CONSIDERATIONS ON THE TIME-CONSISTENCY WITHIN LARGE-SCALE COMPOSITE GEOMAGNETIC MAPS

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Considérations sur l'homogénéité temporelle dans les cartes géomagnétiques de synthèse à l'échelle régionale. Au delà du succès indiscutable, la Carte Digitale Mondiale de l'Anomalie Géomagnétique récemment élaborée met en discussion, de nouveau, le problème de l'homogénéité des images géomagnétiques de synthèse à grande échelle, ayant à la base les données primaires obtenues dans le cadre de la cartographie géomagnétique distincte réalisée à grand interval de temps. On peut remarquer que le modèle mondial en discussion ne mentionne aucune époque magnétique de comparaison. L'aspect est soutenu par la supposition de l'invariance en temps du champ géomagnétique lithosphérique. En fait, il existe une série de facteurs qui peuvent affecter en temps les propriétés magnétiques des roches (le stress tectonique, le chauffage géothermique, les transformations minérales etc. et, par conséquence, peuvent modifier, d'une manière semnificative, l'induction magnétique de la lithosphère. L'étude relève les eventuelles distorsions présentes dans les cartes géomagnétiques à grande échelle, dues à l'omission de l'influence des variations spatio-temporelles du champ géomagnétique de la lithosphère.

Key words: geomagnetism, synthesis geomagnetic maps, secular variation, temporal homogeneity.

1. INTRODUCTION

Beyond its undoubtedly success, the recently achieved World Digital Magnetic Anomaly Map (Korhonen *et al.*, 2007; Maus *et al.*, 2007) has raised again the issue of the consistency of the large-scale composite geomagnetic images based on raw data gathered within distinct geomagnetic surveys carried out during a long time-span. As it can be noticed, no geomagnetic epoch has been assigned to the world model provided. That came from the assumption that the geomagnetic field of the lithosphere would be a time-invariant. In fact, several factors may affect rock magnetic properties (*e.g.* tectonic stress, geothermal heating, mineral transforms) and, consequently, may significantly modify the geomagnetic induction in the lithosphere.

The paper attempts at revealing possible distortions generated in the large-scale composite geomagnetic maps by neglecting space-time variation of the lithospheric field.

Two study areas were approached, that relate to cross-border regions between Romania, Republic of Moldova and Ukraine (Fig. 1), where previous attempts to merge national airborne geomagnetic maps had successfully been made (Beşuţiu *et al.*, 2000; Beşuţiu *et al.*, 2006).

2. METHODOLOGY

To infer the geomagnetic anomaly, two main algorithms (see Fig. 2) were used for each case-history:

(i) the first approach was similar to the World Digital Magnetic Anomaly Map (WDMAM) achievement, deriving geomagnetic anomaly model directly from data gathered at various epochs, by simply subtracting the IGRF models computed at each survey epoch. After several attempts made worldwide (*e.g.* Golovkov, 2007), IAGA released the IGRF-10 version (http://www.ngdc.noaa.gov/IAGA/vmod/igrf.html);

(ii) the second one, started by creating time-consistency to the previous data by fitting them to the datum provided by a geomagnetic reference network not affected by secular variation. Then, an IGRF-10 model appropriate to the epoch of the geomagnetic network was removed to get the geomagnetic anomaly valid at the epoch of the reference network.

The second methodology had been previously successfully applied in merging national airborne geomagnetic maps of Romania, Republic of Moldova and Ukraine within the Low Danube area (Beşuţiu *et al.*, 2000), and in creating cross-border consistent geomagnetic images along the northern state border between Romania and Ukraine (Beşuţiu *et al.*, 2006).

The two versions of the geomagnetic anomaly thus obtained were then compared, and the revealed deviations are discussed in terms of time-inconsistencies within the composite map.

3. DATA PROCESSING

The first study case refers to the **DEEP** project (**D**ynamics and Structure of the SW Margin of **E**ast-**E**uropean **P**latform as Inferred from Geophysical Data), which represents a joint venture of the Institute of Geodynamics of the Romanian Academy (IGAR) and the Institute of Geophysics of the National Academy of Sciences of Ukraine (IG-NASU).

Raw geomagnetic data used to construct the composite map along the state borders between the two countries (Beşuţiu *et al.*, 2006) were rather different (Fig. 3). The airborne survey of the Ukrainian part was performed in 1980. The lines were constantly flown at 2500 m above the sea level. Contour maps of the geomagnetic anomaly at the epoch 1980.0, as obtained by subtracting a LO-IZMIRAN geomagnetic reference field model, were available as raw data. The Romanian part was surveyed at various heights (ranging between 400 m and 2500 m above the sea level) during four flight campaigns: 1965, 1966, 1967 and 1968. ΔF intervals between each observation point and the base station of the map were recorded and then transformed into annual mean values of the total intensity scalar of the geomagnetic field. All the observations were transferred at the unique altitude of 2500 m, similar to the Ukrainian data, by using a computer code based on the algorithm for data transfer from one surface to another (Ivan, 1994).

To provide time-consistency to the previously gathered geomagnetic information on the territories of the two countries, a joint cross-border geomagnetic reference network (Fig. 4) was designed and surveyed in less than one month in order that be not affected by the secular variation (SV) effect. Base-stations were carefully chosen in areas of no geomagnetic anomalies, based on prior geomagnetic information provided by the map of the ground vertical component (Airinei *et al.*, 1985).

After data acquisition and processing, a consistent set of annual means of the total intensity scalar of the geomagnetic field were obtained for the network stations. They were upward continued at the flight altitude by using the normal vertical gradient of the geomagnetic field (Beşuţiu, 1999), and compared to the previous maps datum. Based on the revealed deviations, SV corrective functions were constructed and applied to the original data to provide time-consistency. Finally, a consistent set of geomagnetic data valid at the epoch of the reference network (2004.5) was obtained and used to compute the geomagnetic anomaly by removing the IGRF-10 model (Fig. 5).

To check the accuracy of the joining operation, high order derivatives, well known for their sensitivity to the datum discrepancies, were computed. The image of the horizontal gradient of the geomagnetic anomaly is shown in Figure 6. As it can be seen, there is no anomalous effect along the state-borders, advocating for the high quality of the joining operation between two surveys separated by about a 13 years time-span.

