A 3D crustal gravity modelling of the Romanian territory

D. Ioane*, D. Ion**

* University of Bucharest, Faculty of Geology and Geophysics, 6 Traian Vuia St.
020956 Bucharest, Romania
** Signal Estimation Technology, Calgary, Canada
Corresponding author: ioane@gg.unibuc.ro

Abstract: *The completion of the Bouguer gravity map for the Romanian territory, as well as the calculation of the mean gravity dataset in a 5' x 7.5' grid, enabled a 3D modelling approach for the crustal structure. The geophysical model has been built using information derived from published crustal models based on refraction seismic and borehole data, each layer getting a mean density value describing the main density contrasts. The discrepancies observed between the crustal model gravity effect and the Bouguer gravity map may lead to improvements in the geophysical model in both geometry and petrophysical features. The 3D stripped gravity map that was derived from the above mentioned gravity maps may be interpreted in terms of subcrustal density inhomogeneities, mainly related to the Trans-European Suture Zone and the Vrancea seismogenic area.*

Key words: *3D gravity modelling, Crustal model, 3D gravity stripping, Romania*

Introduction

The project of a crustal 3D gravity modelling in Romania may be dated back in the late '50, as for the first time Bouguer gravity anomalies have been contoured at the scale of the whole territory. Such a scientific attempt became possible during the early '90, when the gravity map covering also the mountainous areas in Romania has been completed (Nicolescu and Rosca, 1992).

Besides a homogeneous and good quality gravity dataset, structural and density information in a regional sense and at a crustal scale are required for a regional 3D modelling. Such data are available nowadays due to important geological and tectonical information presented at the territory scale (Dumitrescu and Sandulescu, 1962; Dumitrescu and Sandulescu, 1970; Sandulescu et al., 1978; Polonic, 1998, Sandulescu and Visarion, 2000). Geophysical works, such as gravity interpretations (Socolescu et al., 1964) or regional refraction seismic experiments (Radulescu, 1988; Hauser et al., 2001; Hauser et al., 2006) and petrophysical studies, have been performed during the last decades.

Important steps in studying the crustal structure using geophysical data in the region where Romania is located are due for the last decade to M. Bielik, T. Grabowska, S. Shanov, T.P. Yegorova and P. Szafian.

The gravity data

A gravity dataset with mean values in the 5' x 7.5' grid, based on the Bouguer gravity map of Romania (Nicolescu and Rosca, 1992), was determined and incorporated in the gravity map of Europe (Ioane, 1993). This homogeneous distribution of gravity mean values on the territory opened new possibilities for easy handling of the data for studies including processing and modelling at a regional scale.

The Bouguer gravity map of the Romanian territory based on the 5' x 7.5' mean gravity values is represented in Figure 1. Since this grid includes one gravity value for an area of ca 10 km^2, the resulted map is suitable for deep structures analysis and interpretation, local and weak gravity anomalies being already removed by this procedure.

The total gravity interval represented in this map exceeds 150 mGal. The lowest gravity anomaly is located in the south-western part of Romania, overlapping the Getic Depression, while the highest gravity anomaly is located in its south-eastern part, overlapping Central Dobrogea. Such large gravity variations, displayed in several areas on quite short distances, suggest the presence of significant density inhomogeneities at crustal and lithospheric depths.

