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Heat Field, Deep Processes and Geoelectrical Model of East Carpathians

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ABSTRACT

Deep heat flow (HF) determinations were made in 950 holes in the Carpathian region. The HF changes from 40 to 130 mW/m^2. The deep processes model (alpine geosyncline) corresponds to these variations. The geoelectrical researches yielded a model of conductive layers distribution in the crust and the mantle of the region. The conductors are detected in the crust of the Transcarpathian depression and the mantle of Pannonian basin and Fold Carpathians. They agree with partial melting zones.

1. INTRODUCTION

In the Ukraine, the Carpathian region is a complicate structure whose central part is occupied by the Carpathians surrounded by the Transcarpathian depression in the west and by the Precarpathian foredeep in the east [Glushko, 1979, Glushko et al, 1986, Geodynamics…, 1998, Kruglov et al, 1985] (fig. 1).

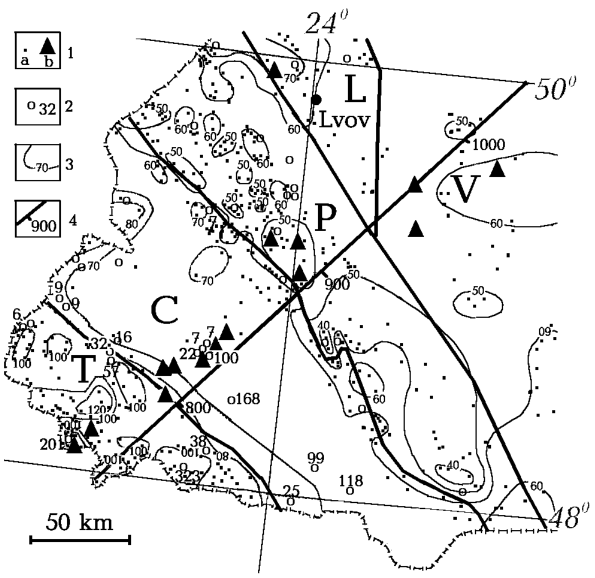

Fig. 1. A scheme of geophysical investigations in Carpathian region

1 - the points of: a – heat flow determinations, b - deep geomagnetic soundings, 2 –the points of helium isotopes ratio (fig. shows abnormal R values: R= ^{3}He/^{4}He·10^{-8}) [Gordienko et al., 2001], 3 – isolines of heat flow, mW/m^2 [Gordienko et al., 2002], 4 – Geotraverse II. 5 – Tectonic regions: Transcarpathian depression (T), Flysh Carpathians (C), Precarpathian foredeep (P), Lviv Paleozoic depression (L), Volyn'-Podoliya plate (V).

Transcarpathian depression (fig. 1) appears to be a neogenic depression superimposed, together with the Eastern-Slovakian basin, on a pre-miocenic heterogeneous basement that had undergone complex dislocations. It has a multilevel structure 30-35 km wide and is filled with a 3,000 m thick orogenic neogenic molasse dislocated into gentle folds that are complicated in the central parts by salt diapirs. The Vyhorlat-Gute Ridge of neogenic-quaternary (1-16 my ago) volcanic formations is a superimposed element of the depression. In Transcarpathian depression there are many warm springs. The Carpathians or Flysh Carpathians (fig.1) are a meganticlinorium striking SE wards at an angle of about 120^0 in the Ukraine, and are separated from the Transcarpathian depression by the Pieniny Klippen Zone. The Flysh Carpathians and foredeep are almost completely amagmatic, and are composed of thick cretaceous, paleogenic and lower miocenic flysh strata that are monotonous in lithology and tectonic style. Three main zones are delimited within the Carpathians near Precarpathian foredeep. In the north-east the Precarpathian foredeep bounds the Lviv Paleozoic Foredeep and Volyn'-Podoliya plate (fig.1).

The folding stage of Carpathian region took place 25 my ago and after it (12 my ago) the magmatic activization began. Therefore high heat flows, partial melting zones in the crust and upper mantle are probable here.

This work presents a model of the deep process in the tectonosphere, a thermal model of the tectonosphere, results of a 2D modeling of the Geotraverse II induction vectors obtained by the authors in the 100-10800 s period range.