During the next step of the procedure, geomagnetic anomalies were also distinctly inferred for each survey (Figs. 7, 8) by subtracting IGRF-10 models appropriate to each survey epoch (1965.5, 1966.5, 1967.5, 1968.5, and, respectively, 1980.0).

Finally, the two versions of the geomagnetic anomalies were compared side by side. Thereafter, geomagnetic models derived at the surveys epoch were subtracted from the geomagnetic anomaly as obtained after providing time-consistency to the previous data by the help of the reference network. Figure 9 shows the results for both Ukrainian and Romanian territories. Comments are provided within the next section.

The second case dealt with MAGLODAN project, a joint venture of the Geological Institute of Romania (IGR), IG-NASU and Institute of Geophysics and Geology of the Academy of Sciences of Republic of Moldova, aimed at achieving consistent geomagnetic models across the state borders between Romania, Republic of Moldova and Ukraine in the Low Danube area (Fig. 10). Contour maps of the geomagnetic anomalies for 1965.0 and, 1980.0 epochs (as inferred by subtracting LO-IZMIRAN reference models) were available for the Ukrainian and, respectively, Moldovan parts, and ΔF intervals at the epoch 1967 for the Romanian territory were available as raw material. All previous maps were constructed at 1000 m altitude. Time-consistency was provided for the epoch 1998. 5 in a similar manner by the help of a joint cross-border geomagnetic reference network (Beşuţiu *et al.*, 2000).

The analysis made in the present study followed the same procedure as in the case of the DEEP data and results are shown in Figure 11.

4. MAIN RESULTS

The main results are synthetically presented in a map form. For the analysis based on the DEEP results, comparisons were made between the time-consistent models referred at the epoch 2004.5 and geomagnetic anomalies obtained for the epochs of each survey used within the composite map (1965.5, 1966.5, 1967.5 and 1968.5 for the Romanian territory, and, respectively, 1980.0 for the Ukrainian area). The latter were subtracted from the geomagnetic anomaly valid at the epoch of the reference network (2004.5). The revealed deviations (Fig. 9 and Fig.11) may be attributed to residual effects of the space-time variations in the lithospheric field or/and to some incapacity of IGRF models to accurately predict SV effects.

Looking at the images provided by the above-mentioned pictures, it seems that the geomagnetic anomaly derived for the epoch of the geomagnetic reference network (2004.5) is significantly lower than the previous models (directly derived by removing IGRF-10 at each survey epoch), with a decreasing trend striking ESE-WNW.

A similar situation has been revealed by the analysis made on the MAGLODAN data (Fig. 11), where models achieved for surveys made in 1966, 1967 for the Romanian territory, 1965 for the Black Sea shelf, and 1980 for Moldova and SW Ukraine were compared to a time-consistent data set valid at the epoch 1998.5. The ESE–WNW trend is present within all situations.

5. CONCLUDING REMARKS

At a first sight, images provided by the two approaches exhibit a quite similar pattern. The puzzle of maps constructed for surveys made at different epochs apparently shows consistency (*e.g.* in the upper part of Figure 8).

However, when compared to the time-consistent models obtained by using the reference network, significant deviations (above the accuracy threshold) between the two types of geomagnetic anomalies were revealed in all cases.

Large-scale hidden trends may affect the composite geomagnetic maps especially when they largely develop on longitude.

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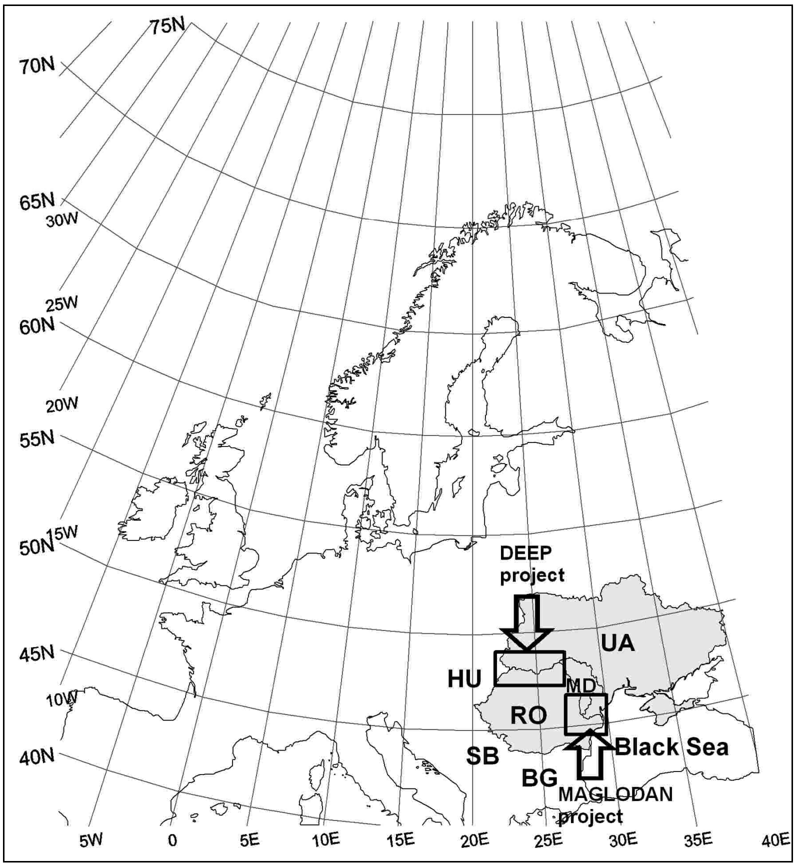

Fig. 1 – Location of the study area. Arrows show the location of the analyzed composite maps.