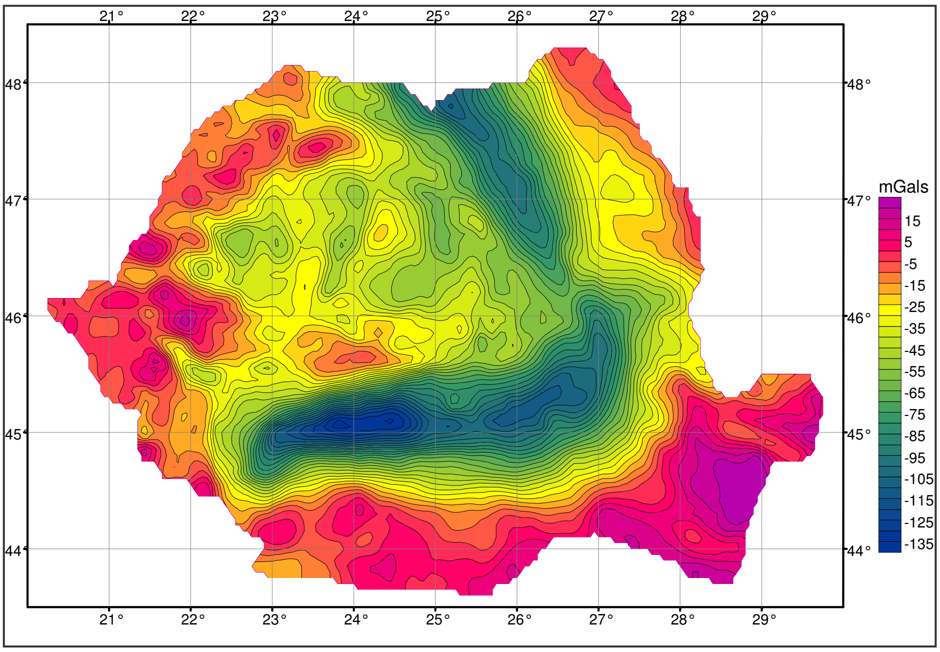

FIG. 1 – Bouguer gravity anomalies (Romania)

Structural data at crustal scale

The first information related to the crustal structure of the Romanian territory was derived from regional gravity data, of great importance being the map of the Mohorovicic discontinuity (Socolescu et al., 1964). The calculated depths of the base of the crust are ranging between 28 and 42 km, greater depths being associated with the mountainous areas. Since this information is based on gravity it was not considered in this 3D gravity modelling for obvious reasons.

The refraction seismic experiments performed during the late ’60 and the ’70 led to a crustal model of the Romanian territory, well constrained on the seismic lines and completed with gravity isostatic anomalies on large areas (Radulescu, 1988). This crustal model, which includes maps at Mohorovicic and Conrad depths, was utilized so far in numerous regional tectonic and geodynamic models.

The map at Moho depths (Figure 2) shows a large depth interval where the base of the crust is located in Romania, describing highest crustal thickness at the East Carpathians bending zone (exceeding 50 km) and lowest crustal thickness on the eastern end of the Pannonian Depression (less than 30 km). Thin crust was also described in the Transylvanian Depression and the Moesian Platform, while thicker crust seems to be developed beneath the North Dobrogean Orogen and the eastern end of the East European Platform.

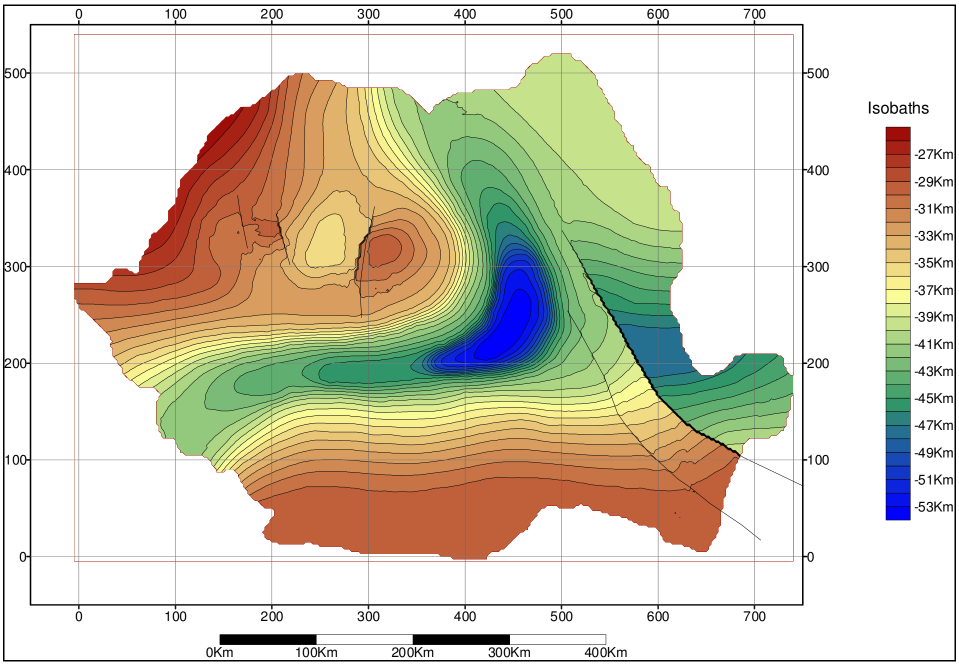

FIG. 2 – Map at the Moho discontinuity (Romania)

The map at Conrad level (Figure 3) displays large depth variations of the discontinuity between the upper and lower crustal layers, being situated between 30 km beneath the Eastern Carpathians bending zone, and 10 km beneath the central part of the Transylvanian Depression.

