BOUGUER GRAVITY ANOMALIES ON THE TERRITORY OF ROMANIA

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ABSTRACT

The Bouguer gravity map of Romania has been completed, after more than three decades of gravity data selection and compilation, from measurements carried out at various scales, from reconnaissance networks to micro-gravimetric ones (Nicolescu & Rosca, 1993).

The WEEGP European project, dedicated to compile the first Bouguer gravity map of Europe, had its headquarters at the University of Leeds, UK. It fulfilled an old wish of European geophysicists, many years almost impossible, due to the confidentiality of gravity observations for military reasons.

For being able to participate in the WEEGP project with data from Romania, additional processing of the Bouguer gravity map had to be carried out, in order to meet the Romanian regulations requirements. A 5’ x 7.5’ dataset of mean Bouguer gravity anomalies,

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a solution that most European countries agreed at that time, has been produced and incorporated into the gravity map of Europe (Ioane & Ion, 1992).

The newly created 5’ x 7.5’ grid with values of mean Bouguer gravity anomalies favored later on the application of computer aided data processing techniques, such as filtering, horizontal gradient or gravity stripping.

The Bouguer gravity map of Romania, built on mean 5’ x 7.5’ values, is suitable for regional and crustal geological structures interpretation. The method employed to evaluate the mean gravity values filtered the small and local gravity anomalies, the resulted anomalies being mostly associated with large scale geological structures.

Transformed gravity maps for the Romanian territory will be presented in this paper (residuals, horizontal gradient, gravity stripped), followed by brief geological interpretations.

Keywords: Bouguer gravity map of Romania, WEEGP European project, 5’ x 7.5’ dataset of mean gravity anomalies, residual, horizontal gradient and gravity stripped maps

INTRODUCTION

In 1992 the Geological Institute of Romania decided to participate with gravity data in the compilation of the Bouguer gravity map of Europe, within the West East European Gravity Project (WEEGP). Gravity data from European countries have been gathered, compiled and plotted during 1992 - 1993 at the University of Leeds (UK).

Considering the Romanian regulations regarding the gravity data confidentiality, no point gravity value and its geographical coordinates were allowed to be published or utilized. Under such circumstances a dataset of 5’ x 7.5’ Bouguer mean gravity values for the Romanian territory has been prepared (Ioane & Ion, 1992) and included in the continental gravity map. Most European countries decided to contribute as well with mean gravity data in the WEEGP project.

After being utilized to build the Bouguer gravity map of Europe, the mean Bouguer gravity dataset for Romania has been included in the Bureau Gravimetrique International database (Toulouse, France), and has been employed in global or continental scientific projects, such as Earth Geopotential Model (EGM 96) or European Gravimetric Geoid (EGG 97).

The Bouguer gravity anomalies contoured on the 5' x 7.5' mean values, covering the territory of Romania, are suitable for interpreting large regional and crustal geological structures. Local gravity anomalies, determined by small and shallow geological bodies, have been already filtered by the employed averaging technique.

A brief geological interpretation of the Bouguer gravity anomalies map, the residual gravity and horizontal gradient ones, as well as those obtained after applying the gravity stripping technique, will be presented in this paper.

THE 5' X 7.5' BOUGUER MEAN GRAVITY VALUES DATASET

The Bouguer gravity map of Romania has been built for the 2.67 g/cm^3 density value, using gravity measurements carried out during 1961-1987, which covered the whole Romanian territory (Nicolescu & Rosca, 1993).

The mean Bouguer gravity anomalies have been obtained using an averaging technique similar to that usually performed when estimating mean elevations in the terrain reductions procedure. The final result was one mean gravity value for each 5' x 7.5' geodetic block, this value being derived from a variable number of irregularly located gravity point values.

The averaging technique was applied on the 1: 100000 Bouguer gravity map sheets and produced 2770 gravity mean values on the corresponding 5' x 7.5' geodetic blocks.

