TRANS-EUROPEAN SUTURE ZONE OVER THE ROMANIAN TERRITORY IN THE LIGHT OF NEW SATELLITE DATA

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La zone de suture trans-européenne sur le territoire de la Roumanie révélée par les nouvelles données satellitaires. Les actuelles missions satellitaires dédiées à la mesure des champs magnétiques et de la pesanteur de la Terre représentent une opportunité unique pour mieux comprendre ces champs potentiels, à l'échelle globale et régionale. En outre, ces nouvelles mesures de haute résolution et haute précision permettent l'étude des différentes structures géologiques et tectoniques. Parmi celles-ci, ici on étudie la Zone de Suture Trans-Européenne (Trans-European Suture Zone – TESZ). Ce travail a comme objectif principal de mettre en évidence la signature géophysique d'un segment important de cette structure, connu sous le nom de Zone de Tornquist-Teisseyre (Tornquist-Teisseyre Zone – TTZ), à travers des données magnétiques et gravimétriques satellitaires.

Key words: magnetic and gravity field, satellite data, Champ satellite, Trans-European Suture Zone.

1. INTRODUCTION

Measurements of the Earth's magnetic and gravity fields are concerned with answering fundamental questions about the Earth's deep interior and its lithosphere. Satellite missions over more than two decades have immensely improved our understanding of these fields. New magnetic and gravity missions are flying or are planned to be launched during the next years, providing a continuous observation of temporal changes in the potential fields.

The first satellite offering vector magnetic data was MAGSAT (1979-1980). At the beginning of the Decade of Geopotential Field Research, the Danish satellite Ørsted[1] was launched in February 1999 and since then it has provided scalar and vector data, allowing not only a second highly accurate snapshot of the geomagnetic field but also the continuous recording of its evolution during the last

[1] http://web.dmi.dk/fsweb/projects/oersted/

five years. The German satellite CHAMP[2] was launched in July 2000, being planned to measure both the magnetic and gravity fields, with an estimated lifetime of about five years.

GRACE[3], twin satellites launched in March 2002, are making detailed measurements of the Earth's gravity field which will lead to discoveries about gravity and the Earth's natural systems. The science data from GRACE mission will be used to estimate global models for the mean and time variable Earth gravity field approximately every 30 days for the 5 year lifetime of the mission. The science data from the GRACE mission consists in the inter-satellite range change measurements, and the accelerometer, GPS and attitude measurements from each satellite.

Among the future geomagnetic satellite missions planned to be launched during the next years, two are of high interest for our scientific community: GOCE and Swarm. GOCE[4] (The Gravity Field and Steady State Ocean Circulation Explorer) will be dedicated to measure the Earth's gravity field and model the geoid with high accuracy and spatial resolution. It is the first Earth Explorer Core mission to be developed as a part of ESA's Living Planet Programme and is scheduled for launch in 2006. Swarm[5] will be a constellation of three satellites, planned to be launched in 2009. They will survey the magnetic field with a unique spatial coverage and temporal variation; Swarm data will be also used in various applications such as space weather, radiation hazards, navigation and resource exploration.

All the present Earth's satellite exploring missions, with their high data quality and the new models obtained from, have greatly improved the global and regional knowledge of the planetary structure, with attendant geodynamic implications. More specifically, maps obtained from high resolution magnetic and gravity field models can be used to infer different geological and tectonic structures. One of them is known as the Trans-European Suture Zone (TESZ) which is the most prominent geological boundary in Europe, separating mobile Phanerozoic terranes in the south and west from the Precambrian East European Craton. In this study we are mainly interested in a prominent segment of the TESZ, known as the Tornquist-Teisseyre Zone (TTZ). In order to show how satellite data are used in understanding this special tectonic zone, we first summarize the geological situation characterizing the Romanian territory within the regional context. Thereafter we briefly present the magnetic and gravimetric maps obtained before the so-called "Decade of Geopotential Field Research".

[2] http://www.op.gfz-potsdam.de/champ/
[3] http://www.csr.utexas.edu/grace/
[4] http://www.esa.int/export/esaLP/goce.html
[5] http://www.esa.int/export/esaLP/swarm.html

These maps are based on various measurements (ground-based or aeromagnetic) made over Romania's territory during the last four decades. Finally, we present and discuss magnetic and gravity maps obtained from CHAMP and GRACE satellite data.