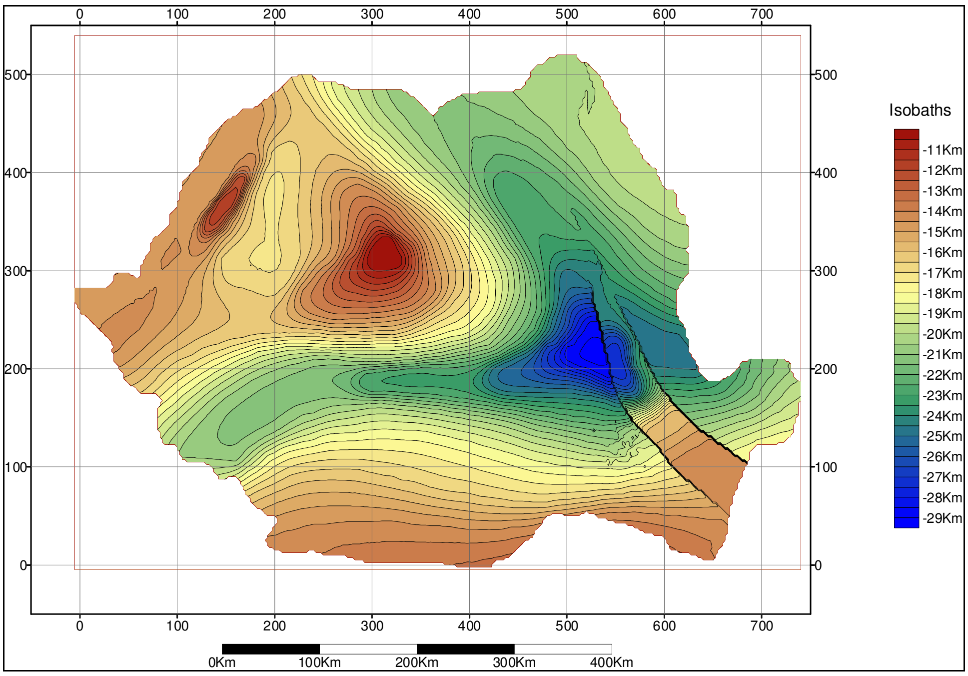

FIG. 3 – Map at the Conrad discontinuity (Romania)

The map at the boundary between the basement and the sedimentary cover, presented in Figure 4, is a result of a compilation of seismic and borehole data (Polonic, 1998). There are displayed important variations of this limit in both depths (reaching 18 km within the Focsani Depression) and altitudes (more than 2,000 m in the Southern Carpathians). Major areas with deeply buried basement are developed outer of the Eastern and Southern Carpathians, with depths greater than 10 km.

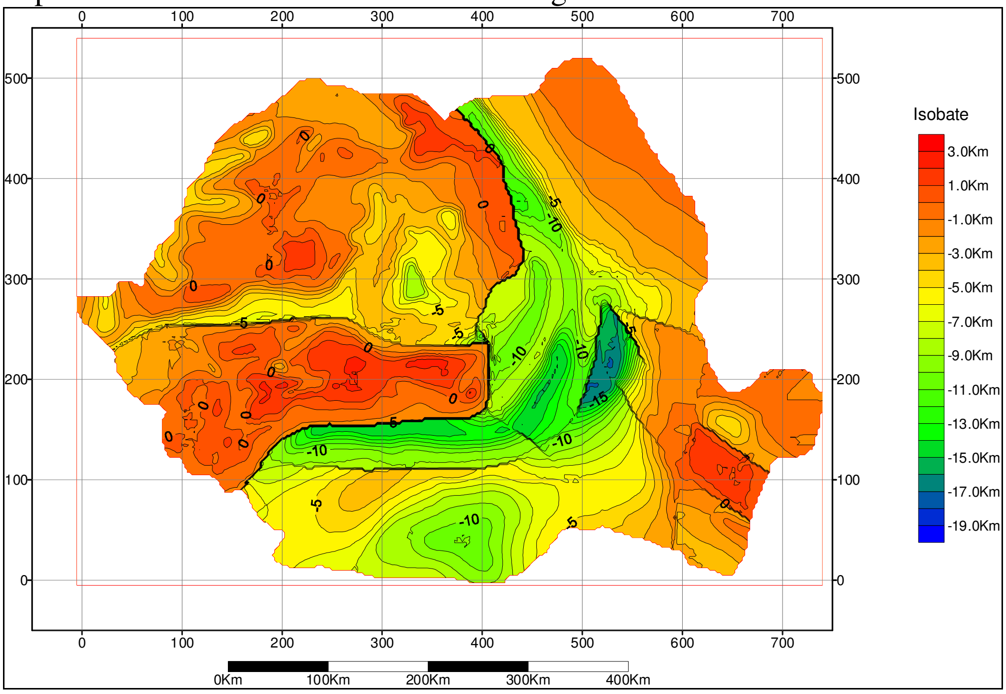

FIG. 4 – Map at the top of the crystalline basement (Romania)

Due to the significant density contrast between the Neogene and pre-Neogene sedimentary deposits, a map of the thickness of Neogene low density geological formations have been prepared (Figure 5), using available data from tectonic maps at the scale of the Romanian territory (Dumitrescu and Sandulescu, 1962; Dumitrescu and Sandulescu, 1970). Greatest thicknesses of Neogene deposits are found outer of the Carpathians, within the Carpathians foredeep, in the Transylvanian Depression and at the eastern end of the Pannonian Depression.