The highest Bouguer gravity mean value is +30.0 mGal (Central Dobrogea), while the lowest gravity mean value is -136.5 mGal (Getic Depression).

Considering the 1 mGal interval of the contoured Bouguer gravity map of Romania (Nicolescu & Rosca, 1993), the evaluation accuracy of the 5' x 7.5' mean gravity values could not be better than 0.5 mGal (Ioane & Atanasiu, 1998).

To check the quality of the obtained mean gravity values dataset, two other averaging procedures have been applied:

- the arithmetic mean of 25 values, taken on a 1' x 1.5' grid on the contoured Bouguer gravity map;

- the arithmetic mean of all gravity point values in each 5' x 7.5' geodetic block.

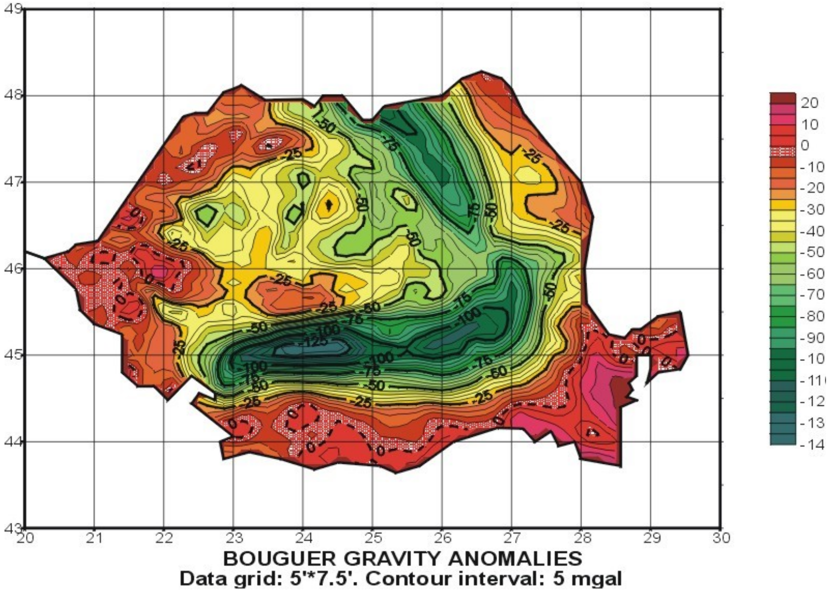

Figure 1 – Bouguer gravity map of Romania built on 5' x 7.5' mean data (Ioane & Ion, 1992; Ioane & Atanasiu, 1998)

When comparing the results, the averaging technique employed to produce the mean Bouguer gravity dataset showed a good quality, 70% of the differences between the mean gravity values evaluating procedures ranging between 0 and 0.5 mGal (Ioane & Atanasiu, 1998).

The Bouguer gravity map of Romania built on the mean gravity values data set was originally contoured at the University of Leeds using 1 mGal interval between isolines (Ioane & Ion, 1992).

For data processing utilized in scientific publications, the Bouguer mean gravity data for the Romanian territory have been contoured using 5 mGal interval between the map isolines (Figure 1).

The 5' x 7.5' Bouguer mean gravity values dataset has been used as input in other projects developed in Romania, such as the computation of a gravimetric geoid (Ioane et al., 1996), or the isostatic maps of Romania (Rosca, 1998).

APPLIED DATA PROCESSING TECHNIQUES

The mean 5' x 7.5' Bouguer gravity values, presented as a gridded dataset which covers the whole Romanian territory, favored the application of computer based data processing techniques. During the '90 several basic data processing methods have been applied using the mean gravity dataset as input, the running averages and the total horizontal gradient being most popular among the Romanian gravity geophysicists at that time (e.g. Ioane, 1999; Ioane & Atanasiu, 2000).

The gravity stripping data processing technique have been also employed, based on the 5' x 7.5' gravity and topographic mean values, using a 3D approach for modelling the gravity effect of geological structures necessary to be removed, in view of interpreting deeper geological ones (e.g. Ioane et al., 2005; Ioane & Ion, 2005).