2. GEOPHYSICAL INVESTIGATIONS

In the Carpathian region (fig. 1) deep heat flow was determinated at 550 points (950 boreholes). Most determinations fall in the Precarpathian foredeep. Most scarcely studied were Fold Carpathians. The HF values were corrected for paleoclimate, underground water movement, young overthrusth formation, structural effect. The HF change limits are from 40-50 mW/m^2 in the Precarpathian foredeep to 120-130 mW/m^2 in the Transcarpathian depression. The HF determination error is 7-10% [Gordienko et al., 2002]. The HF isolines are drawn at 20 mW/m^2 interval in the Transcarpathian depression and at 10 mW/m^2 in the rest territory of the region.

A new model of the deep process in the tectonosphere of the Carpathians is set up according to an advective-polymorphic hypothesis [Gordienko et al., 2003]. Within Carpathian geosyncline portions of the material from the asthenosphere (220-480 km depths) move consecutively to depth of 160-220 km, 100-160 km, and 40-100 km (70-190 my ago). The two latter ascents are accompanied by submersion of the cold material into the asthenosphere. From 40-100 km, magma moves on into the crust. In the case of recent activization (1-12 my ago) substance is not the deep-seated (over 220 km) asthenosphere which is the source of partially molten material but rather its portion that remains after the completion of the geosynclinal process (the top layer occurring at the depth of about 100 km).

At the centre of the Ukrainian Carpathians Deep Seismic Sounding profile II (Geotraverse II) is situated. Model of deep process differs from the former one [Gordienko et al., 2002] by a more detailed account of the evolution and the sizes of separate tectonic zones of the region. On its basis a thermal model of the tectonosphere co-ordinated with heat flow distribution was set up (fig. 2).

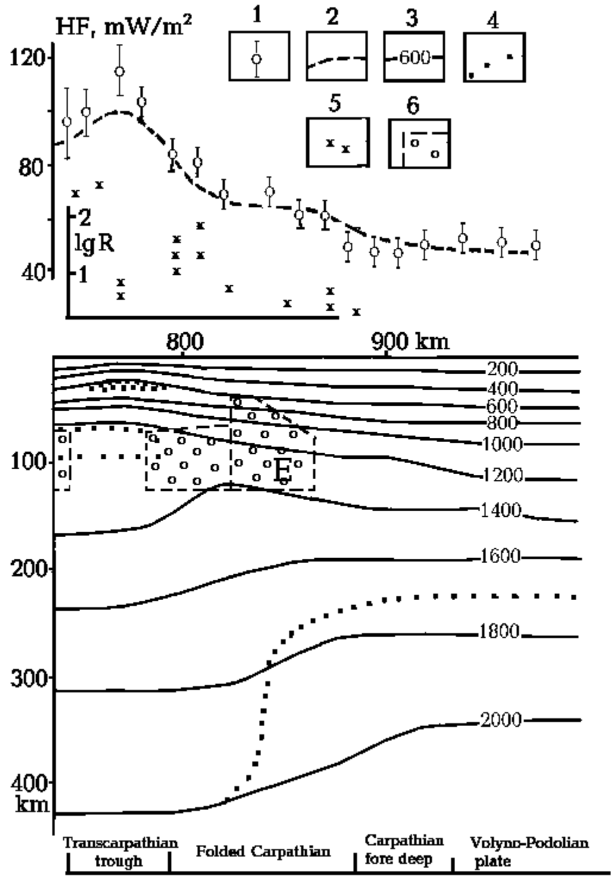

Fig. 2. Present thermal model of the Ukrainian Carpathians along Geotraverse II.

1, 2 - deep heat flow (1 - experimental, 2 - calculated), 3 - isotherms, ^{0}C, 4 - margins of the partial melting zones, 5 - values of helium isotopes ratio (lg R), 6 – possible conductive objects.

Partial melting zones in crust and upper mantle (at a depth of 60-90 km) of the Transcarpathian depression are distinguised. The crustal zone bottom lies at a depth of 25-28 km (i.e. M-discontinuity). The top may be at depths of 15-20 km in different places (fig. 3).