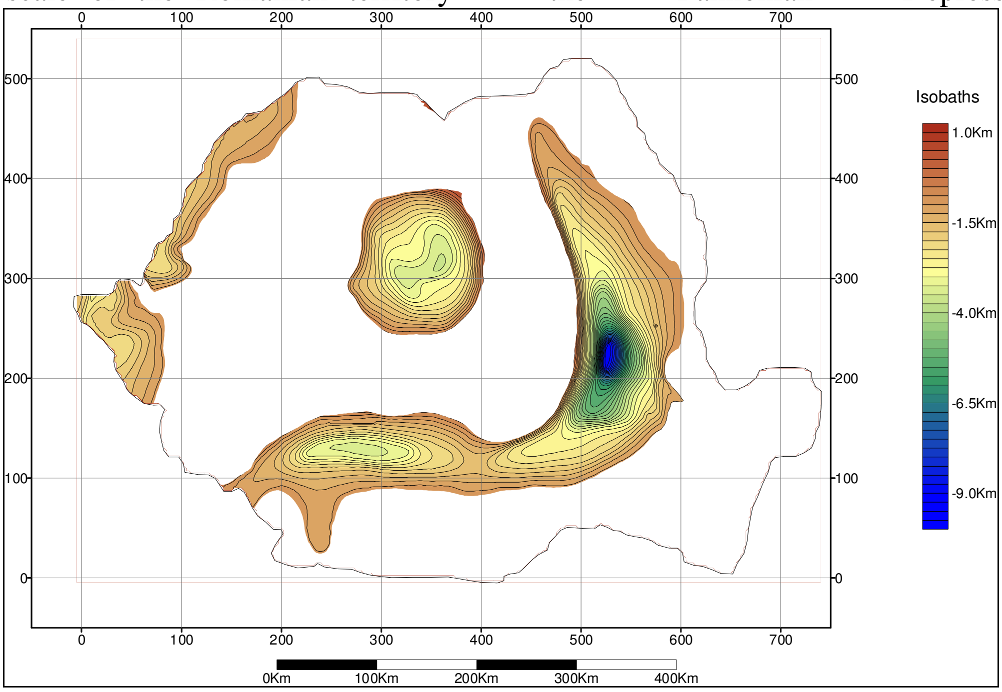

FIG. 5 – Map at the top of pre-Neogene sedimentary cover (Romania)

The uppermost surface that was included in this structural model is the topography (Figure 6), the main features of the topographic relief in Romania being described using the 5’ x 7.5’ mean altitudes dataset (NRB, 1979).