By applying data processing techniques on the Bouguer gravity map of Romania built of the 5' x 7.5' mean values data set, new transformed gravity maps have been obtained, more suitable for geological interpretation of large and deep geological structures.

By applying a “traditional” filtering procedure of Romanian geophysicists, called “running averages” on the Bouguer gravity map, two new gravity maps have been computed for the territory of Romania:

- Filtered gravity map, showing the regional trend of Bouguer anomalies, determined by the largest and deepest geological structures;

- Residual gravity map, illustrating detrended effects of Bouguer anomalies associated with particular geological structures, such as uplifted basement, deep sedimentary basins or important magmatic intrusions.

The distance between the 9 gravity values (L), included in the computation for each 5’ x 7.5’ point with mean values by the “running averages” array, has been differently established using a number of trials for the two filtered gravity maps:

- L = 40 km for the Filtered gravity map;

- L = 80 km for the Residual gravity map.

The computation of the total horizontal gradient of the Bouguer gravity anomalies for the Romanian territory has been done using the formula presented in Constantinescu et al. (1964), previously applied with good results in Romania (e.g. Proca et al., 1993; Ioane, 1999).

Elongated anomalies with high values of total gradient of Bouguer gravity are usually interpreted as revealing the location and direction of geological tectonic contacts or regional faults, due to important density contrasts, and hence, rapid horizontal variation of gravity (Ioane, 1999).

The idea of “deep gravity interpretation by stripping” has been presented by S. Hammer during the early ’60 as a possibility of improving the interpretation of Bouguer gravity maps in oil fields, when looking for deeper-seated structural traps.

The Gravity stripping data processing procedure includes the modelling of the "shallow" geological structures and the computation of their gravity effect using characteristic density values. When removing the gravity effect of the modelled overlying geological structures from the original Bouguer gravity map, a new map is obtained, theoretically including effects of geological structures situated beneath the stripping depth level.

The newly obtained stripped gravity map may be interpreted as representing effects of depth variations between the basement and sedimentary cover (e.g. Ioane et al., 2005), or even large geological structures, causing deep density inhomogeneities, situated beneath the Earth crust (e.g. Ioane & Ion, 2005).

Modelling of gravity anomalies geological sources is a very important tool in gravity data processing and interpretation, either as 2D (i.e. Sperner et al., 2004) or 3D (i.e. Hackney et al., 2002), but this technique will be not discussed in this paper.

GEOLOGICAL INTERPRETATION OF REGIONAL BOUGUER GRAVITY ANOMALIES IN ROMANIA

Bouguer gravity map of Romania

The Bouguer gravity map for the Romanian territory, illustrated in Figure 1, cumulates the effects of density contrasting geological structures, situated either in close neighborhood, or overlapped at different depth levels. When analyzing the Bouguer gravity map of Romania, the most striking anomalies are those elongated low intensity anomalies, colored in green, associated to the East Carpathians (NNW-SSE) and South Carpathians (W-E). The significant decrease in Bouguer gravity values is determined at regional and crustal scales by three important density contrasts:

a) between the thickened crust beneath the Carpathian mountains and the neighboring upper mantle higher density geological units (areas with thinner crust, such as the platforms);

b) between the high density crystalline basement and low density sedimentary cover, the latter being thicker within the Carpathians;

c) due to deep sedimentary depressions situated along the Carpathians, either regionally elongated (TESZ: the Trans-European Suture Zone, i.e. Ioane et al., 2019), or locally developed (Focsani and Getic depressions).

Gravity anomalies associated to shallower geological structures, situated within platforms or depressions, are to be observed in the Bouguer gravity map, but they are better illustrated by the residual gravity anomalies map (Figure 3).