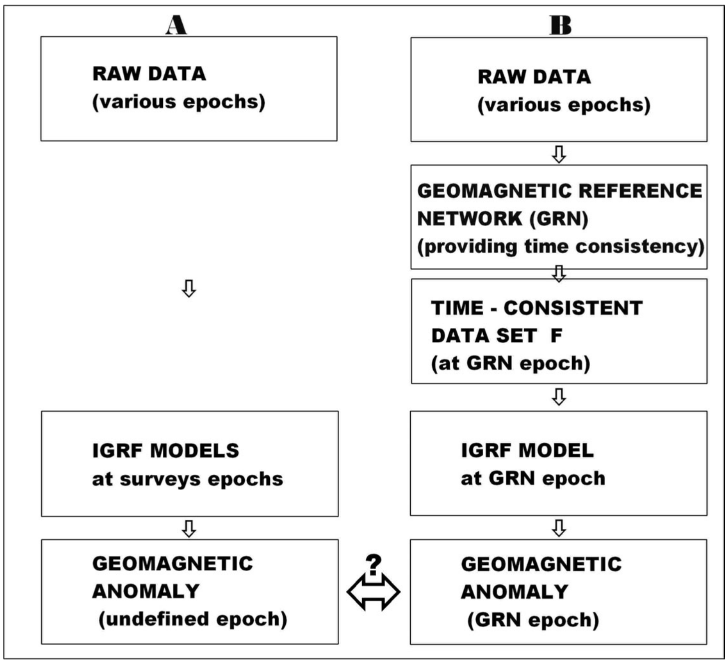

Fig. 2 – Cartoon showing basic principle for data analysis.

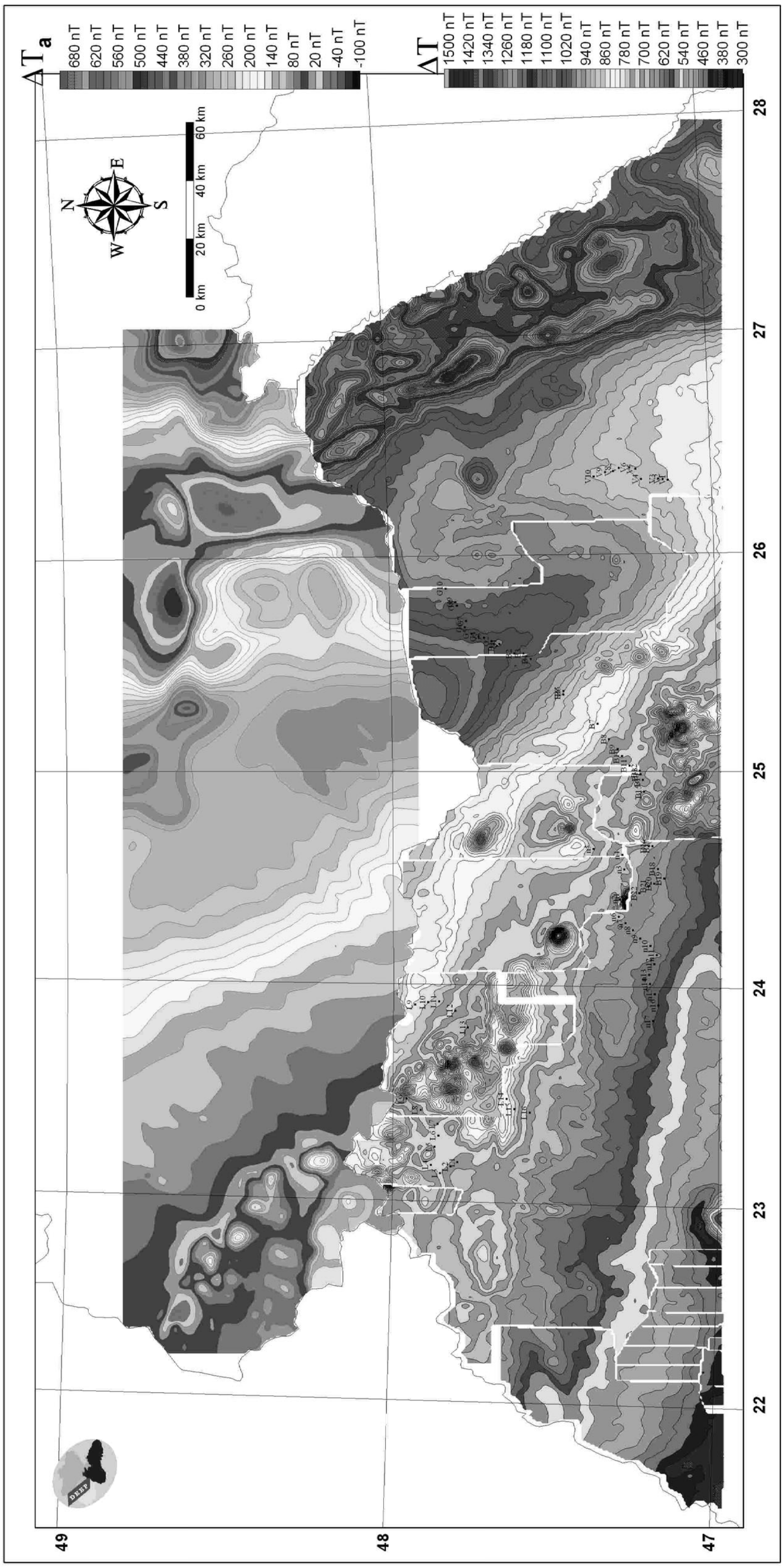

Fig. 3 – Raw geomagnetic information used in the construction of the geomagnetic composite maps for the DEEP project.