2. GEOLOGICAL DESCRIPTION

2.1. THE EASTERN CARPATHIANS

The Carpathian Mountains are part of the Alpine-Himalayan chain, formed about 35 million years ago in the Tertiary Alpine orogeny. The Carpathian system is as long as the Alps (1,300 km, ending on the Danube, at Bratislava and the Iron Gate, only 500 km apart), but has only half their height. The system underwent Quaternary glaciation only in the Krkonoše, Tatra, Rodna and the Southern Carpathians. The far older and lower remnants of the Hercynian Mountains lie parallel to the north, running from the Vosges *via* the Ardennes, the Black Forest and Southern Poland to North Dobrogea on Romania's Black Sea coast. For the most part the Carpathians are 35-40 km wide (double that in the Parâng area and three times in the Rodna). The Eastern Carpathians consist of three distinct bands with Flysch (or turbidite) sediments on the external part, young crystalline massifs in the centre, and volcanic Neogene on the inner side.

The Eastern Carpathians have mainly resulted from an important tectonic activity, which affected the European continental margin of the Tethyan domain. These tectonic processes started in the Cretaceous, as results of compressive phenomena, pushing the Foreapulian continental block toward the European margin. Located between the two continental margins, the Tethyan domain was either consumed through subduction processes, either affected by obduction ones (Săndulescu, 1984). A second compressional period occurred in the Miocene and was determined by extensional phenomena, accompanied by strike-slip displacements in the Pannonian Basin, or differential motions of the crustal blocks situated in the East Carpathian foreland (Săndulescu, 1984).

In the Eastern Carpathians, several major tectonic units have been described, originating either from the Tethyan domain, or from the Tethys European margin. The tectonic units which resulted from the Tethyan domain structuration were separated in Pienides and Transylvanian Nappes, both overthrusted on elements belonging to the European continental margin. Each unit is constituted by several overthrusted nappes, having specific structural and stratigraphic characteristics. The youngest structural unit belonging to the Eastern Carpathians is the Neogene depression (Focşani depression) (Bădescu, 1998).

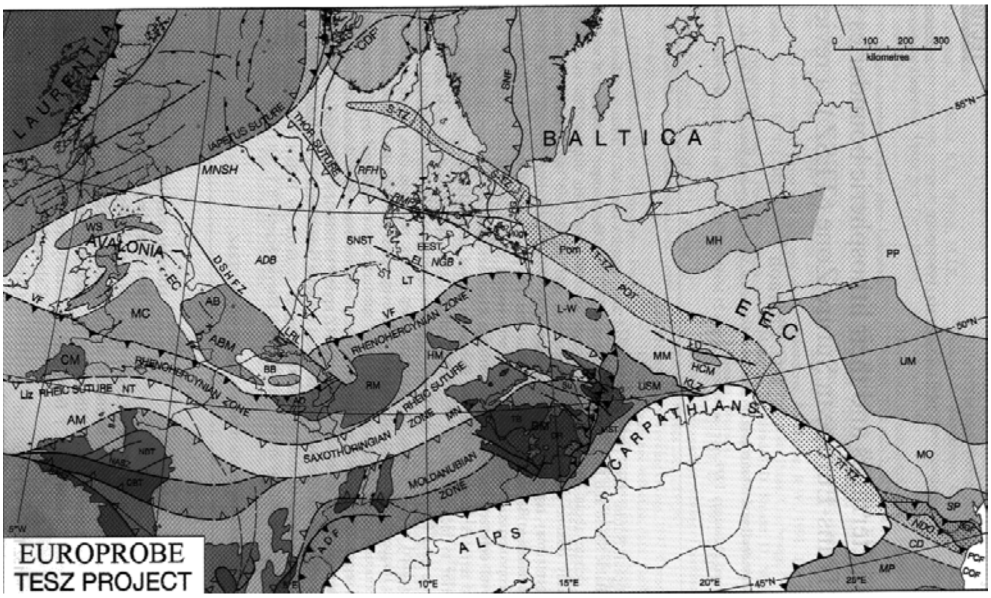

Fig. 1 – The TESZ zone as suggested by the Europrobe Project (after Pharaoh *et al.*, 2000).