Filtered Bouguer gravity anomalies

The filtered Bouguer gravity anomalies map (Figure 2) illustrates in a simpler and clearer manner effects of large and deep geological structures in Romania. The blue colored areas situated toward the Romanian territory boundaries are interpreted, at regional and crustal scales, as determined by the thinner crust characteristic for the Moesian Platform (S) and Pannonian Depression (NW), and by the high density East European Platform and North Dobrogea Orogen (NE and E). The elongated low gravity anomalies (colored in red) and crossing the entire territory have been already discussed when interpreting the Bouguer gravity map (Figure 1). The intensity of these low anomalies, strongly preserved in the Filtered gravity map, illustrates the trans-crustal development of the geological structures responsible of deep regional gravity effects.

Additional comments, regarding features better depicted in the filtered gravity map, may refer to the following:

- the circular low gravity anomaly in the area of Apuseni Mts (NW), colored in red, may suggest the presence of a small mountainous root, considering classic isostatic models. Largely developed low density magmatic structures (such as granitic intrusions), may also determine here low gravity anomalous effects at this scale;

- the N-S elongated ellipsoidal high gravity anomaly situated in the Transylvanian Depression, colored in blue, is considered to be associated with uplifted crystalline basement (already pierced by deep boreholes – Ciupagea et al., 1970), a thin upper crust and uplifted lower crust, as interpreted on refraction seismic data (Radulescu, 1988);

- the interruption and eastward displacement of the elongated low gravity anomalies associated with the Carpathians, a feature not to be observed in the geological map of Romania, scale 1: 1000000, may be interpreted as being determined by the eastward push of the Tisia tectonic block in connection with the Miocene lateral escape of Apulia (Ioane & Stanciu, 2021), as a geodynamic consequence of African and Eurasian plates collision.

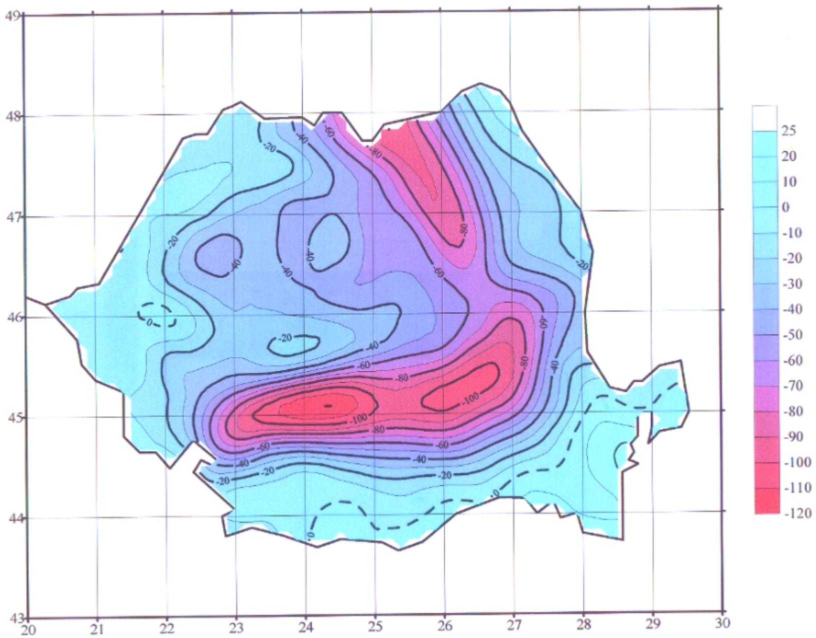

Figure 2 – Filtered Bouguer gravity anomalies for the Romanian territory (Ioane & Atanasiu, 2000)

Residual Bouguer gravity anomalies

The residual Bouguer gravity anomalies have been detrended by filtering, the regional and deep crustal/lithospheric density inhomogeneities gravity effects being removed. The residual gravity anomalies, as depicted in Figure 3, may represent the best source of information for geological structures located at the depths of crystalline basement/sedimentary cover boundary, or for locating large magmatic structures in density contrast with the surrounding geology.

