Exploring seisimicity using geomagnetic and gravity data – a case study for Bulgaria

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OBJECTIVES
Performance of seismic hazard evaluation certainly requires comprehensive analysis of location, orientation and length distribution of fault systems with a variety of geophysical methods. It is crucial for seismotectonic model compilation and proper seismic sources definition.

METHODS
Directional derivatives of the Bouguer gravity anomalous field

The main objective of this research was to use the capability of gravity and field data for revealing of deep structures in the earth’s crust of Bulgaria and to examine the possible correlation between regional and local anomalies with high gravity gradient and increased seismicity.

The methods of first gravity derivatives was applied in the present research. The horizontal derivatives along two orthogonal axes have been calculated and geometrically summed. When applied to two dimensional survey, the Total Horizontal Gradient (THG) tends to place narrow ridges over abrupt changes in density and locating maxima can be done by simple inspection or automated procedure.

RESULTS
Interpreted gravity and geomagnetic transitions described above in the text are used and combined in Fig. 4 with geological and seismological information to constrain the seismic source model for the territory of Bulgaria that is applied in seismic hazard assessment. It is seen from the map that a number of the geologically interpreted structures coincide with observed on the surface dislocations and epicenter clusters (well illustrated in northern Bulgaria) which confirms the reliability of the applied methodology.

The complicated geo field in southern Bulgaria is demonstrated by mosaic structure of geomagnetic field (Fig. 3), complex configuration of gravity anomalies (Fig. 2) and spatial seismicity distribution. Well defined regional, local Bouguer, low gravity and magnetic anomalies are the best example of such occurrence and serve as a constraint for position and parameters of the geological structures in depth.

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DATA
Gravity and magnetic data which have been used for the present study cover 95% of the Bulgarian territory. We used digitalized maps from Solakov et al., 2009, and prepared grids with 1.5 km grid cell spacing for gravity and 3 km grid cell spacing for magnetics (Figs 1 and 3). The Total Horizontal Gravity Gradient and upward continuation of geomagnetic anomalous field to a common altitude of 3 km were calculated using these data and the Fourier techniques (Figs 2 and 4). Seismological data are based on the following catalogues:

- Catalogue of earthquakes in Bulgaria and adjacent regions (Gregorova et al., 1979)
- New catalogue of the earthquakes in Bulgaria for the period from V century BC to XIX century (1899) (Christoskov et al., 1979).
- Earthquake Catalogue for Central and South-Eastern Europe (Shebalin et al., 1998).
- Catalogue of earthquakes in Bulgaria and surroundings for the period 1991-2006. Data have been checked and complemented with the data from two other catalogues first - of the earthquakes in Greece and surrounding areas for the period 1958-1999 (Papazachos et al., 2000) and second - catalogues of seismic activity in the Mediterranean and surrounding area for the period 1901-2004 (Papazachos et al., 2005).

DELINEATED GRAVITY ANOMALIES

Moesian gravity zone.
• More than 30 gravity anomalies with mainly W-E orientation.
• Some of them, (21), (24), outline the southern board of the Moesian platform, while (20), (26), (30) indicate borders of blocks in the northern Bulgarian arc.
• In the north-eastern part of the zone the borders are mainly of fault’s type and those which have more significant density contrast are marked by gravity transects: Vertical displacements along the fault planes could reach several kilometers as it is proved by boreholes.
• To the south, towards the Balkan transform zone, the gravity transects (27 and 28) are caused by a fault zone connected to the salt body revealed on the surface. Three other transects are delineated on the map in Fig. 2. These are: South-Moesian gravity transition (step) (24), Varditza transition (31) and Kotel transition (32).

Rhodope gravity zone.
• The most saturated zone by intensive gravity anomalies.
• Two orientations of the gravity anomalies dominate: Maritsa transition (73) reflects the gravity effects of deep linear dislocation which depth extends to more than 20 km. Strouma transition (74) coincides with the Strouma fault zone which is characterized by diverse striking dislocation lines. Across the main Strouma line’s direction can be traced Curvature gravity transition (76) well exposed as intensity and size.
• Inside the Rhodope domain several anomalous zones and connected to them transects are displayed in the THG map. These are Meza transitions (83) striking N-NW along the Meza graben which is filled by young volcanic rocks.
• Gradients of group (78) indicate border faults of Sofia depression in the West Srednogorie unit.

Thrace gravity zone.
• More than 20 gravity axes here follow mainly linear structures of young magmatic activity.
• 'Looking from N to S and from E to W the first anomaly in this zone is the East-Balkan maximum (35) which is caused by antilithic structure and rupture basic intrusions.
• Burgass group of positive anomalies (34) is formed as a result of large plutonic bodies' influences which have increased density and ultra-basic composition. Borders of the magmatic ensemble are delineated by transitions (33).
• Group (54) is connected to thrust and fault surfaces inside the Strandzha block.
• Following to the East Elhovo gravity transition marks the transition with the Sakar block structures. East Rhodopyan gravity gradient anomalies (56 and others) are caused by metamorphic bodies.

DELINEATED MAGNETIC ANOMALIES

• Most intensive are anomalies in the southern part of the territory. The large number of relatively narrow magnetic anomalies show presence of multiple shallows, separate magnetic sources. The identification of major geologic and seismological structures using magnetic data is troubled by the "masking" effect caused by shallow bodies. For this reason upward continuation of the field was performed to a common altitude of 3km (Fig. 3).

- Straparolitska geomagnetic zone. The Burgass zone (33 45.42 55.) is caused mainly by Straparolitsa metamorphic and magnetic rocks, which outcrop at places on the surface. The average depth of occurrence of the anomalous bodies is 3 to 5 km.

- Pazardzhisko magnetic zone. This elongated magnetic zone has distinguished reflection in the geomagnetic field. In the territory are included 3 magnetic subzones:
  - South Srednogoriski magnetic belt includes Pazardzhishko-Zlatovratska magnetic chain (24 15.42 15.) which comprises of Pazardzhishka, Plovdivska and Zlatovratska anomalies. They all are caused by plutonic structures with upper Cretaceous age. Northeastward the Chirpano-Elhovsko magnetic chain is situated. It is outlined by elongated, in W-E direction, separate anomalies in the southern periphery of Central Srednogorje. It is caused by crack intrusions under the Zagorski graben and at the Chirpano, drop, and eastward from Rodnevo, Manastirska, Granditski and Rodaski intrusions.

- Burgass magnetic subzone covers East Srednogorie and Strandzha. It reflects the products of upper Cretaceous activation of intermediate to mafic magmatism. Burgaskozemno anomaly group (27 25.42 30) takes central position with circular configuration. This is caused by the volcano-plutonic structure with inverse magnetization and average depth of over 5 km.