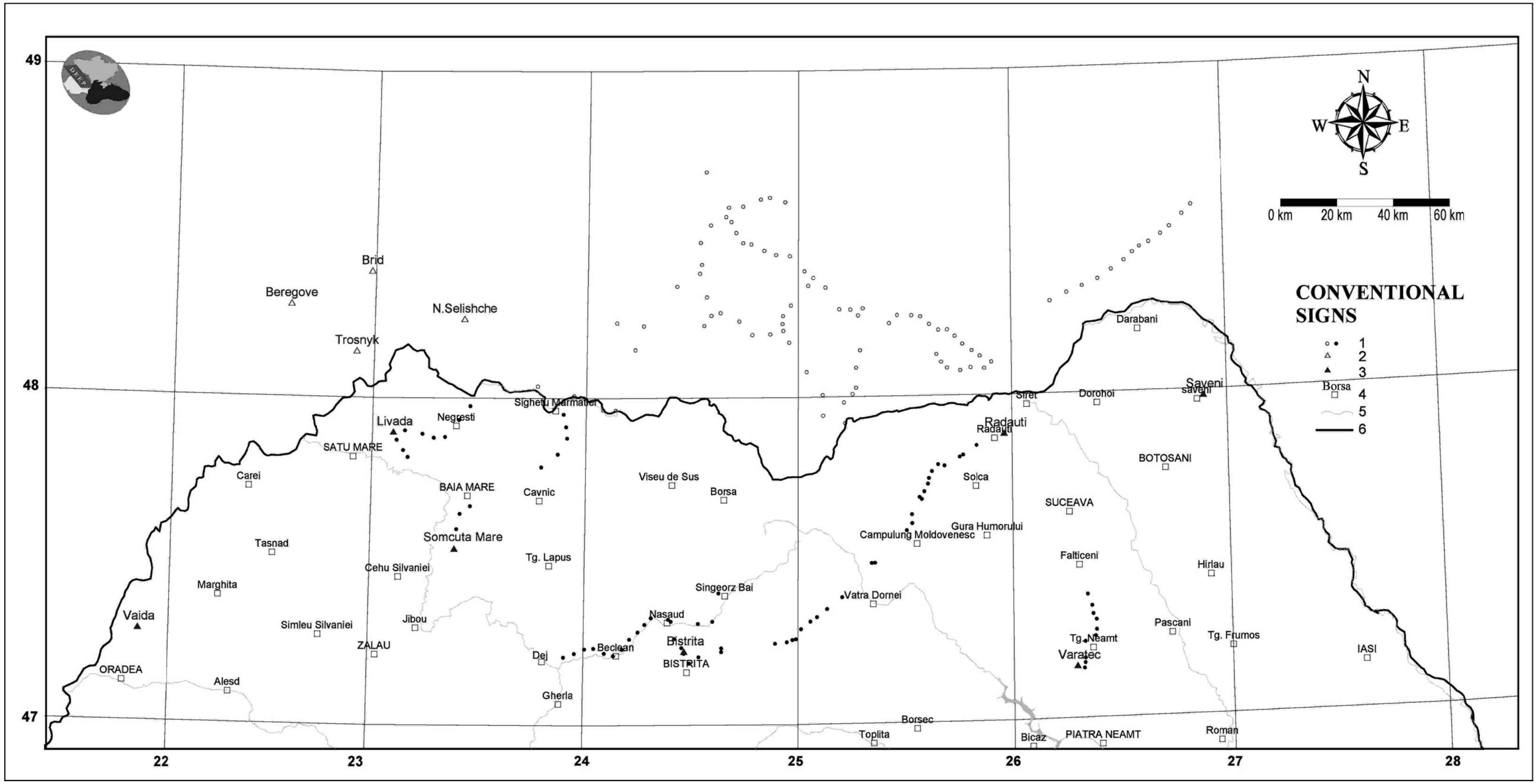

Fig. 4 – The geomagnetic reference network for the construction of the consistent geomagnetic model across the state-borders between Romania and Ukraine (modified after Beşuţiu *et al.*, 2006).
1, control points; **2**, Ukrainian SV base stations; **3**, Romanian SV base stations; **4**, settlements; **5**, rivers; **6**, state-border.

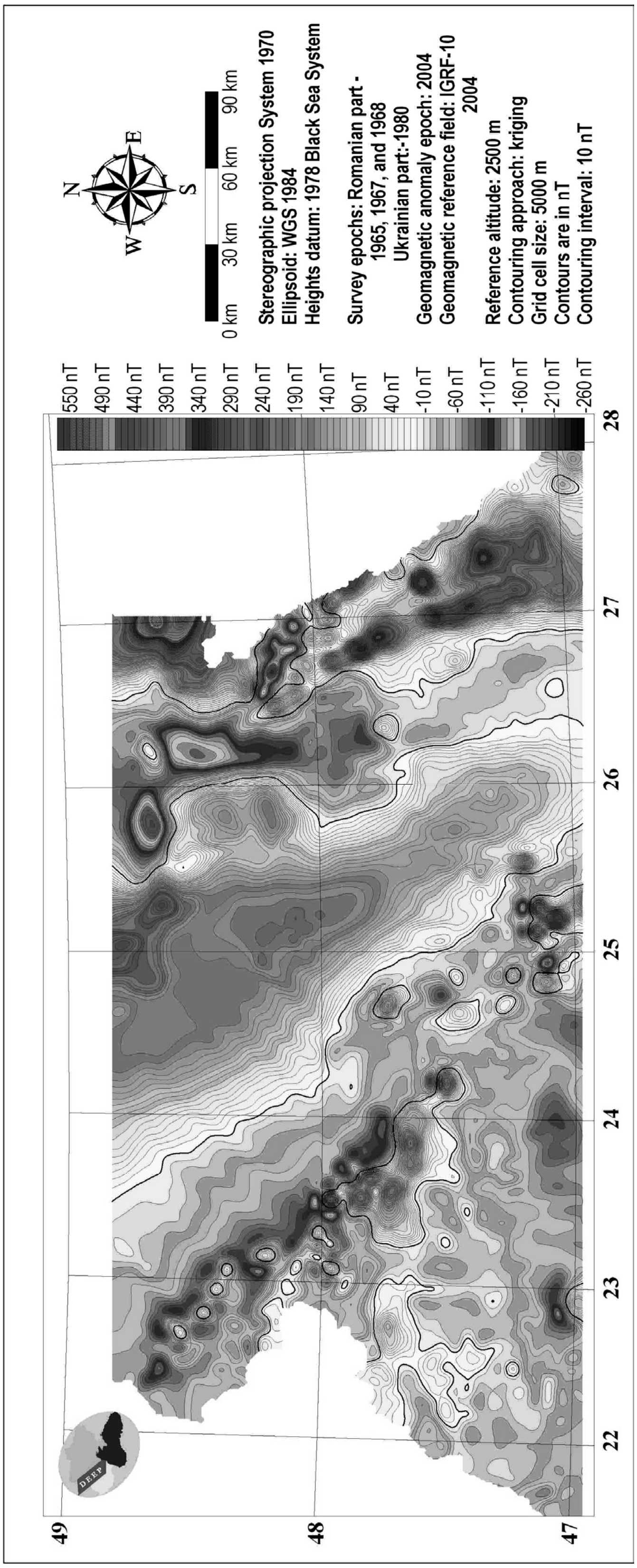

Fig. 5 – Total intensity scalar geomagnetic anomaly within the cross-border area between Romania and Ukraine – DEEP project (according to Beşuţiu *et al.*, 2006).