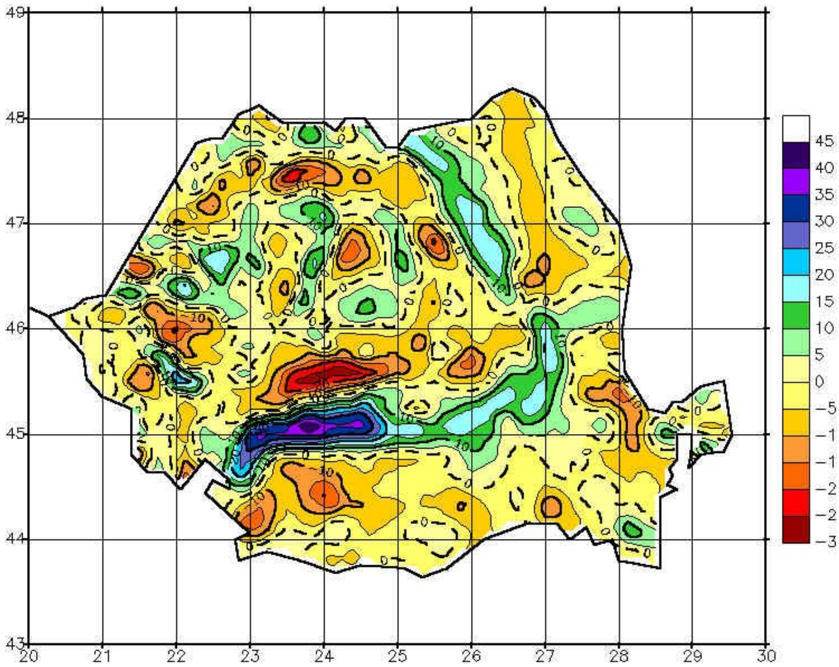

Figure 3 – Residual Bouguer gravity anomalies for the Romanian territory. Orange and Red colors: High gravity anomalies; Green and Purple colors: Low gravity anomalies (Ioane & Atanasiu, 2000)

The main geological structures that may be analyzed and interpreted on the residual gravity anomalies map are considered to be the following:

- the elongated low gravity anomaly along the East Carpathians, interpreted as mainly due to the TESZ deep basin filled with Mesozoic sedimentary deposits (Hauser et al., 2007; Ioane et al., 2019);

- the low gravity anomalies at the East Carpathians Bend, interpreted as being determined by both the TESZ continuation and past subduction zones (Ioane & Stanciu, 2021);

- the most intense residual anomalies, located at the western part of South Carpathians, are formed by two highs (red color) and one low gravity anomalies (purple color). The geological structures seem to be remnants of a strong compressional regime directed NW-SE, having as results the Getic Nappe, with overthrusting crystalline structures in the Sebes Mts, uplifted crystalline basement in the western part of the Moesian Platform, and a very deep basin filled with sedimentary deposits between them. This elongated low gravity anomaly, which represents the lowest of Bouguer gravity values in Romania, seems to be much more complicated than the geological interpretation stated above, the high compressional tectonics probably determining an in-depth displacement of the whole lithosphere with the accumulation of a thick pile of sediments. To that particular tectonic evolution we should add the presence of the Getic Depression, filled with low density sedimentary deposits, and large granitic intrusive structures, also characterized by lower density than the crystalline basement;

- the triangular high gravity anomaly, contoured in the central part of the Transylvanian Depression, is associated with uplifted crystalline basement and uplifted lower crust, as also interpreted on the filtered Bouguer gravity map;

- the low gravity anomalies located around the gravity high interpreted above are due to thick sedimentary deposits in depressionary areas, such as the Sighisoara Depression. Diapiric salt bodies at the Transylvanian Depression boundaries with the

Carpathians and the Apuseni Mts. contribute locally to these intense regional low gravity anomalies;

- the NW-SE elongated high gravity anomalies in the Moesian Platform may be interpreted as uplifted shoulders of rifted geological structures, largely developed southward, in the Bulgarian part of the Moesian Platform;

- the low gravity anomaly, located in the NE part of Romania, is determined by a large body of lower density granitic gneisses within the East European Platform crystalline basement.

