ukraine, at a depth of 35 km, a temperature of 1000 °C is reached only under the Transcarpathian Trough with a crustal thickness of 25—30 km. Thus, partial melting of rocks in the lower part of the Ukrainian crust seems unlikely [Gordienko, 2012, etc.]. Judging by the velocity sections of the crust along the DSS profiles, significant negative anomalies are not visible. Of course, we cannot exclude minor melting (with a melt concentration of up to 1—2 %) due to low melting impurities. They do not create noticeable velocity anomalies, limiting themselves to velocity decreases of 0.1—0.15 km/s.

The temperature distribution is the most complex in the 50—100 km depth range. The maximum anomalies caused by different-age influxes of superheated deep matter under the crust are here. Naturally, mantle rock partial melting zones are widespread just at these depths. Their difference was the excess of the solidus temperature T_s=1013+3.914–0.0037H^2, where H is the depth in km. Partial melting occurs at 50 km (Fig. 4, *a*) only in the Carpathians and at the Scythian Plate, where the partial melting is associated with the Alpine and Cimmerian geosynclinal processes. At the Scythian Plate, the calculated temperatures are possibly somewhat elevated since the used version of the development of the Cimmerian geosynclinal process is not very accurately known geologically. We used the younger dates of the possible ones. In areas where the heating of subcrustal depths is associated with recent activation, the temperatures at 50 km have already noticeably decreased after the material's removal into the crust and are below the solidus.

At a depth of 75 km (Fig. 4, *b*), partial melting zones are much more widespread. In addition to the Carpathians and the Scythian Plate, they are also present in many areas in the zone of recent platform activation, Donbas, and the Dnieper-Donets Basin. At 100 km, the areas with temperatures above the solidus are again sharply reduced, and the influence of heat and mass transfer in the RA period is already noticeably less. In some areas, the calculated T is a few tens of degrees below the solidus. The differences are less than the error, but melting is still not shown in Fig. 4, *c*.

The temperature distribution at depths of 150–400 km is shown in Fig. 5.

At depths of 150—200 km, temperature variations are sharply less. The differences between the platform and Phanerozoic geosynclines are not very large: ±150 °C, that is, approximately one step between reliable isolines. To roughly the same extent, negative anomalies are distinguished in areas with reduced heat generation of the crust and mantle rocks against the platform background. Phanerozoic riftogen regions can also probably be distinguished similarly (with positive anomalies relative to the platform). However, data to substantiate such disturbances (for example, under the Dnieper-Donets Basin) are absent.

Deeper, at 300 and 400 km, there is the lower boundary zone of advection processes. Positive anomalies are under the inactivated platform. Temperatures here exceed the solidus. There is readiness for recent activation.

Conclusion. The research (including two previous publications [Gordienko et al., 2025a,b]) made it possible to present a relatively detailed version of the thermal field of Ukraine aimed at constructing the temperature distribution over the entire tectonosphere thickness. It demonstrates a sufficiently high quality of the experimental material and calculation methods: 1) heat flow distributions; 2) deep seismic sounding data on the velocities of longitudinal seismic waves in the rocks of the Earth's crust; 3) methods for converting them into heat generation, 4) calculations of crustal heat flow; 5) deep heat and mass transfer in the tectonosphere schemes of Ukraine during its geological history; 6) calculation of three-dimensional thermal effects of these movements; 7) comparison of the obtained results with independently established temperatures at depths of up to approximately 200 km. The last procedure allowed us to evaluate the quality of the final result and select the step of isolines for its presentation.

Thus, one considers the problem set by the authors to be solved. It is also necessary to note the evident shortcomings of the constructed model. First of all, it's purely regional nature. There are numerous local thermal anomalies in the Ukrainian territory, many of which have not been considered, and their sources are missing in the calculation model. It is often related to the scale of the image of the resulting temperature distribution. More significant limitations are related to the shortcomings of geological information. Let us mention the main ones. These include the absence of a probable positive temperature anomaly beneath the Dnieper-Donets Basin. A noticeable error in temperature calculations beneath the central part of the Scythian Plate is possible. Data on the Cimmerian processes in the Hercynian folding zone are absent there. The model assumed they practically coincided with those occurring in the surrounding Cimmerides. That is to say, the abnormal temperatures may be exaggerated. As noted above (and in the two previous articles), the study of recent activation events is still far from complete. Therefore, one may state that the article reflects the current level of the solution to the problem, but the field for continuing research is still vast.

References

Gordienko, V.V. (2022). About geological theory. *Geofizicheskiy Zhurnal*, *44*(2), 68—92. https://doi.org/10.24028/gj.v44i2.256266.

Gordienko, V. (2012). *Processes in the Earth's tectonosphere (Advection-polymorphic hypothesis)*. Saarbrucken: LAMBERT Academic Publishing, 256 p. (in Russian).

