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Deep Heat Flow, Thermal and Geoelectrical Models of Dnieper Anomaly

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ABSTRACT

In the last three years new deep heat flow (HF) determinations were made in 100 holes in the north-east part of Ukrainian Shield (East-European platform). The value of Dnieper HF anomaly is determined as 60-65 mW/m^2 (background values are 40-45 mW/m^2). According to the thermal model the depth of the top border of the partial melting zone of crustal substance is 25-30 km. The top of the asthenosphere is defined by isotherms of 1,200-1,250 ^{0}C (50-60 km). The HF anomaly is confirmed by electrical conductivity anomalies in the crust and mantle.

1. INTRODUCTION

In the territory of the Ukrainian Shield (USh) and its slopes the Earth's heat flow (HF) determination network is very sparse (except a part of the Kirovograd block). On about 45% of its area HF was not determined at all, while on its 32% one HF determination falls on each 1,000 km^2 [Gordienko et al., 2002]. But here intensive HF anomalies may occur, which is exemplified by the eastern part of the Kirovograd block with HF values of 65 – 70 mW/m^2, the background value being 45 mW/m^2. This fact urges on geothermal studies of the Shield. The HF interpretation is ambiguous, therefore the geothermal studies of the respective regions should be logically supplemented by geoelectrical ones that enable control of the geothermal models.

2. DEEP HEAT FLOW DETERMINATION IN THE KIEV REGION

Here solitary data distinguish a hypothetic Dnieper HF anomaly [Gordienko et al., 2002] striking SE –wards from the region north-west of Kiev. Temperature (T) was measured in 2002-2003 in 50 boreholes 20 to 230 m deep; for 20 boreholes the values of T and HF determined earlier were used [Formation…, 1979, Gordienko et al., 1980].

The calculation of paleoclimatic correction with acceptable error is not a great problem: The respective method has been worked out and tested in the conditions of the Ukraine [Gordienko et al., 2002]. Corresponding to the thermal conductivity of rocks, the corrections were evaluated in HF values and were introduced as follows: 6-7 mW/m^2 to the depth of 30 m and 8 mW/m^2 below it

The overflow of underground waters' correction reflected mainly the effect of their pumping out. In many cases we were able to determine T with sufficient accuracy only at one deep point. The geothermal gradient was calculated from temperature variation between it and the surface.

The surface temperature (T_o) was determined in some boreholes (located at 13 points of c. Kiev and its vicinity) as a result of the extrapolation of the thermogram to the surface with considering of varying thermal conductivity (in the cenozoic rocks it was thought to increase from 1.3W/m^{o}C in the 0-20 m depth range to 1.75 W/m^{o}C in the depth range of 0-60 m or more, in the cretaceous rocks -1.75W/m^{o}C, in the Jurassic rocks –1.2W/m^{o}C [Gordienko et al., 1980, 2002 etc.]. The To distribution is shown in fig 1. The mean value is 8.0±0.2^{o}C.

The HF values calculated with taking into account the corrections were grouped at 32 points and given on a scheme (fig.1). It is seen that HF value is rather stable in the territory of Kiev and its immediate vicinity. Its mean value is 55±5mW/m^2, the error is estimated at 5-10 % (fig 1).

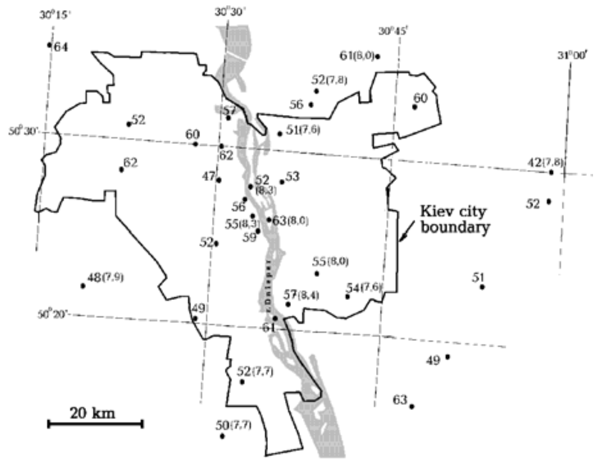

Fig. 1. A scheme of deep heat flow (in mW/m^2) and the mean annual surface temperature (the parenthesized numbers in ^{o}C) distribution in c. Kiev and its vicinity.