Total horizontal gradient of Bouguer gravity anomalies

Of special interest for regional tectonics in Romania are the map computed for the total horizontal gradient of Bouguer gravity anomalies (Ioane & Atanasiu, 2000).

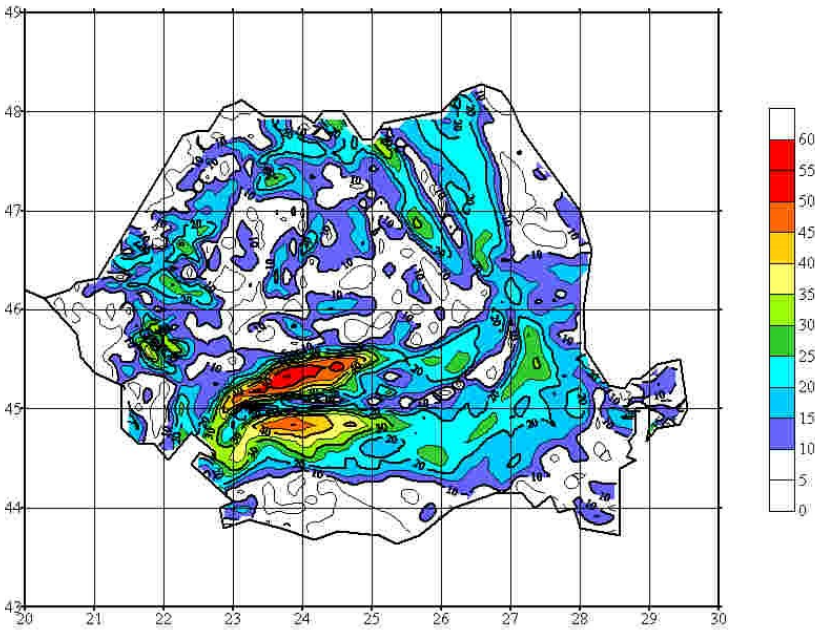

Figure 4 – Total horizontal gradient of Bouguer gravity anomalies for the Romanian territory (Ioane & Atanasiu, 2000)

The elongated high anomalies of horizontal gradient of Bouguer gravity may usually locate contacts between two geological structures having an important density contrast. Such tectonic contacts are usually provided by faults of various lengths and depths, when displacing the crystalline basement/sedimentary cover upward or downward and determining this way a rapid variation of gravity all along the newly created density contrast.

The map of total horizontal gradient of Bouguer gravity anomalies in Romania, presented in Figure 4, displays as colored features only anomalies higher than a selected threshold value, aiming at mostly emphasizing elongated gradient anomalies revealing information on regional tectonics.

The most important horizontal gradient anomalies are associated with the Carpathians:

- two elongated horizontal gradient anomalies are situated on both sides of the East Carpathians until the Trotus river zone, where the deep Carpathian structures illustrate a discontinuity and an eastward displacement. The NNW-SSE anomaly situated outer of the East Carpathians is determined by the fault system which is rapidly downlifting the East European Platform crystalline basement westward, beneath the East Carpathians sedimentary nappes. The NW-SE anomaly, situated inner of East Carpathians, represents the gravity effect of the Campulung regional fault, in fact a tectonic contact between the overthrusted metamorphic structures and the sedimentary nappes;

- after the East Carpathians discontinuity, the regional horizontal gradient anomalies resume at ca 46 North latitude, indicating that the East Carpathians Bend Zone is not tectonically rounded, as suggested by geographical or geological maps, but controlled by two NE-SW directed fault systems;

- the western part of the South Carpathians is characterized by W-E horizontal gradient lineaments, their high intensity suggesting that the tectonic contacts/fault system which determines these anomalies are very steep and very deep, creating this way a strong density contrast. Toward the Danube, these two important tectonic lineaments change abruptly direction, from W-E to NNE-SSW, accommodating the local tectonics to the South Carpathians bend zone when crossing the Danube in Serbia.