Gordienko, V.V. (2017). *Thermal processes, geodynamics, deposits*, 285 p. Retrieved fromhttps://ivangord2000.wixsite.com/tectonos.

Gordienko, V.V., & Gordienko, I.V. (2025a). Crustal heat flow in Ukraine. *Geofizychnyi Zhurnal, 47*(1), 108—119. https://doi.org/10.24028/gj.v47i1.311435.

Gordienko, V.V., & Gordienko, I.V. (2025b). Mantle heat flow in the territory of Ukraine. *Geofizychnyi Zhurnal*, *47*(3), 69—79. https://doi.org/10.24028/gj.v47i3.323482.

Gordienko, V., & Gordienk,, I. (2023a). Thermal models of the continents and oceans tectonosphere. *NCGT Journal*, (2), 113—130

Gordienko, V.V., Gordienko, I.V., Goncharova, Ya.A., & Tarasov, V.N. (2024). Boundary of recent activation and seismicity on the platform part of Ukraine. *Geofizychnyi Zhurnal*, *46*(1), 28—37.https://doi.org/10.24028/gj.v46i1.298658.

Gordienko, V.V., Gordienko, I.V., Zavgorodnyaya, O.V., Kovachikova, S., Logvinov, I.M., & Tarasov, V.N. (2011). *Ukrainian Carpathians (geophysics, deep processes)*. Kiev: Logos, 129 p. (in Russian).

Gordienko, V.V., Gordienko, I.V., Zavgorodnyaya, O.V., Kovachikova, S., Logvinov, I.M., Tarasov, V.N., & Usenko, O.V. (2005). *Ukrainian Shield (geophysics, deep processes)*. Kiev: Korwin Press, 210 p. (in Russian).

Gordienko, V.V., Gordienko, I.V., Zavgorodnyaya, O.V., Kovachikova, S., Logvinov, I.M., Pek, J., Tarasov, V.N., & Usenko, O.V. (2006). *Dnieper-Donets Basin (geophysics, deep processes)*. Kiev: Korwin Press, 143 p. (in Russian).

Gordienko, V.V., Gordienko, I.V., Zavgorodnyaya, O.V., Logvinov, I.M., & Tarasov, V.N. (2015). *Donbass (geophysics, deep processes)*. Kiev: Logos, 159 p. (in Russian).

Gordienko, V.V., Gordienko, I.V., Zavgorodnyaya, O.V., Logvinov, I.M., &Tarasov, V.N. (2017). *South-Ukrainian monocline, Scythian plate, Black Sea (geophysics, deep processes)*, 131 p. Retrieved from https://ivangord2000.wixsite.com/tectonos (in Russian).

Gordienko, V.V., & Gordienko, L.Ya. (2023b). Mantle gravity anomalies of Eurasia, North America and Atlantic regions. *Geologiya i korysni kopalyny Svitovogo okeanu*, (2), 50—62 (in Ukrainian).

Shcherbakov, I. (2005). *Petrology of the Ukrainian Shild*. Lvov: WUKC, 366 p. (in Russian).

Tauzin, B., van der Hilst, D., Wittlinger, G.,& Ricard, Y. (2013). Multiple transition zone seismic discontinuities and low velocity layers below western United States. *Journal of Geophysical Research: Solid Earth*, *118*(5), 2307—2322. https://doi.org/10.1002/jgrb.50182.

Температури тектоносфери України

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Розглянуто тривимірну теплову модель тектоносфери України. У її основі — схема ендогенних режимів. Відповідно до неї побудовано моделі тепломасопереносу в кожному з регіонів для вікових процесів, які можуть помітно вплинути на обчислювані температурні аномалії. Останні розраховуються щодо теплової моделі платформи за умов типової теплогенерації порід кори та мантії. Виконано зіставлення розрахункових температур із незалежно встановленими за різними петрологічними даними. Отримано середню розбіжність близько 70 °C, що відповідає помилці кожного методу близько 50 °C і дає змогу проводити достовірні ізолінії через 150 °C. Для умов кори крок ізотерм було скорочено до 100 °C, оскільки тут можна використовувати деякі додаткові відомості, які уточнюють температуру. Отримана теплова модель виявляє помітні негативні аномалії у західних платформних районах із зниженою теплогенерацією порід (переважно — Український щит). Виявлено перевищення температури солідуса порід у деяких районах України на глибинах 25 км (Карпати, Скіфська плита, окремі частини активізованої платформи, Донбасу та Львівського прогину), 50 та 100 км (Карпати та Скіфська плита, невеликі вкраплення на платформі), 75 км (плавлення набагато ширше під активізованою платформою, на Донбасі та Львівському прогині) та на 400 км (під неактивізованою платформою). Зазначено недостатню геологічну вивченість території України, через яку в деяких районах похибка результатів може суттєво збільшитись. Це стосується насамперед південної частини Скіфської плити та західної частини Південноукраїнської монокліналі.

Ключові слова: тепломасоперенесення у тектоносфері, тривимірна теплова модель.