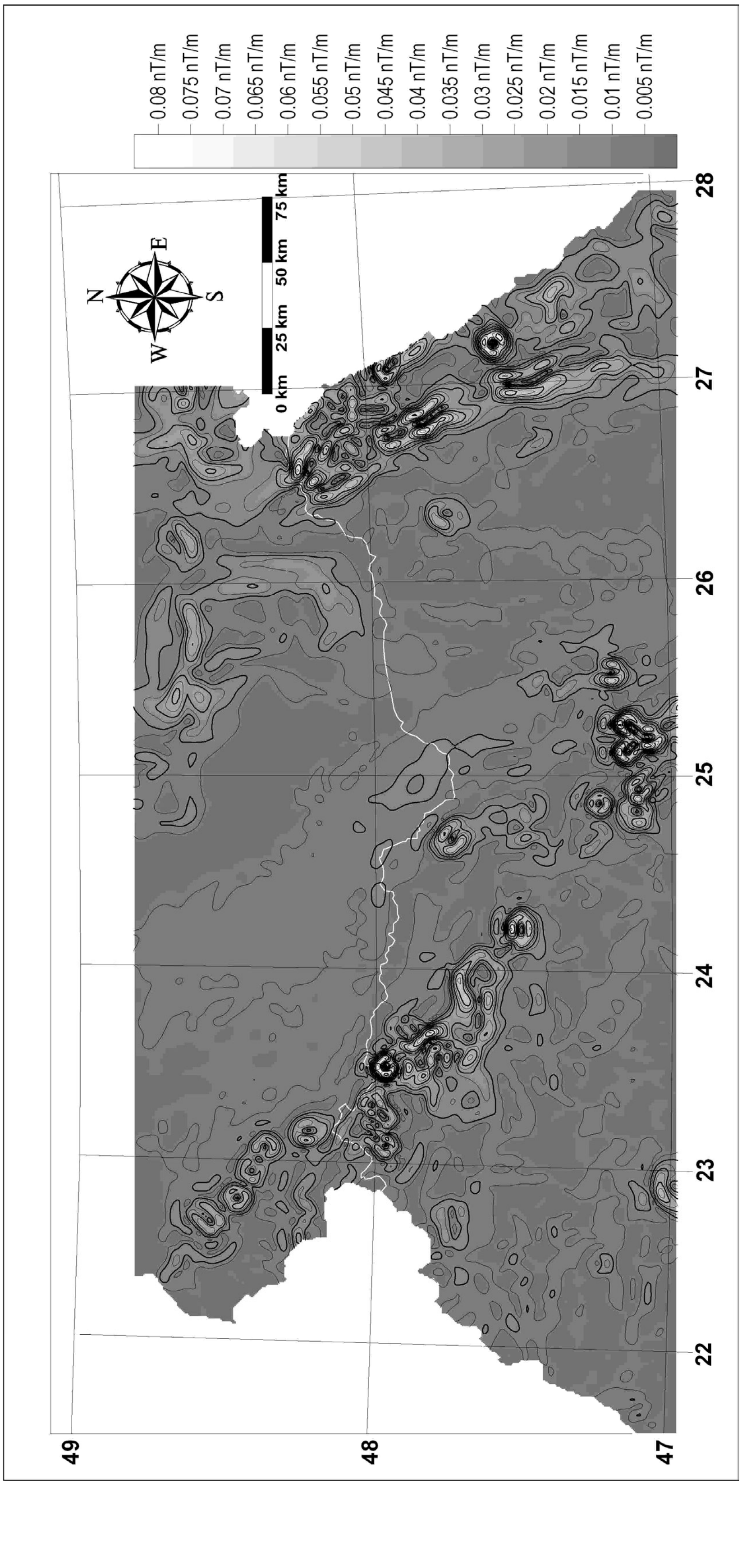

Fig. 6 – Total horizontal gradient of the residual geomagnetic anomaly.