ADB, Anglo-Dutch Basin; ADF, Alpine Deformation Front; CD, Central Dobrogea; MNSH, Mid-North Sea High; MP, Moesian Platform; NDO, North Dobrogea Orogene; NGB, North German Basin; POT, Polish Trough; RFH, Rynkobing-Fyn High; RG, Ronne Graben; RMFZ, Romo-Mon Fracture Zone; SP, Scythian Platform. Postulated Palaeozoic terranes and possible terrane/sub-terrane boundaries: DSHFZ, Dowsing-South Hewett Fault Zone; EEST, East Elbian Suspect Terranes; EL, Elbe Lineament; KLZ, Kraków-Lubliniec Zone; LRL, Lower Rhine Lineament; LT, Lüneburg Terrane; LU, Lysogory Unit (?Terrane); MM, Malopolska Massif (?Terrane); MST, Moravo-Silesian Terrane; NT, Normannian Terrane; PCF, Peceneaga-Camena Fault; SNST, Southern North Sea Terrane; SGF, Sfântu Gheorghe Fault. Proterozoic-Palaeozoic tectonic elements: AB, Anglian Basin; AD, Ardennes Massifs; AM, Armorican Massif; BB, Brabant Massif; BM, Bohemian Massif; CBT, Central Brittany Terrane; CDF, front of Caledonian deformation (see text for explanation); CM, Cornubian Massif; COF, Capidava-Ovidiu Fault; DR, Drosendorf Unit (of BM); EC, Eastern English Caledonides; EEC, East European Craton; EFZ, Elbe Fault Zone; GF, Gföhl Unit (of BM); HM, Harz Mountains; HCM, Holy Cross Mountains; L-W, Leszno-Wolsztyn Basement High; MC, Midlands Microcraton; MH, Mazurska High; MN, Münchberg Nappe (of BM); MO, Moldavian Platform; NASZ, N Armorican Shear Zone; NBT, N Brittany Terrane; PP, Pripyat Trough; RM, Rhenish Massif; USM, Upper Silesian Massif (=MST); SNF, Sveconorwegian Front; SASZ, S Armorican Shear Zone; S-TZ, Sorgenfrei-Tornquist Zone; Su, Sudetes Mountains; TB, Tepla-Barrandian Basin (of BM); T-TZ, Tornquist-Teisseyre Zone; UM, Ukrainian Massif.; VF, Variscan Front; WS, Windermere Supergroup.

2.2. THE TRANS-EUROPEAN SUTURE ZONE

The Trans-European Suture Zone (TESZ) is a broad and complex geological and tectonic transition area across the European continent, separating the ancient lithosphere of the Baltic Shield and Eastern European Craton from the younger Phanerozoic lithosphere of Western and Southern Europe. Stretching on 2,000 km from the North Sea to the Black Sea, and continuing perhaps across the Atlantic Ocean to North America, it represents the most fundamental lithospheric boundary in Europe. The significance of this zone has been prioritised for research in a series of recent international scientific projects, especially within the wide-ranging EUROPROBE programme and related research activities, in particular the TESZ Project, POLONAISE, TOR, EUROBRIDGE, as well as the CELEBRATION 2000 seismic experiments. One major result obtained during the EUROPROBE programme was a detailed tectonic map of Central and Eastern Europe. Fig. 1 (after Pharaoh *et al.*, 2000) clearly shows the large tectonic structures and also underlines the TESZ zone. For Romania's territory, this map shows that TESZ seems to be situated between the Siret fault (East) and the Solca fault (West), and between the Ukrainian boundary (North) and the Bistrița fault (South).

The TESZ is characterized by a thick crust (about 45 km), low heat flow, and a tectono-thermal age around 3000-800 Ma. The Palaeozoic mobile belt of Western Europe is characterized by a thinner crust (about 30 km), higher heat flow, and a tectono-thermal age around 450-290 Ma. These contrasting types of crust are juxtaposed by the Caledonian and Variscan orogenic episodes (Guterch *et al.*, 1986).

Recent studies (*e.g.*, Pharaoh *et al.*, 2000) have shown that this zone is associated with geophysical anomalies situated at different depths, from the near surface to the uppermost mantle.