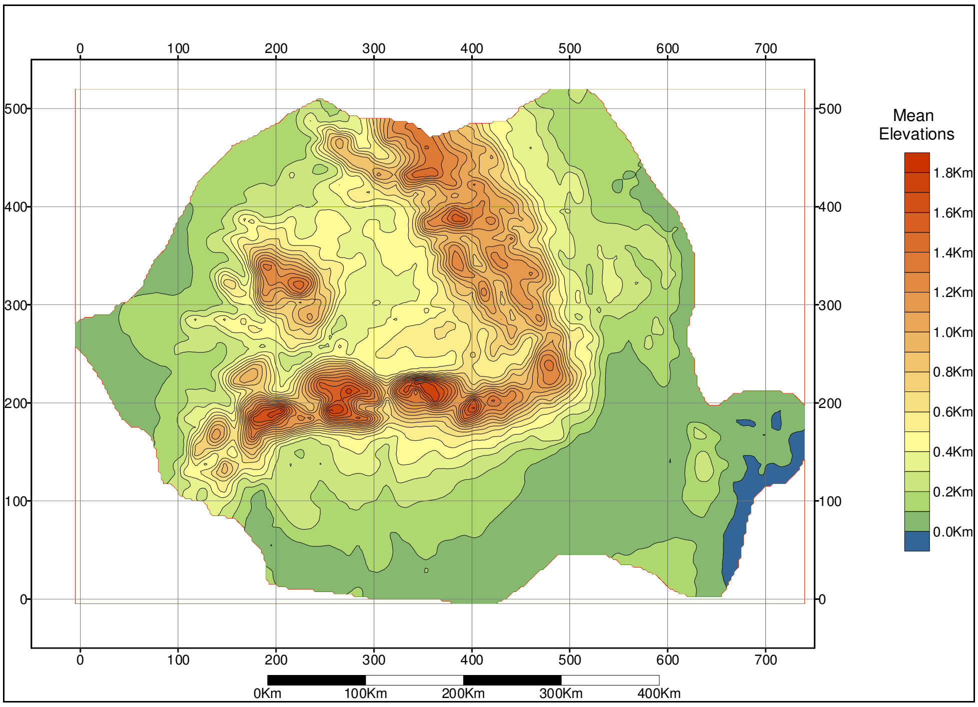

FIG. 6 – Map of mean altitudes (Romania)

The geophysical model and its 3D gravity effect

For this first attempt of 3D modelling the crustal gravity effect of the Romanian territory the structural maps described above have been used as limits between crustal compartments with significant density contrasts.

Therefore, the crustal geophysical model consists of the following density boundaries:

- map of topographic relief;
- map at the top of pre-Neogene geological formations;
- map at the top of crystalline basement;
- map of the top of lower crustal layer;
- map at the base of the Earth’s crust.

The mean density values attributed to these crustal layers are the following:

- 2.27 g/cm^3 for Quaternary and Neogene sedimentary deposits;
- 2.57 g/cm^3 for the pre-Neogene sedimentary deposits;
- 2.77 g/cm^3 for the upper crustal layer;
- 2.97 g/cm^3 for the lower crustal layer;
- 3.27 g/cm^3 for the upper mantle.

The gravity effect of this 3D crustal model for the Romanian territory has been computed using a software developed by Marian Ivan, University of Bucharest, Romania. The result of the 3D gravity modelling is presented in Figure 7 as a gravity map displaying important regional gravity variations of ca 200 mGal.

The comparison of the original Bouguer gravity map (Figure 1) with that calculated for the crustal model (Figure 7) shows both discrepancies and similarities:

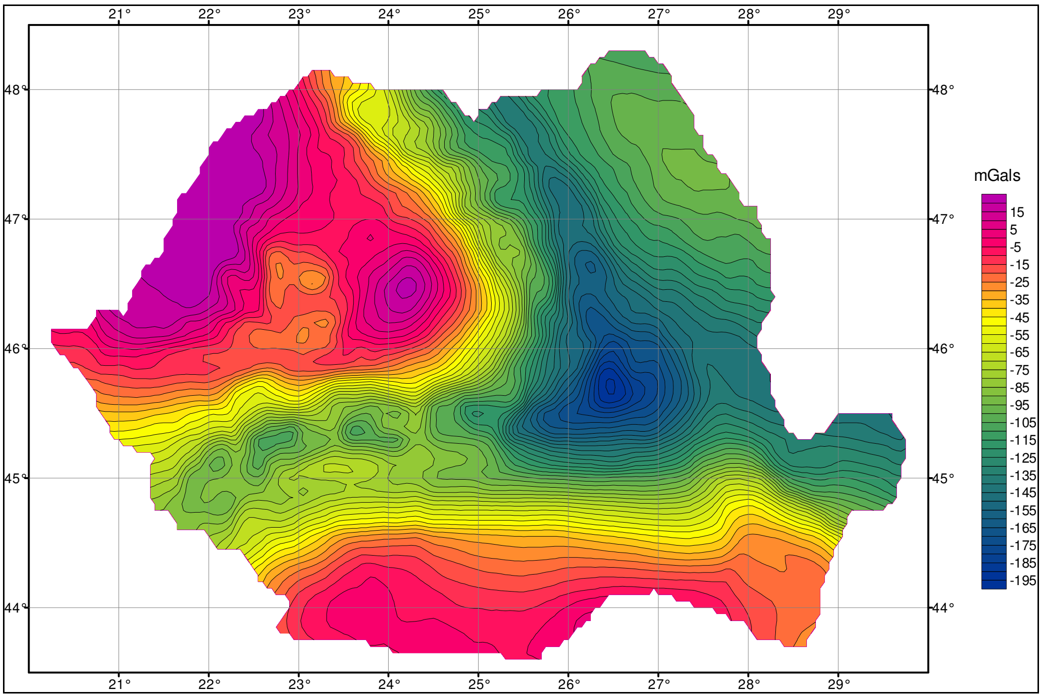

FIG. 7 – Gravity effect of the crustal model (Romania)

- besides crustal effects, the Bouguer gravity map includes also gravity effects from density inhomogeneities situated beneath the Mohorovicic discontinuity;
- the crustal layers that we considered for the geophysical model do not include lateral density variations within the layer, such density contrasts being determined in this case only by their depth variations;
- the mean density values that we used to define major density contrasts may be not sufficiently representative for large volumes of rocks, such as in deep sedimentary basins, in the upper or lower crustal layers;
- the total gravity variations, that are close to 150 mGal in the Bouguer gravity map and close to 200 mGal in the gravity effect of the 3D model. As main causes are considered to be the differences between real crustal structures and the geophysical model, as well as cumulative effects with subcrustal inverse density contrasts in the Bouguer gravity map.