Total horizontal gradient of residual Bouguer gravity anomalies

This data processing technique is a concept introduced in the scientific literature by the author of this study, and has never been encountered in this form in any scientific paper or geophysical textbook during the last five decades. The procedure is based on the analysis of regional residual gravity maps, where rapid horizontal variation of gravity is still observed in some areas. Since the residual of a Bouguer gravity map contains gravity effects of shallower geological structures than the filtered one, it is likely that the horizontal gradient of the residual gravity map will illustrate better the effects of shallower tectonic contacts or fault systems than the horizontal gradient maps computed on the Bouguer gravity data can reveal.

The map presented in Figure 5 illustrates several lineaments of horizontal gradient anomalies computed using this technique, some of them overlapping those already described and interpreted in Figure 4. This situation suggests that the tectonic contacts or faults overlapped in both maps have an important upward development, such as the high intensity anomalies located in western South Carpathians.

The main differences when comparing the two maps of horizontal gradient (Figures 4 and 5), are the following:

- the horizontal gradient lineaments associated to the East Carpathians, where, besides the NNW-SSE lineament overlapping the Campulung Fault, a parallel lineament developed outer of East Carpathians seems to represent the tectonic eastern limit of the sedimentary nappes with the East European Platform, such as the Casin-Bisoca Fault;

- the two NE-SW horizontal gradient of Bouguer gravity anomalies, depicted as tectonic boundaries of the East Carpathians Bend Zone, also known as the Vrancea seismic zone (Figure 4), are absent in the horizontal gradient of residual gravity anomalies map (Figure 5), suggesting that those tectonic features are deeper within the lithosphere and do not develop at shallow depths.

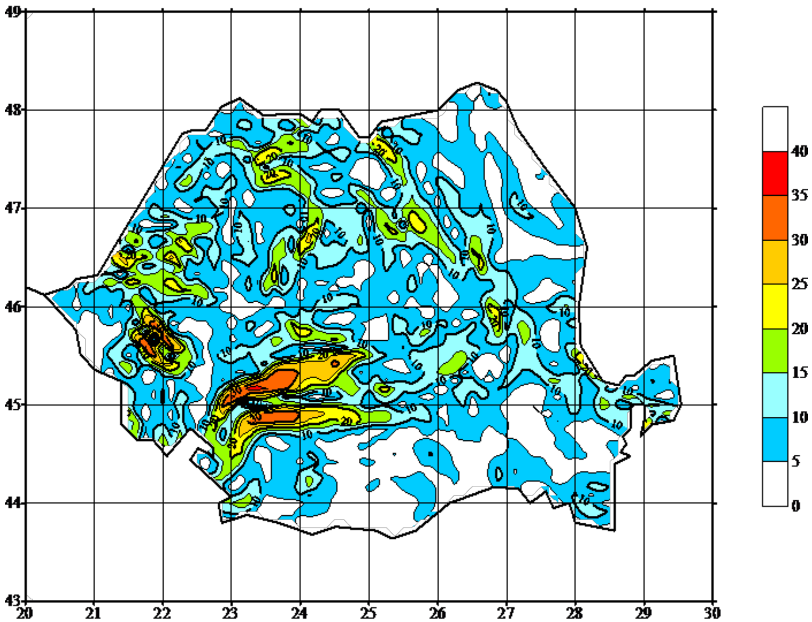

Figure 5 - Total horizontal gradient of the residual Bouguer gravity anomalies for the Romanian territory

The Bouguer stripped map of Romania

The Bouguer gravity stripping data processing technique has been applied in Romania either for oil exploration (Ioane et al., 2005), or for getting information on the subcrustal geological structures (Ioane & Ion, 2005).