Recently, a difference in the geoelectrical structure of the upper mantle beneath the TTZ and the Precambrian Platform has been detected in Poland (Dadlez *et al.*, 1994). The essential difference has been established by jointly interpreting the deep magnetotelluric (MT) and magneto variational (MV) soundings. The conductance can increase by as much as a factor of two from the Precambrian to the Palaeozoic Platform, with possibly an anomalous behaviour within the TTZ itself. During the last decades magnetotelluric soundings have been carried out on Romania's territory (Stănică *et al.*, 1986; Stănică *et al.*, 1999). Evidence provided by MT data defines the electrical constitution and thickness of the crust and upper mantle, the geometry and interrelation between the West Palaeozoic Platform and East Precambrian Platform.

The TESZ zone has been investigated using seismic data obtained over this region. Recent seismic studies (Czuba *et al.*, 2002; Alinaghi *et al.*, 2003) have shown clear depth variations for the two Moho branches between the Elbe line and the TESZ zone. The crustal depth of the TESZ is indicated by an increase in Vp/Vs values. Other seismic observations (Guterch *et al.*, 1999; Grad *et al.*, 2002; Sroda *et al.*, 2002) have demonstrated a very distinct asymmetry between the maximum thickness of the sedimentary cover in the Polish Trough (16-20 km) and the crustal root (~50 km) associated with TESZ/TTZ. Other studies have also revealed seismic anisotropy for the northern part of the TESZ zone and offered tomography-based lateral variations of the upper mantle (TOR Working Group *et al.*, 2002).

This important tectonic zone has been studied using potential field data. Indeed, results of gravity and magnetic anomalies interpretations confirm that the border of the East European Craton in SE Poland is located in the NE foreland of the Holy Cross Mountains (Grabowska and Bojdys, 2001). The same study also revealed two SE-NW belts of residual gravity anomalies, cutting Mesozoic and Palaeozoic formations. Potential field methods applied in northern and central Europe (Banka *et al.*, 2002) and combined with seismic data (Williamson *et al.*, 2002) clearly showed the magnetic feature of the crustal structure of the TESZ, and especially strong magnetic contrast between the highly magnetic East European Craton and the less magnetic Palaeozoic-accreted terranes of central Europe.

Some other geophysical parameters can be used to better understand these geological and tectonic structures. Here, we are interested by the TTZ signature on the magnetic and gravity fields. In order to better use the new information brought by the recent satellite missions, a short overview of the previous existing maps (magnetic and gravity) from Romania’s territory is given bellow.

3. PREVIOUS MAGNETIC AND GRAVITY MAPS FOR ROMANIA’S TERRITORY

During the last 20 years several studies have been performed to characterize the particularities of the lithosphere on Romania’s territory. Information on the constitution of the platform basements and the depth at which they are situated was obtained using various geophysical methods. For example, the detailed interpretation of the magnetic anomalies situated on Romania’s territory has been considered by several authors (Gavăt *et al.*, 1965; Constantinescu *et al.*, 1972; Airinei, 1985; Visarion *et al.*, 1988, 1998; Beşuţiu, 2001). The magnetic and gravity field anomalies on Romania’s territory are in close connection with the geological structure (foreland, folded units, inter- and intra-mountainous depressions).

In Fig. 2 (after Airinei *et al.*, 1986) we present a synthetic map showing the vertical component of the magnetic anomaly. The magnetic residuals show high-value magnetic field for the East European Platform, as well as different shapes and orientations of the existing anomalies. The residual map is a good indicator of the petrographic constitution of the basement. This configuration is specific for the western part of the Ukrainian Shield. The Epi-Palaeozoic Platform is characterized by low magnetic field values. This low anomaly is bordered by weak horizontal gradients.