Above it (approximately to depth of 6-7 km) some magma intrusions in crust occur which may continue practically up to the surface through the fluid-saturated channels in zones of permeable deep faults. It is confirmed by the detection of abnormal values of helium isotopes ratio in underground waters indicating gas escape from the mantle (fig. 2, 3).At seven sites the helium isotopes ratio appears to be indistinguishable from the background R value of 2.8; at four sites it reaches insignificant anomalous values averaging to 8; at 10 sites pronounced anomalies with an average value of R amounting to 113 have been detected [Gordienko et al, 2001].

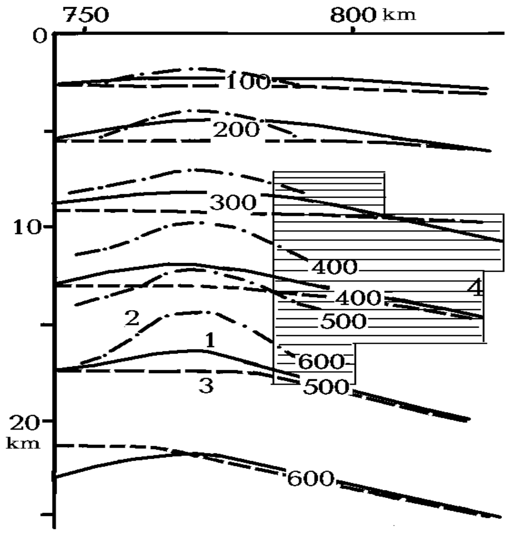

Fig. 3. Present crustal thermal model of the Transcarpathian depression along Geotraverse II.

1-3 - isotherms, ^{0}C (1 - at the crust advection 3 my ago, 2 - 1 my ago, 3 - without the crust advection), 4 – contour of the Carpathian conductivity anomaly.

According to the thermal model (fig. 2), the degree of dry melting in the subcrustal part of the upper mantle of the Transcarpathian depression is insignificant - 1-2 %, the resistance is about 100 Ohm·m, S is 300 S. Further west, in the Debrecen zone, the degree of melting grows and S of the asthenosphere may increase to 1,000 S. For the conductivity of the objects located in the lower sedimentary deposits and consolidated Earth’s crust, the basic role is played by fluids separated at partial melting and dehydration of rocks. In the permeable zones of deep faults their concentration may be from one to several percents and their resistance may reach 1 Ohm·m or less. The induction vectors (real – Cu and imaginary – Cv parts) obtained by the authors in the 100-10,800 s period range at magnetovariation observation points within about 20 km wide belt were brought to the Geotraverse II line and a geoelectrical model was set up by 2-D modeling, [Logvinov et al, 2003] (fig. 4). The model was fitted so that deviation of the calculated parameters from the experimental ones did not exceed the double error of the latter.

The object of the Carpathian conductivity anomaly (CCA) is situated at the south-west edge of the Carpathians (SP790 to SP840, fig. 1, 3) in a depth range of 6.6-18 km. The integrated conductivity of the object $G = \sigma \cdot l \cdot h$, [Rokityansky, 1975] ($\sigma$, l, h are conductivity, width and thickness of the separate elements of the object, respectively) is $(1.75 \pm 0.15) \cdot 10^8$ S·m. The resistance distribution in different parts of the object may vary notably assuming values: from 15 to 60 Ohm·m at A, from 0.4 to 20 Ohm·m at B, from 1 to 100 Ohm·m at C. A fault separating the Carpathians from the Precarpathian foredeep and a conductive layer connecting CCA with a fault are entered.