The determined deep HF value features the Kiev territory as promising for the practical use of the Earth's heat: with the minimal profitable value of the density of the geothermal resources of 2 t.s.f. (tonne of standard fuel)/m^2 at the borehole depth to 6 km [Gordienko et al., 2002] (when the cost of the geothermal energy does not exceed the cost of the energy obtained with traditional fuel burning) it is here 2.7 t.s.f./m^2 and may be notably higher (3-3.5 t.s.f/m^2) in some regions. Drilling to 3 km depth promises a profitable supply of heat for heating (with temperature of the water output of more than 60^{0}C), but its concentration is notably lower - 0.6 t.s.f./m^2 [Gordienko et al., 2002]. In each case, further studies of the distribution of this parameter in the Kiev area are a goal.

3. DISTRIBUTION OF DEEP HEAT FLOW

In the parts of the Ukrainian Shield (USh) and the Dnieper-Donets basin (DDB) next to Kiev the deep heat flow is about 40 mW/m^2 (except some positive anomalies situated in boundary faults of the DDB [Gordienko et al., 2002]). The calculated HF value in the immediate part of the Geotraverse II [Gordienko et al., 2002] is also 40 mW/m^2. Thus, one should admit the existence of a positive anomaly in the Kiev area whose contours cannot be defined so far.

The HF data of 5 points situated NW and SE of Kiev suggest the anomaly to extend nearly along r. Dnieper (Dnieper anomaly [Gordienko et al., 2002]) and to have the visible width of about 50 km and the length of 150 km (fig.2). Within the anomaly the Dnieprodzerzhynsk fault passes that strikes nearly parallel to the boundary faults of the Dnieper-Donets basin [Map…,1988].The maximal HF within the anomaly is 60-65 mW/m^2, i.e. its parameters are typical for deep HF disturbances in the recent activization zones of the Ukraine [Gordienko et al., 2002].

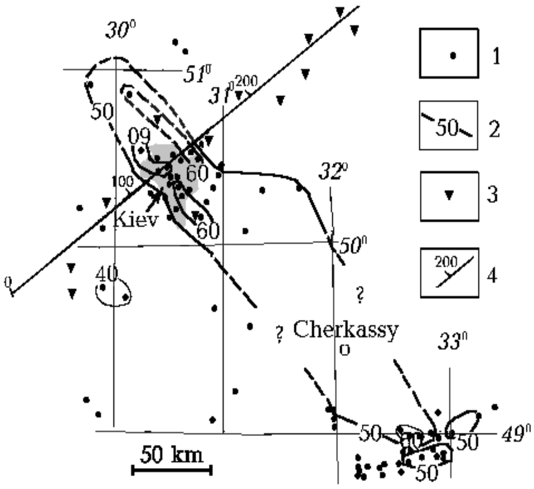

Fig. 2. A scheme of deep HF distribution in the studied part of the Dnieper anomaly and the location of the profile of geoelectrical investigations.

1- points of HF determination, 2 - HF isolines, 3 - points of geoelectrical investigation, 4 - profile along which the geoelectrical model of crust is set up.

The anomaly may extend to a notable distance (to 250 km) south-east of Kiev (fig.2). To draw the anomaly the data available were used. The anomaly contours may be changed if a new information comes.

4. HEAT FLOW ANOMALY AND RECENT ACTIVIZATION

The existence of a recent activization zone in the region is confirmed by the surface elevation. For the last 3 my its amplitude has exceeded 50 m. The strike of the elevations nearly corresponds with the HF anomaly strike, the size of maximal amplitude (more than 50 m) zones is 25x65 km. This, of course, does not allow us to conclude unambiguously the deep HF anomaly nature since it cannot be excluded that in the region in question high heat generation crustal rocks occur.

The local earthquakes are unknown in the anomaly area. The gravity field is decreased by 10-15 mGl. The magnetic field in the northern anomaly part is increased to 100-150 nT and decreased to 100-150 nT in the southern part.

The unambiguous explanation of the HF value necessitates setting up of thermal models and their verification by independent data. Consider versions of temperature distribution in the Earth’s crust corresponding with two hypothetical models: 1) The high HF of the region is due to high heat generation in the crustal rocks, i.e. it is stationary, 2) the HF anomaly is due to the effect of the overheated mantle melts that recently intruded into the crust.

In the first case we shall reserve in our calculation the usual relations of the heat generation values between the upper and lower crust and the mantle HF value. We shall obtain 220^{o}C at 10 km, 380^{0}C at 20 km, 500^{o}C at 30 km, 600^{0}C at 40 km. In the second case we shall assume the parameters of the substance transfer process used earlier to set up similar models on the Volyn’-Podylla plate and on the Kirovograd block of the Shield [Gordienko et al., 2002] . We shall obtain 260^{0}C at 10 km. 600^{0}C at 20 km, 850^{0}C at 30 km, 1,050^{0}C at 40 km.