- the gravity regimes for the East European Platform (north-eastern part of the territory), Moesian Platform (southern part of Romania) and Pannonian Depression (north-western part of the territory) are in good agreement in both gravity maps;
- the gravity low anomalies developed along the Carpathians and in the region of the Predobrogean Depression look also similar. As an exception is the Vrancea zone, where the geophysical model determines a very intense gravity low anomaly. This may be due to imperfections of the utilized structural maps at crustal depths, but also to the absence of the gravity high, that is

expected to be associated at lithospheric depths with a high density subducted slab;
- the gravity low anomalies in the area of the Apuseni Mountains show similar features in both gravity maps.

3D gravity stripping of the Romanian territory

Considering the processing and interpretation technique described in the early '60 (Hammer, 1963) and subsequent works that employed this procedure in regional and crustal interpretations (Blizkovsky and Novotny, 1981; Bielik, 1988; Ioane et al., 2005), we calculated the stripped gravity map for the Romanian territory in a 3D approach. The gravity effect of the crustal geophysical model (Figure 7) was substracted from the Bouguer gravity map (Figure 1), the result presented as 3D stripped map being determined mainly by deep mass distributions, theoretically situated beneath the Mohorovicic discontinuity (Figure 8). Obviously, the newly derived gravity map includes also gravity effects of crustal structures that were not accurately described in our geophysical model, both in geometry or mean density values.

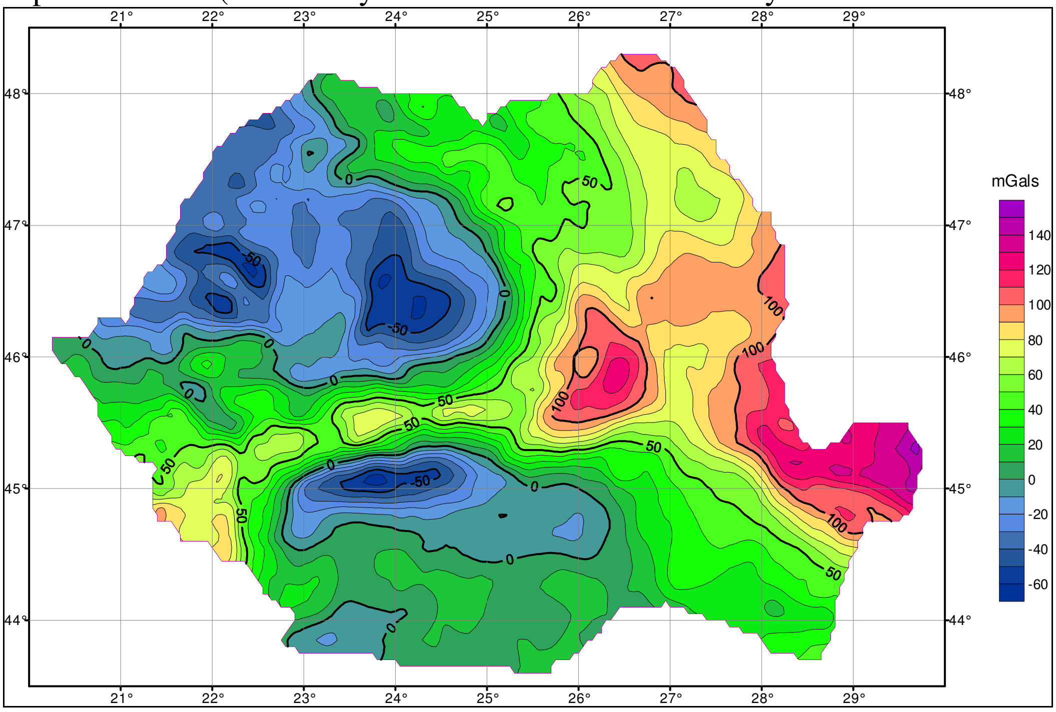

FIG. 8 - Gravity stripped map (Romania)

The most important aspect revealed by this gravity map is the regional separation at lithospheric depths on a NW-SE trending line, that resembles with seismic tomography and gravimetric geoid data (Wortel and Spakman, 2000; Ioane and Pharaoh, 2000), and interpreted as the Trans-European Suture Zone (Pharaoh, 1999).