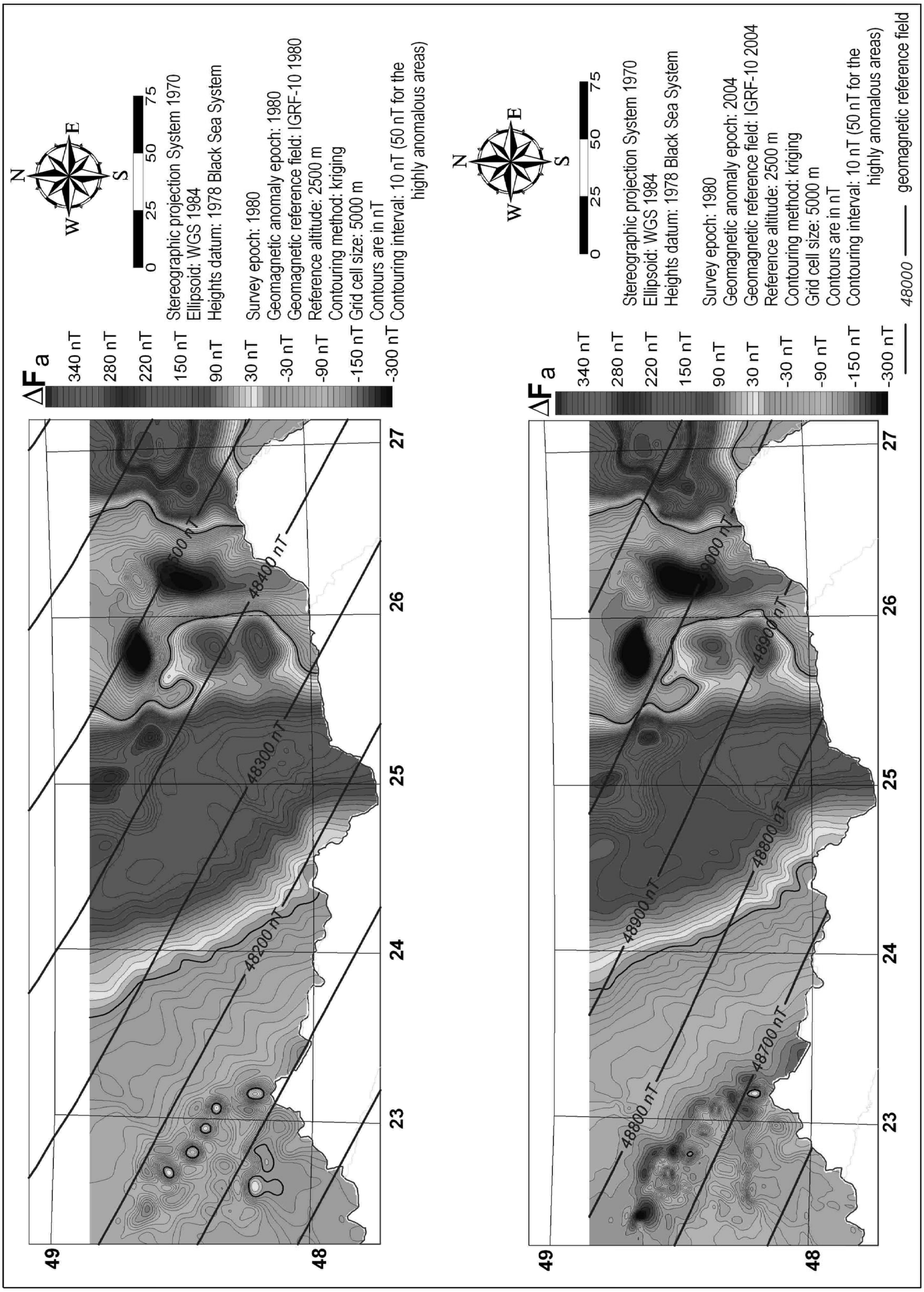

Fig. 7 – Total intensity scalar geomagnetic anomaly on the Ukrainian territory
(up – by subtracting the IGRF–10 for the epoch 1980; down – for IGRF–10 at the reference network epoch 2004).

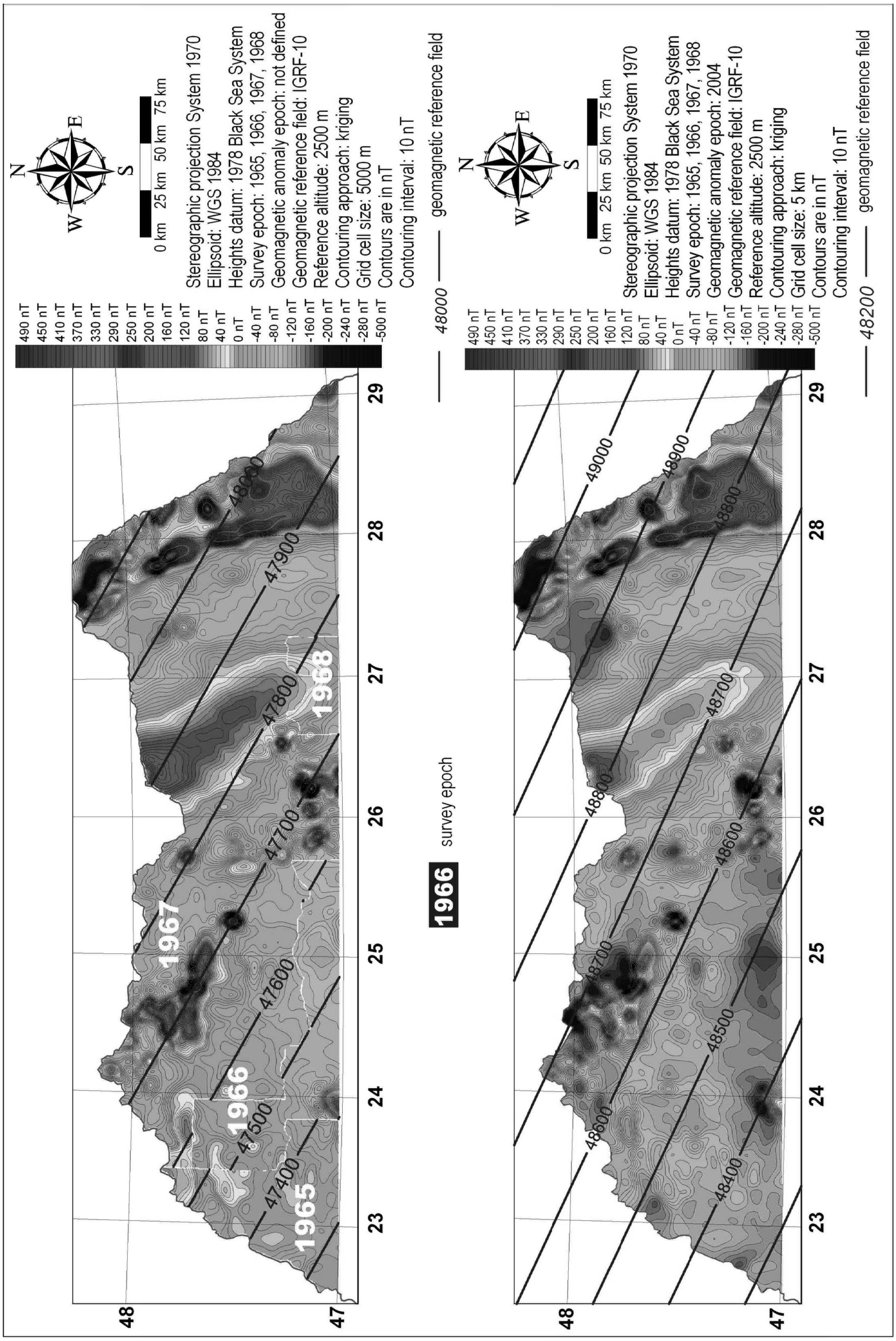

Fig. 8 – Geomagnetic anomaly models for the Romanian area as obtained for various epochs
(up – at the surveys epoch; down – at the epoch of the geomagnetic reference network).