Certainly, the situation in the considered hypothetical activization zone is not quite analogues to that seen under other zones since in the Kiev area the heat generation of crustal formations calculated from the crustal density section seems to be notably lower, which should reduce the background temperatures. Besides, differences may be in the time of crustal intrusions of mantle melt (and, correspondingly, the associated temperature increase). However, it cannot be excluded that a layer of partial melting and dehydration of rocks in the middle crust may also exist under the Dnieper anomaly: here the calculated temperatures exceed 600^{0}C and rocks of the amphibolite facies of metamorphism should exist. In principle, a small zone of partial melting of rocks of granulite facies of metamorphism (their solidus temperature is 1,050^{0}C at a depth of about 40 km) may appear when the crust is sufficiently thick (more than 40 km). Thus, different versions of the explanation of the HF anomaly lead to assumptions of the presence or the absence in the middle and, perhaps, in the lower crust of a layer containing melt and fluids (they may also migrate to notably greater height over the main partial melting layer – to depths of about 5-10 km) and hence, exhibiting a high electrical conductivity.

5. GEOELECTRICAL STUDIES

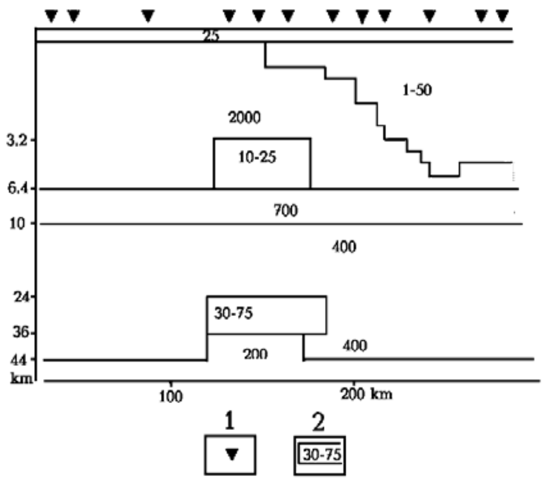

Fig. 3. Geoelectrical crustal model along the profile cutting the Dnieper HF anomaly.

1 – observation points, 2- crustal blocks with s.e.r. value (in Ohm·m).

The MTS curve in the period range of 36-10,800 s at the point Rozhny, at 25 km from the observatory of c. Kiev was combined with magnetic variation sounding curve in the period range of 250,000-44,930,000 s, based on the data of the long-term records of magnetic components at the observatory of Kiev [Semenov, 1998].

The fitting of the geoelectrical section parameters from the curve obtained was based on the 1-D Parker inversion [Parker et al., 1981] (D+ algorithm) and OCCAM [Constable et al., 1987]. The first method can estimate the value of the total longitudinal conductivity of the conductors in the section using data of the whole observed period range simultaneously. The second one consists in fitting a finite number of layers gradually changing their conductivity that approximate the experimental data. The OCCAM inversion is more susceptible to the impedance phase values while the D+ inversion - to the ρ values. In general, the calculated and the experimental data agree well. On the geoelectrical section several layers situated in the upper mantle and the Earth's crust (at depths of about 3 and 30 km) are distinguished.

At the second stage, the magnetic variation observation data in the period range of 100-6,400 s made by the authors together with the results of studying the electromagnetic field variations at several points [Tregubenko et al., 1989, 1994] on the profile cutting the Dnieper HF anomaly were invoked in modeling. Magnetotelluric and magnetovariation data were used. Interpretation was made within the framework of a 2-D model by solving direct and inverse problems [Novozhinsky et al., 2001 etc].

The results obtained suggest conductive bodies (fig.3) at depths of about 3-6 km and 24-36 km in the interior of the vicinity of c. Kiev. The integral conductivity G of the upper body (with specific electrical resistance-s.e.r.-of 10-25 Ohm·m) is about $1.3x10^7$ S·m and that of the lower one – (with s.e.r. of 30-75 Ohm·m) is $1.6x10^7$ S·m.

The calculation shows that the conductivity anomaly may be due to crustal rock heating and content of fluid and melt of about 0.5%. Thus, the temperature slightly exceeds the solidus of rocks of the amphibolite facies of metamorphism of 600-650°C. The geothermal gradient over the melt zone is 25°C/km, the heat flow value is 55-60 mW/m^2.

6. CONCLUSIONS

Though the geoelectrical studies made in the region have a reconnoitering character they suggest the existence of a conductor in the crust under the Dnieper HF anomaly.

This conclusion increases the scientific and applied interest for further studies of the Dnieper deep HF anomaly. The point is that in some recent activization zones studied in the Ukraine some acid magma intrusions into the upper crust and permeable fault zones which are situated above them exist. Within them the heated fluids approach the surface, which provides more geothermal energy than expected from the geothermal resources estimation by the standard method.

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