The gravity highs along the Southern Carpathians may have at least two interpretations:

a) the lack of a crustal root, as was recently suggested by refraction seismic data (Hauser et al., 2006);
b) the trace of an old oceanic suture, with remnants of obducted high density oceanic lithosphere, that would continue beneath the Southern

Carpathians the oceanic suture evidenced by geological mapping in the south-western part of Romania, and towards the south and south-east, in Serbia and Bulgaria (Haydoutov and Yanev, 1997)

The high gravity anomaly located in the Vrancea zone may also have two interpretations:

a) the lack of a crustal root, as was described by the crustal model we used (Radulescu, 1988);
b) the effect of the high density slab subducted beneath the Vrancea zone.

Since an unclear problem for the tectonic models in the Vrancea seismogenic area is whether the subducted slab belongs either to the East European Platform or the Moesian Platform, the gravity stripped map suggests that in Vrancea, at subcrustal depths, the East European Platform was involved in subduction and collision processes. This interpretation supports tectonic and geodynamic models that describe a subduction developed in space and time along the Carpathians and ended in the Vrancea zone.

Conclusions

Using published structural data at crustal levels, which are mainly based on refraction seismic studies and boreholes, a geophysical model has been built at the scale of the Romanian territory in view of a 3D gravity modelling.

The gravity effect of the geophysical model shows either similarities or discrepancies with the Bouguer gravity map, due both to errors in the model geometry and mean density values attributed to the described crustal layers, but also to supplementary subcrustal effects contained in the Bouguer map. The evidenced discrepancies may lead to a better use of isostatic models in the Romanian Carpathians and to an understanding of the quite large differences between results of older refraction seismic experiments (Radulescu, 1988) and more recent ones (Hauser et al., 2006).

The 3D stripped gravity map may represent a useful geophysical information for deep, subcrustal density structures interpretation, such as:

- the NW-SE trending of the Trans-European Suture Zone, interpreted at lithospheric depths;
- the possible continuation beneath the Southern Carpathians of an old oceanic suture;
- the gravity high effect of the Vrancea subducted slab and its affiliation to the East European Platform.

Acknowledgements: The authors are grateful to Marian Ivan for the possibility of using the 3D gravity modelling software for this scientific work.

References

Atanasiu, L., Rosca V., Rogobete, M., 1996, A three-dimensional modelling of the East Carpathian Bend: 1st Congress of Balkan Geophysical Society, Abstr. Book, Athens, 266-267.

Bielik, M., 1988, A preliminary stripped gravity map of the Pannonian Basin: Physics of the Earth and Planetary Interiors, **51**, 185-189.

Bielik, M., 1988, Analysis of the stripped gravity map of the Pannonian Basin: Geologica Carpathica, **39**, 1, 99-108.

Bielik, M., 1991, Density modelling of the Earth's crust in the Intra-

Carpathian basins. Academic Conferences, Vol. LXII, 4, 123-132, Belgrade.

Bielik, M., Sitarova, A., Plasienka, D., Putis, M., 1992, Three-dimensional quantitative interpretation of gravity anomalies in the south-west part of the Male Karpaty Mts (western Carpathians): Geologica Carpathica, **42**, 3, 139-146.

Bielik, M., 1998, Analysis of the gravity field in the western and eastern Carpathian junction area: density modelling: Geologica Carpathica, **49**, 2, 75-83.

Blizkovsky, M., Novotny, A., 1981, Construction of stripped gravity map of the Bohemian Massif. Geophysical sintheses in Czechoslovakia, VEDA Publishing House, 135-149.

Dumitrescu, I., Sandulescu, M., 1962, Harta tectonica a Republicii Populare Romine, scara 1: 1.000.000, Anuarul Comitetului Geologic, XXXII.

Dumitrecu, I., Sandulescu, M., 1970, Romania – Harta tectonica, scara 1: 1.000.000, Atlas Geologic, Foaia nr. 6, Institutul Geologic.

Grabowska, T., Bojdys, G., Dolnicki, J., 1998, Three-dimensional density model of the Earth's crust and the upper mantle for the area of Poland. J. Geodynamics, Vol. 25, No. 1, pp. 5-24.

Hammer, S., 1963, Deep gravity interpretation by stripping. Geophysics, Vol. XXVIII, No. 3, pp. 369-378.