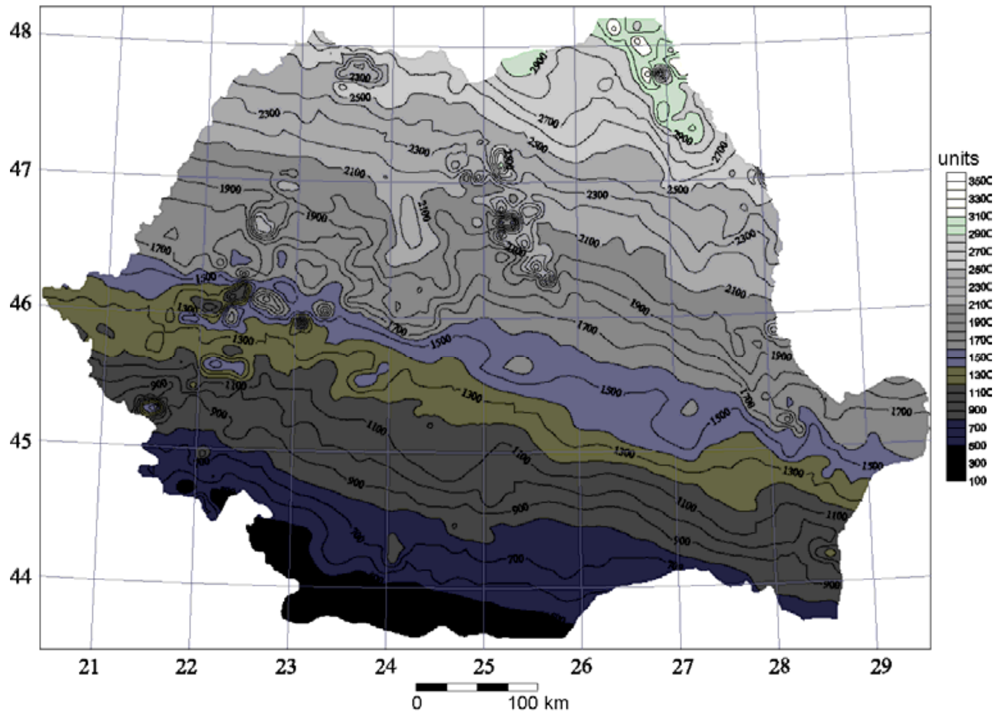

Fig. 2 – Map of the vertical component of the magnetic anomaly over the Romanian territory (after Airinei., 1985), gridded version of the map (d = 5000 m) by Ligia Atanasiu.

Fig. 3 (after Nicolescu, Roşca, 1982) shows the gravity field anomaly map over Romania's territory. This map indicates the existence of very complex features, with a wide range of amplitude variation, of about 150 mgal (-125 mgal in the Southern Carpathian sector, and +25 mgal nearby the Black Sea shore and on the eastern boundary of the Pannonian Basin). In the eastern part of Romania's territory two specific areas can be delimited by two well-determined anomalies. Indeed, in the eastern part on the East European Platform a large gravity anomaly is observed, which is characteristic for the old platforms. On the western part of the Precambrian Platform the isolines present a quasi parallel orientation with an obvious tendency of the gravity values to decrease. These important regional variations hide the local anomalies and their important regional gradient is assimilated with TESZ.