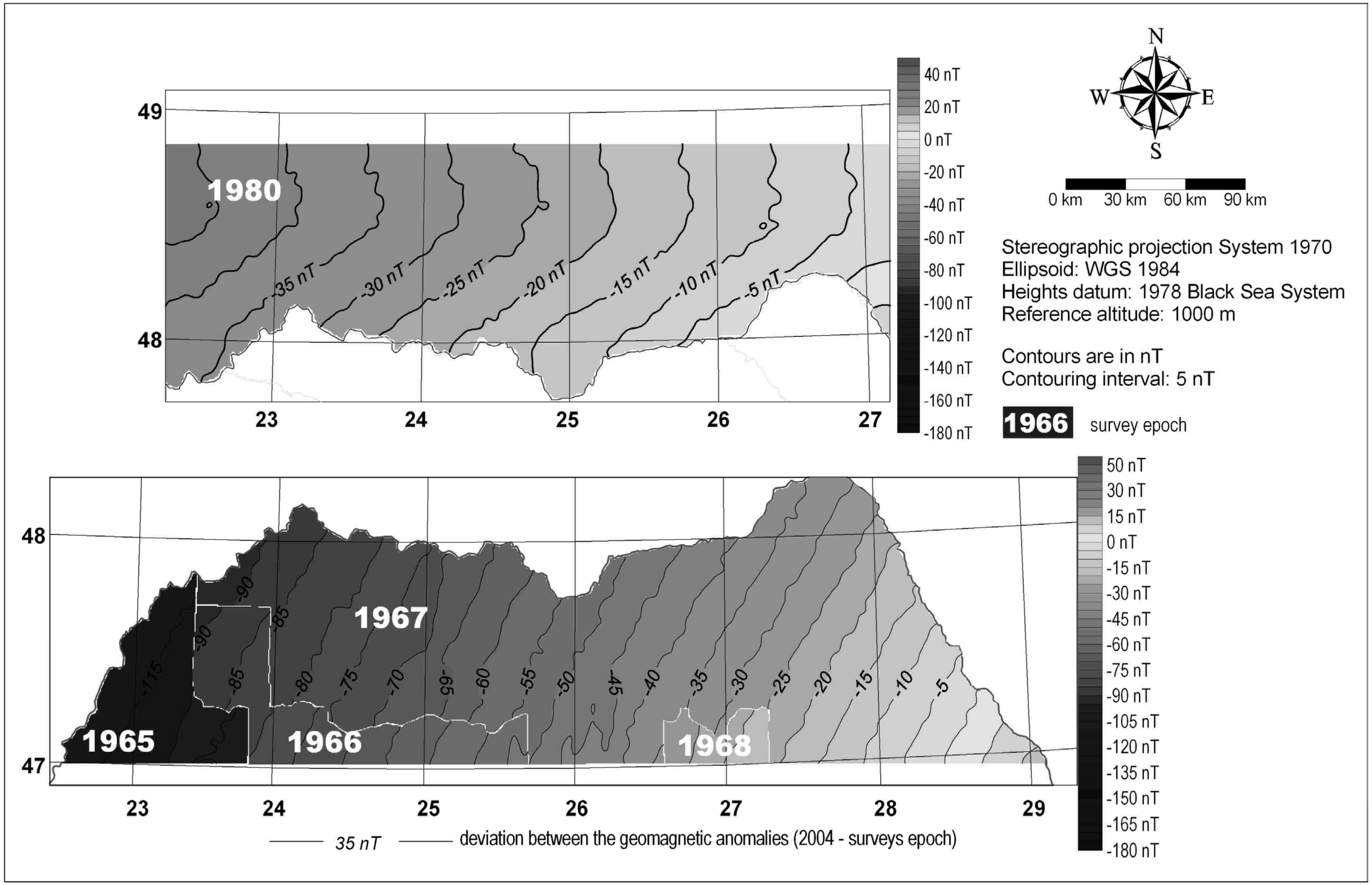

Fig. 9 – Deviation between the geomagnetic anomalies computed for the geomagnetic reference network epoch (2004) and anomalies computed at the surveys epoch (1965–1968 for the Romanian territory and 1980 for the Ukrainian area).