Hackney, R.I., Martin, M., Ismail-Zadeh, A.T., Sperner, B., Ioane, D., 2002, The gravity effect of the subduscted slab beneath the Vrancea region, Romania, In: Michalik, J., Simon, L., Vozar, J. (Eds.), XVII Congress of the Carpathian-Balkan Geological Association, Geologica Carpathica, Bratislava, 119-121.

Hauser, F., Raileanu, V., Fielitz, W., Bala, A., Prodehl, C., Polonic, G., Schulze, A., 2001, VRANCEA'99 – the crustal structure beneath the southeastern Carpathians and the Moesian Platform from a seismic refraction profile in Romania. Tectonophysics, 340, 233-256.

Hauser, F., Raileanu, V., Fielitz, W., Dinu, C., Landes, M., Bala, A., Prodehl, C., Seismic crustal structure between the Transylvanian Basin and the Black Sea, Romania. Tectonophysics, in press.

Haydoutov, I., Yanev, S., 1997, The Protomoesian microcontinent of the Balkan Peninsula-a peri-Gonwanaland piece. Tectonophysics, 272, 303-313.

Ioane, D., 1993, Recent developments in geoid determination in Romania. Proc. "GPS in Central Europe", Penc, Hungary.

Ioane, D., Radu, I., 1995, Global geopotential models and gravity data for the territory of Romania, In: Sunkel, H., Marson, I. (Eds.), Gravity and Geoid. Joiont IGC/ICG Symposium Graz, 1994, IAG Symposium No. 113, Springer, Heidelberg, 640-646.

Ioane, D., Atanasiu, L., 1998, Gravimetric geoids and geophysical significances in Romania, In: Ioane, D. (Ed.) Monograph of Southern Carpathians, Rep. Geod., **7**(37), 157-175.

Ioane, D., Pharaoh, T.P., 2000, Continental tectonics as revealed by geoidal and gravity anomalies along the Trans-European Suture Zone. XXV-th EGS Gen. Assem. Abstr. Vol., Nice.

Ioane, D., Calota, C., Ion, D., 2005, Deep geological structures as revealed by 3D gravity stripping: western part of the Moesian Platform, Romania. Journal of the Balkan Geophysical Society, Vol. 8, No. 3.

Lillie, R., Bielik, M., 1992, Crustal development and tectonic models of western Carpathians from gravity interpretation: Geologica Carpathica, **43**, 2, 63-68.

Nicolescu, A., Rosca, V., 1992, Romania. The Bouguer anomaly map, scale 1: 1,000,000. Geological Institute of Romania.

NRB, 1979, Atlas von Karten mit mittleren gelandehohen nach trapezen mit den massen 5' x 7.5' und 1^0 x 1^0 fur die lander Europas und ein teil von Asien und Afrika. Sofia.

Pharaoh, T.C., 1999, Palaeozoic terranes and their lithospheric boundaries within the Trans-European Suture Zone (TESZ): a review. Tectonphysics, 314, 17-41.

Sandulescu, M., Kreutner, H., Borcos, M., Nastaseanu, S., Patrulius, D., Stefanescu, M., Ghenea, C., Lupu, M., Savu, H., Bercia, I., Marinescu, F., 1978, Romania – Harta geologica, scara 1: 1.000.000, Institutul de Geologie si Geofizica.

Sandulescu, M., 1984, Geotectonics of Romania, Editura Tehnica, 334 p, Bucharest.

Sandulescu, M., Visarion, M., 2000, Crustal structure and evolution of the Carpathian-Western Black Sea areas. First Break, Vol. 18, No. 3, p.103-108.

Shanov, S., Kostadinov, I., 1992, Configuration of the deep geophysical discontinuities beneath the territory of Bulgaria. Geologica Balcanica, 22, 2, 71-79.

Socolescu, M., Bisir, D., Popovici, D., Visarion, M., Rosca, V., 1964, Structure of the Earth's crust in Romania based on the gravimetric data. Rev.Roum.Geophysique, 8.

Sperner, B., Ioane, D., Lillie, R., 2004, Slab behaviour and its surface expression: new insights from gravity modelling in the SE-Carpathians: Tectonophysics, 382, 51-84.

Szafian, P., Horvath, F., Cloetingh, S., 1997, Gravity constraints on the crustal structure and slab evolution along a transcarpathian transect: Tectonophysics, **272**, 233-247.

Yegorova, T.P., Kozlenko, V.G., Starostenko, V.I., Shen, E.L., Botev, E.A., 1998, density inhomogeneities of the upper mantle of the Central Balkans: Geophys. J. Int., **132**, 283-294.

Wortel, M.J.R., Spakman, W., 2000, Subduction and slab detachment in the Mediterranean-Carpathian region. Science, Vol. 290, 1910-1916.