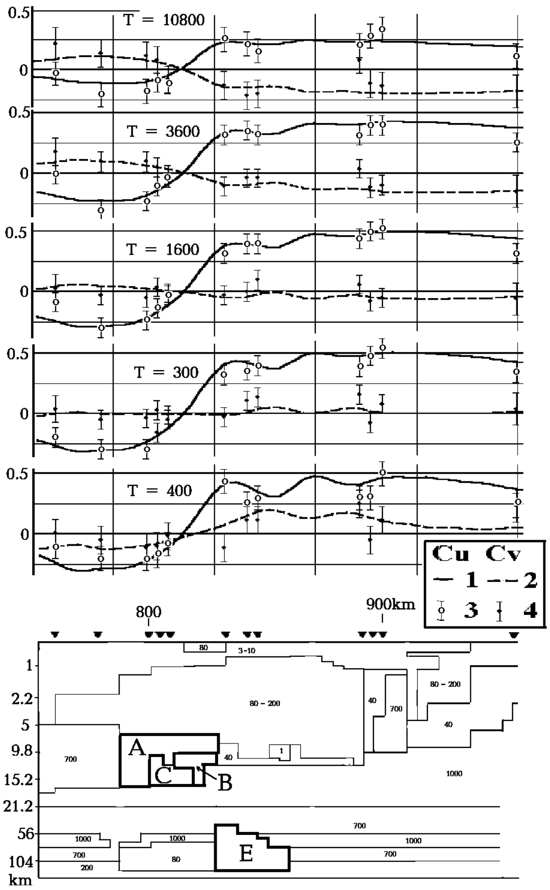

Fig. 4. The results of 2-D modeling (1, 2) along Geotraverse II and their agreement with experimental data. Dots with error bars denote the experimental values (3, 4). The values of resistance in model - are in Ohm·m.

The integrated conductivity of the layer is about $1.3 \cdot 10^8$ S·m. The conductive layer in the upper mantle (asthenosphere) strikes from the Pannonian basin to the Hungary -Ukraine border. Its total longitudinal conductivity (S) is about 1,600 S. Then the conducting object beneath the Carpathians is separated which is not joined with the asthenosphere of Pannonia. The resistance distribution in the most conductive part of the object (E in a fig. 2, 4) may vary notably assuming values from 2.5 to 15 Ohm·m, G of the whole object reaches $5.4 \cdot 10^8$ S·m. It may correspond to a zone of recent activization at the centre of Flysh Carpathians. The thermal model does not include the partial melting zone, as the heat flow anomaly is detected only at north-west edge of region. To south-east heat flow determinations are very rare. Known are the 2D geoelectrical models set up along the Geotraverse II and profiles cutting the Carpathians in other parts of the region [Adam et al., 1997, Ernst et al., 1998, Zhdanov et al., 1985 etc]. The parameters of the main crustal conductive body at the border between the Fold Carpathians and the Transcarpatian depression do not differ significantly from those determined here (the depths are 7-20 km, G =2-$5 \cdot 10^8$ S.m).

The position of the crustal and mantle partial melting zones in the Transcarpathian depression is confirmed first of all by the petrological data on magma sources [Gordienko et al., 2003]. The last stage of magmatism is characterized by magma chambers depths of 50-80 km in mantle and 15-20 km at the "granitic" layer bottom [Kruglov et al., 1985]. In the Transcarpathian depression several tens of magnitude 3-5 earthquakes occured at the hypocenter depth to 8 km.

Similar depths of the magma chambers (8-12, 20-25 and 50-70 km) are determined by the Curie temperature data of titanomagnetite of different composition from young volkanic rock samples (fig. 5) [Glevaskaya, 1983].

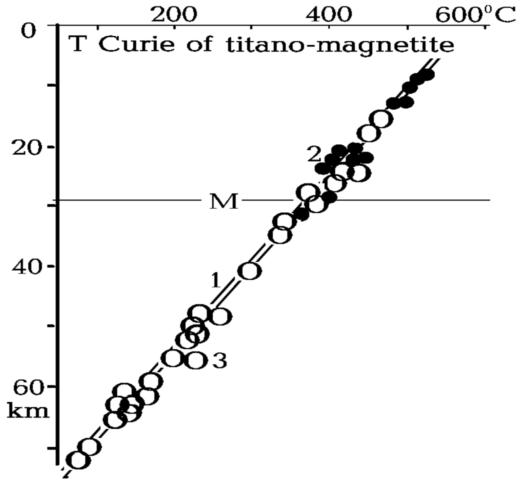

Fig. 5. Magma chambers depths of young magmatism of the Transcarpathian depression according to thermomagnetic data [Glevaskaya, 1983].

1 - magma chambers depths dependence of the Curie temperature of titanomagnetic. 2- for crustal (rhyolites, dacites), 3 - mantle (basalts, diabases) rocks.