In the scientific study dedicated to the computation of the gravity stripped map of Romania (Ioane & Ion, 2005), a difficult challenge was the modeling of the entire crust, situated between its lower boundary, the Mohorovicic discontinuity, and the uppermost geological forming the territory topography, and then to ascribe to each significant layer mean density values:

- 2.27 g/cm3 for Quaternary and Neogene sedimentary deposits;
- 2.57 g/cm3 for pre-Neogene sedimentary deposits;
- 2.77 g/cm3 for upper crustal layer;
- 2.97 g/cm3 for lower crustal layer;
- 3.27 g/cm3 for the upper mantle.

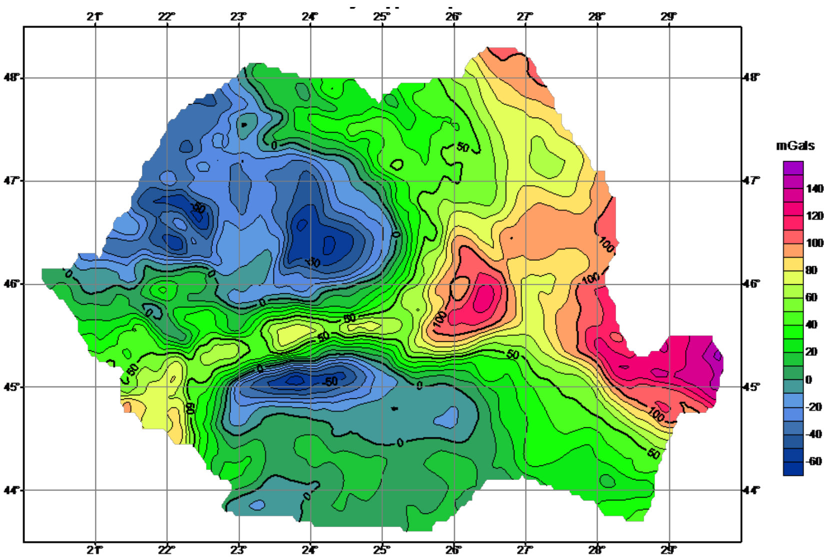

Figure 6 - Gravity stripped map of Romania (Ioane & Ion, 2005)

All such information represented the input in the modeling software developed by Prof. Marian Ivan, University of Bucharest, the computation result being a map representing the gravity effect of the Romanian territory crust. After removing the crustal gravity effect in Romania from the Bouguer gravity map the stripped gravity map of Romania has been obtained (Figure 6). When comparing the Bouguer gravity map (Figure 1) with the stripped gravity map of Romania (Figure 6) there are obvious differences between them, after eliminating the crustal gravity effects and illustrating mainly the lithospheric ones.

The main information obtained when interpreting the stripped gravity map is the diagonal separation crossing Romania from NW to SE, between higher and lower gravity values. Considering also the interpretation of seismic tomography data for depths between 50 and 100 km (e.g. Piromallo & Morelli, 1997), the diagonal limit may be interpreted as the western boundary of the East European Platform beneath the East Carpathians. The mentioned diagonal limit is crossing also the Moesian Platform, a situation difficult to interpret when considering the traditional arrangement of geological units in Romania. After two successive steps in understanding deep tectonics and relationships between the East European Platform and the Moesian Platform (Ioane & Caragea, 2015; Ioane & Stanciu, 2021), a new tectonic model has been developed and published. In this new interpretation, the eastern part of the Moesian Platform, situated east of the Intramoesian Fault, is part of the East European Platform, displaced south-westward along the southern transcurrent fault, component of a Wrench Tectonics System (Ioane & Stanciu, 2018; Ioane & Stanciu, 2021).

The high gravity anomaly contoured in the stripped gravity map at the East Carpathians Bend (red triangle) is interpreted to be mostly determined by the bended frontal part of the East European Platform after post-subduction collision with the Tisia tectonic block. The idea of interpreting this high gravity anomaly as an effect of the postulated Vrancea lithospheric slab was initially very tempting (Ioane & Ion, 2005), but the interpretation of recent seismic tomography sections (van der Meer et al., 2018) stated that the slab is situated much deeper, beneath the bended EEP western limit (Ioane & Stanciu, 2021), and hence its gravity effect is considerably weak.

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