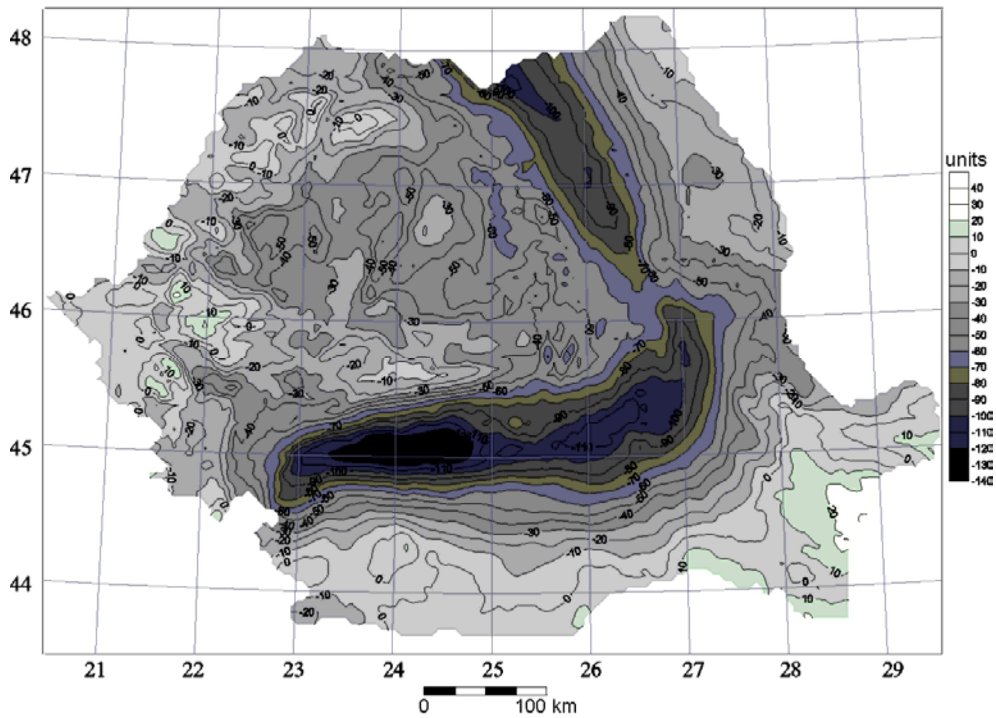

Fig. 3 – Map of the gravity field (Bouguer anomaly) over the Romanian territory (after Nicolescu, Roşca, 1982). Gridded version of the map (d = 5000 m) by Ligia Atanasiu.

4. MAGNETIC AND GRAVITY MAPS OBTAINED FROM SATELLITE DATA

In the following we take advantage of data and models provided by CHAMP and GRACE missions. We are mainly interested in obtaining satellite maps for the TESZ zone, in order to find out some signatures of this region into the satellite data, and to characterize them.

4.1. MAGNETIC MAPS

Let us note that the first magnetic satellite data used to study the TESZ region were those provided by MAGSAT. Indeed, MAGSAT data-based studies of central Europe have revealed correspondence between tectonic elements and geological structures, and long-wavelength satellite-altitude anomalies. Over the TTZ, the magnetic gradient was estimated at about 18 nT and a half wavelength of 720 km along a MAGSAT orbit at 325 km altitude (Taylor and Ravat, 1995).

Here, in order to get a magnetic map for the TESZ zone, we used the MF2 lithospheric magnetic field model derived from CHAMP data.[6] The MF2 model provides the spherical harmonic coefficients of the scalar potential of the magnetic field for the lithospheric part, only. Indeed, this version of the magnetic field covers the degrees 16 to 80, representing the visible portion of the lithospheric field (considering that the contributions from the core field are concentrated in the first 15 coefficients).

MF2 is obtained from all available quiet time CHAMP scalar and vector data, from August 2000 to August 2002. The scalar data were filtered along-track by fitting and subtracting a 3-parameter subset of degree-1 internal and external dipoles. The vector data were filtered in a similar way, fitting the 11 parameters of a full degree 1 internal and degree 2 external fields. The two data sets were merged giving a 3:1 weight of the scalar data over the vector data. No regularisation at all was applied to the zonal coefficients. Above degree 40, the tesseral and sectorial coefficients were damped in order to reduce noise. All coefficients were equally rolled off to zero in the interval of degrees 76-80.

Taking advantage of the high resolution and accuracy of this model, we computed a synthetic data grid located between 44-48° lat N and 21-29° long E. The values are estimated on a $0.25° \times 0.25°$ grid for all three magnetic field components X, Y, Z and also for the total magnetic field intensity. These synthetic values were thereafter used to draw maps at the satellite altitude and Earth's surface. Here we present the total field intensity only (Fig. 4). This map shows that an important gradient characterizes the western part of the East European Platform, part of which is situated on Romania's territory. For Europe, this large gradient zone covers an area from the North Sea to the Black Sea.

4.2. GRAVITY MAPS

With the launch of the new satellite gravity field missions CHAMP and GRACE, the quality of global gravity field models has been improved. Data provided by CHAMP mission led to a new global gravity field model called EIGEN-1S (Reigber *et al.*, 2001, 2002).

EGM96 (Lemoine *et al.*, 1998) is a geopotential model of the Earth consisting of spherical harmonic coefficients complete up to degree and order 360. It is a composite solution, consisting of: (1) a combination solution up to degree and order 70; (2) a block diagonal solution from degree 71 to 359; and (3) the quadrature solution at degree 360.

For this model, synthetic data were obtained. Fig. 5 presents the gravity field (free-air anomaly) for the region we are interested in. All the transformations of gravity field were performed with the $1° \times 1°$ resolution. A chain of maximum

[6] http://www.gfz-potsdam.de/pb2/pb23/SatMag/litmod2.html

positive anomalies is clearly observed in the western part of Romania's territory. The obtained negative anomalies characterize some structure of the East European Platform. The large gradient zone indicates, like the magnetic map, the signature of TESZ, which on the Romanian territory is overthrust by the Carpathian thrust-belt of Alpine age.