The results of the interpretation of local magnetic anomalies (oral information by Unakovskaya) determine the bottoms depth of all their sources to be about 15 km. I.e. at this depth, the Curie temperature of magnetite (580^{0}C) is reached, which agrees well with the thermal model. The crustal velocity section of the Transcarpathian depression [Chekunov et al, 1969] compared with the velocity distribution in the heated normal continental crust, shows velocity inversion. The velocity increase in the middle crust may be explained by rock basification and the velocity decrease in the lower crust- by partial melting (fig. 6).

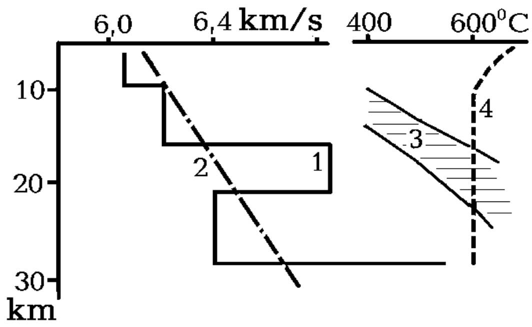

Fig. 6. Thermal and velocity models of the Transcarpathian depression.

1, 2 - seismic waves velocity distribution in consolidated crust (1 – by DSS data [Chekunov etc, 1969], 2 - calculated without partial melting consideration), 3 - temperatures, 4 - solidus of the rocks of the amphibolite facies of metamorphism [Kruglov et al., 1985 etc].

The partial melting chambers in the upper crust (above 15-20 km) are sporadic even if they exhibit some high-velocity anomalies, the latter are at the level of the velocity determination error.

The thermal model suggests overheating of the mantle beneath the Carpathian region, which should be expressed in rock discompaction. The corresponding mantle gravity anomaly has been calculated along the Geotraverse II (fig. 7). Along the Geotraverse II the gravitation effect of the crust and the normal mantle has been calculated (fig. 7-2) [Gordienko, 1999]. It appears to be well above the observed field. The consideration of the mantle gravity anomaly (fig. 7-3) allows to match the calculated and the observed field.

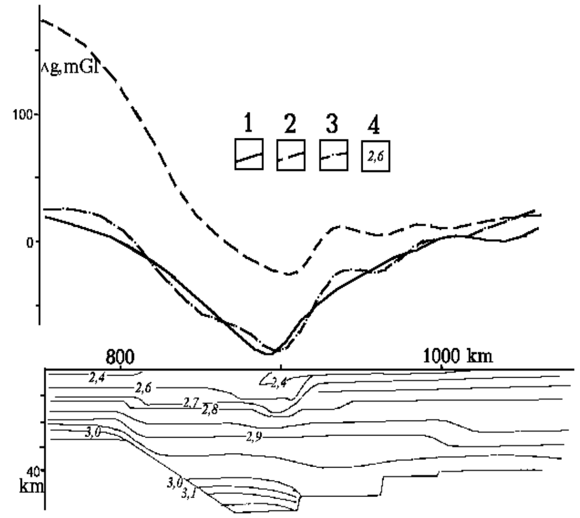

Fig. 7. Density model along Geotraverse II.

Gravity field: 1 - observed, 2-3 - calculated (2 – for normal densities of the upper mantle rocks, 3 – considering the abnormal density of the upper mantle rocks), 4 - density values (g/cm^3).

3. CONCLUSION

The model of the deep process of the Carpathian region is set up for the Ukraine. The good agreement of seismic, thermal, magnetic, geoelectrical, helium isotopes ratio and geological data of the model of such a process is shown. The geologic-geophysical models include asthenosphere with its top at a depth of about 70 km beneath the Transcarpathian depression, a partial melting zone in crust in a depth range from 6-8 km to 20-25 km and permeable zones impregnated by fluids of deep faults of the Transcarpathian depression.

A comparison of geoelectrical parameters and the situation of the object of the Carpathian conductivity anomaly with geologic-geophysical models of the region gives reason to believe that the anomaly is due to penetration of fluids connected with partial melting zones in the crust of the Transcarpathian depression.

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