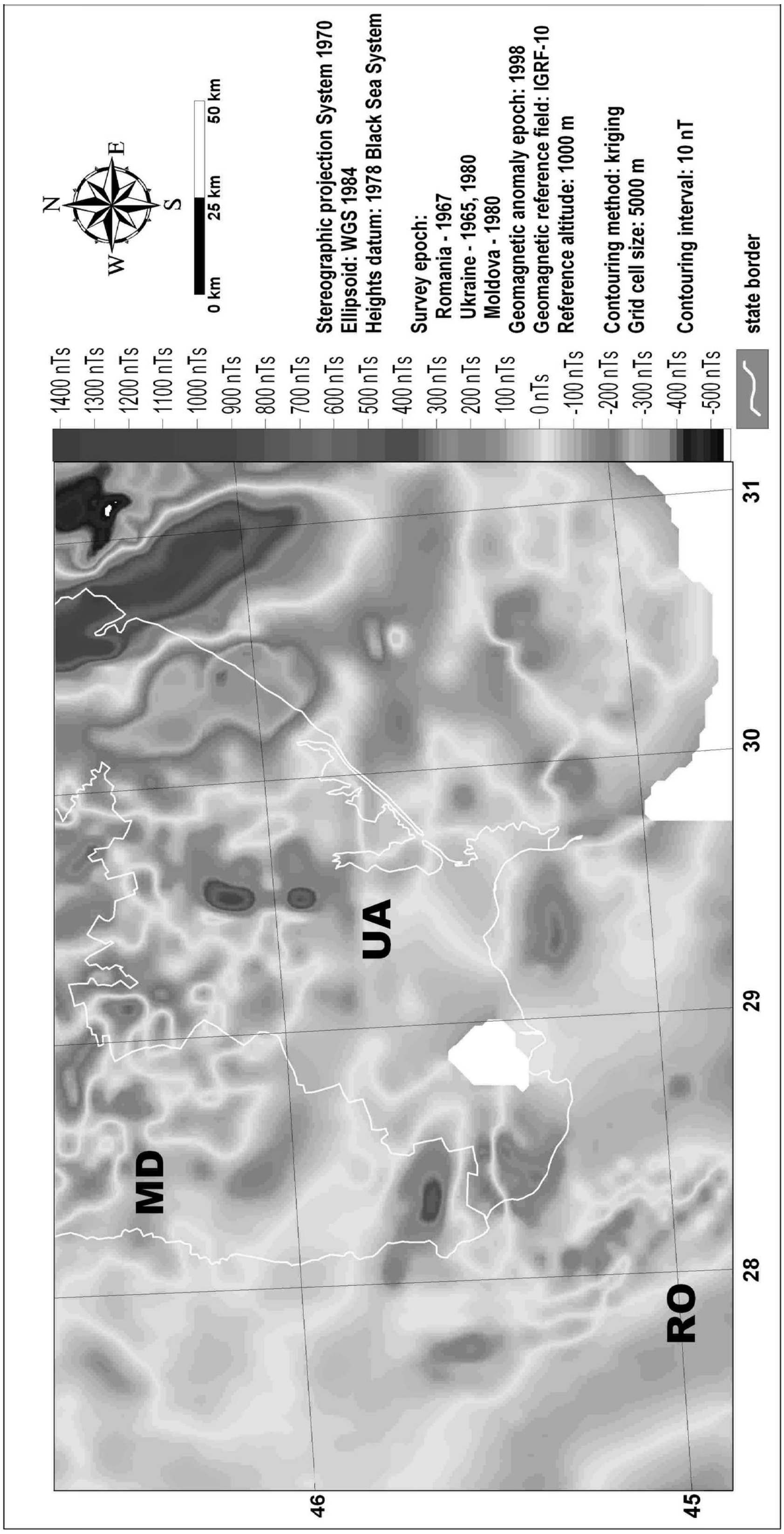

Fig. 10 – Total intensity scalar geomagnetic anomaly within the Lower Danube area (according to Beşuţiu *et al.*, 2000).

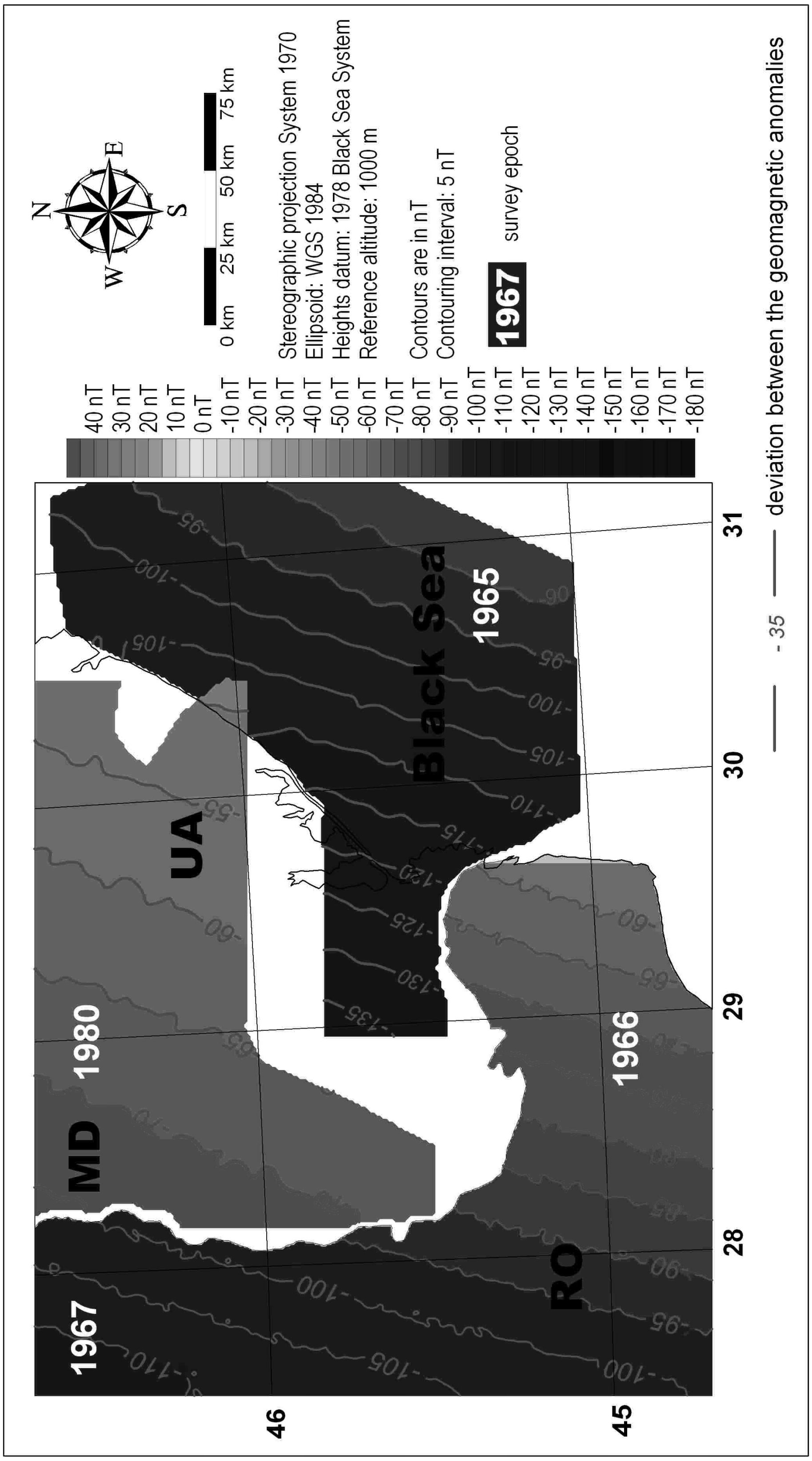

Fig. 11 – Deviation between the geomagnetic anomalies computed for the geomagnetic reference network epoch (1998) and anomalies computed at the surveys epoch (1965 for Black Sea area, 1966–1967 for the Romanian territory and 1980 for the Moldavian-Ukrainian area).

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