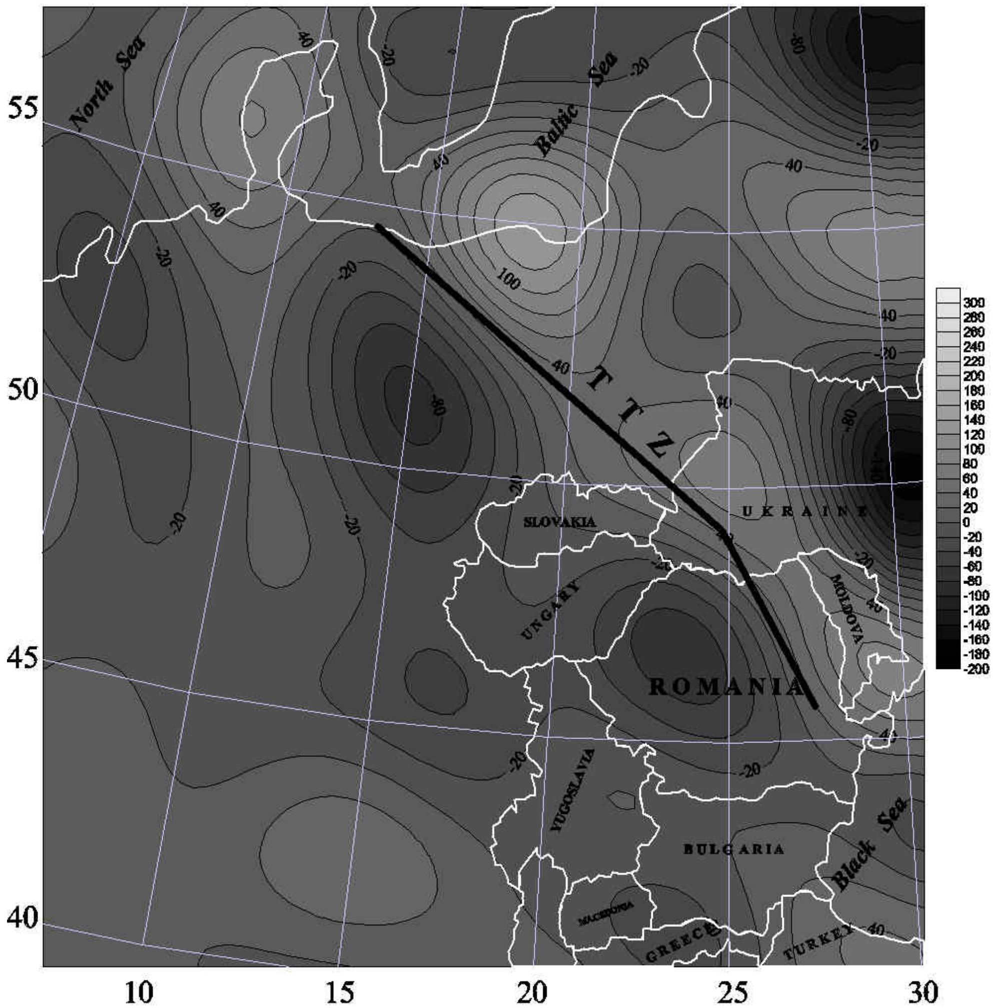

Fig. 4 – Total magnetic intensity field for the East European region computed over a synthetic 0.25° × 0.25° resolution grid, obtained from the MF2 spherical harmonic model. CHAMP scalar and vectorial data from Aug. 2000 to Aug. 2002 have been used.

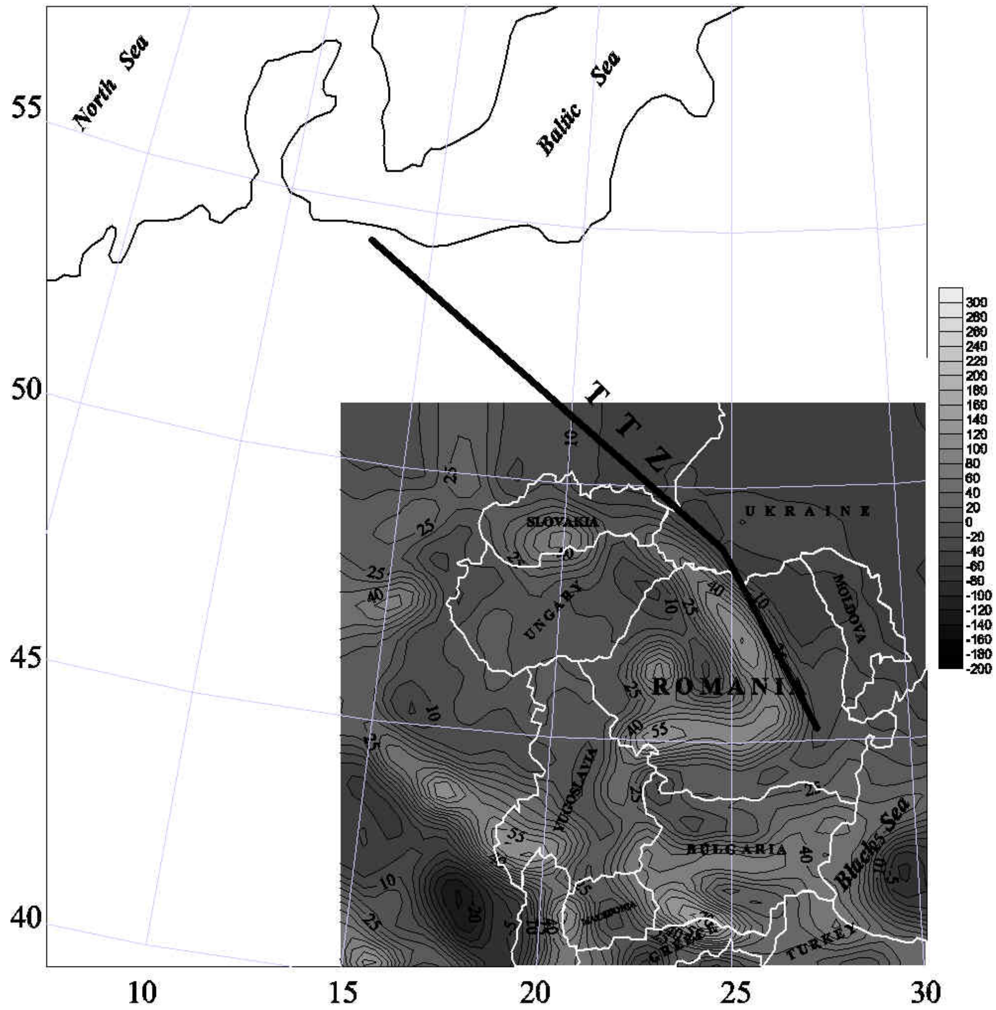

Fig. 5 – Map of the gravity field (free air anomaly) for the Eastern European region computed over a synthetic 1° × 1° resolution grid, obtained from the EGM96 spherical harmonic model.

5. CONCLUSION

In the present study we analyse, in a simple way, the signature of the TTZ in satellite data, magnetic and gravity. As shown in Figs. 4 and 5, both the magnetic and gravity maps clearly indicate that this zone is observed at the satellite altitudes.

A part of the East European craton is clearly delineated in the presented magnetic map, bringing an indication about the thickness, age, and vertically integrated magnetization of the crust in this region. The TTZ, marking the south-western edge of this craton, clearly runs in a NW-SE direction, from the North Sea to the Black Sea. Under the North Sea, this boundary makes an arch and eventually merges with the western boundary of the older Scandinavian Shield. The TTZ ends under the Black Sea. The gravity map also indicates the presence of this zone. Indeed, the area covered by the high gradient values corresponds to the TESZ.

When satellite magnetic and gravity data are combined with other geophysical information, such as seismic or heat flow, they can be used to better understand regional tectonics and local structure. Considering, for example, the heat flow information, a large zone with low values of this parameter covers most of the East European Platform. Moreover, the entire Carpathian arch displays an increase of heat flow from the outer to the inner tectonic units. This heat flow information can be added to the gravity data obtained from the last satellite missions.

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