Interpretation of magnetic data using magnitude transforms in the Burgas depression and adjoining Black Sea shelf

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Интерпретация на магнитни данни с прилагане на магнитудни трансформации в Бургаската депресия и прилежащия шелф на Черно море

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Абстракт. Данните за аномалното магнитно поле ΔT на изток от меридиан 27° и.д. в пределите на Бургаската депресия и прилежащия Черноморски шелф са анализирани с прилагане на оригинална система от магнитудни трансформации ТРЕЛ (TREL). Тези трансформации се влияят слабо от ориентацията на намагнитеността на геоложките тела и екстремумите им се разполагат над централните точки и осови линии на телата. Периферните екстремуми на диполното поле не се появяват, което улеснява анализа на магнитното поле и идентификацията на неговите геоложки причинители. В допълнение системата ТРЕЛ позволява получаването на оценки за дълбочината и типа форма на магнитните тела с автоматизиране на операциите по решаване на обратната магнитна задача и изобразяване на получените резултати по цялата дължина на профил или площ на магнитна карта.

Проследени от север на юг магнитните аномалии променят ориентацията си от Балканидна с азимут 100° на такава с азимут 135° в паралел на Странджанските структури. Както на север така и на юг се наблюдават аномалии с положителен и с отрицателен главен екстремум. За разрешаване на усложнената интерференционна картина е построена карта на модула на аномалния магнитен вектор T. С помощта на отношенията между тази магнитудна трансформация T, нейните градиенти R и E, и Лапласиана L се намира, че горната повърхност на сравнително тесни издължени дайкови тела е на дълбочина от 0.7 до 2.1 km, докато тела с форма близка до елипсовидната и изометричната имат центроид на дълбочина от 1.5 до 3.5 km с тенденция на увеличаване на дълбочините в югоизточна посока. Интензивността на аномалиите съответства на намагнитеност, характерна за базичен състав на тела с магмен произход. Разпределението на удължените магнитни аномалии на шелфа може да се тълкува като проява на регионална рифтова структура с ограничено развитие.

Introduction. The Burgas depression is the largest dominant structure of Eastern Srednogorie. The main factor of its development is the intensive magmatic activity during the Upper Cretaceous and later. The geophysical data and especially data for the magnetic anomalous field in the area under consideration are an important source of information for the depth structures of magmatic origin (Yossifov et al. 1986, Popov et al. 1993). New methods and means of magnetic data interpretation allow more detailed analysis and automated inversion to be applied. These possibilities are presented below on the data available in the Burgas area and adjoining Black Sea shelf.

Method TREL for magnetic data analysis. TREL is a system of magnitude magnetic transforms effective in the process of magnetic field analysis and source identification (Stavrev and Gerovska, 2000). This system consists of the magnetic transforms T, R, E and L:

Magnitude T of the anomalous magnetic vector,

$T = (X^2 + Y^2 + Z^2)^{1/2}$, where X, Y and Z are magnetic components;

Modulus of the gradients R and E,

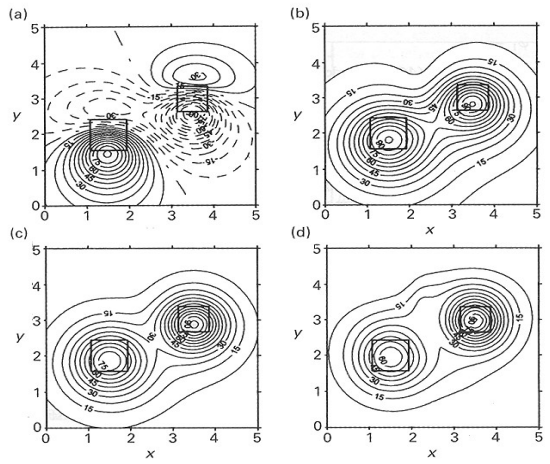
$R = |\text{grad } T|$, $E = \{[(\text{grad } X)^2 + (\text{grad } Y)^2 + (\text{grad } Z)^2]/2\}^{1/2}$;

Laplacian L of T,

$L = \text{div}(\text{grad } T) = (2E^2 - R^2)/T$.

The magnetic components and derivatives involved are calculable from measured Total magnetic field and from Gradiometric data using Fourier spectral technique.

For a 2D anomaly of a homogeneous causative body, the proposed transforms do not depend on the inclination of magnetization. In the 3D case a weak influence exists. The proposed transforms have only non-negative values. With respect to their shape, the peripheral magnetic extrema are removed, the anomalous configuration is simplified and the resolution of complicated interference patterns is improved. Their calculation does not require additional data for the direction of magnetization, which is an essential advantage over the reduction-to-the-pole and pseudogravity-field transforms. A joint analysis of the measured field and its transforms *T*, *R*, *E* and *L* offers possibilities for more confident separation of the anomalous effects and direct correlation to their sources.



Model test. The test performed on the 3D models confirms the useful properties of these transforms.

The two model sources (Fig. 1) under the black boxes have normal and reverse magnetization with inclination of 45° and 225°, and different depth of 1.25 km and 1.0 km, respectively.

(a) Model magnetic field ΔT (nT) with a complicated interference picture and extremes outside the source projections (dashs show negative field contours);

(b) Magnitude transform T (nT) of ΔT with a simplified pattern of positive values and extremes above the sources;

(c) Gradient transform E (nT/km) of ΔT with a better centricity above the sources;

(d) Laplacian transform L (nT/km^2) of ΔT has the best centricity and sensitivity to the source position.

Fig. 1. Model anomalies ΔT, T, E, L.

Field application. Magnetic field of the Burgas depression and adjoining shelf area (Fig. 2).
Analysis of the anomalous magnetic field ΔT:
Groups according to orientation: A-B, C, P, Q, S – anomalies with Strandzhanian orientation, 135°;
V, W, F - with Balkanian orientation, 100°.
Groups according to the sign: A-B, F - with negative principal extreme (Campanian, Maestrichtian?);
V, W, S, – with positive principal extreme (Santonian).
Set of anomalies that are not well identified: N, K, D, P, Q, G – peripheral or independent?

All of the above anomalies ΔT are represented by the transform T with maximums centered over the sources without need of data for the magnetization orientation as input, which is an *advantage* over the Reduction To the Pole (RTP). The points and axes of extremes of T-transform show a *movement* to the north of about 1 km with respect to the original field ΔT (see for example anomaly A). The anomalies ΔT have extremes located to the south of the central point or axis of the sources because the normal magnetic inclination for this area is about 60° and the declination is 3°E. Thus, the T-transforms by their maximums locate better the anomalous effect above the sources.
The group of complicated anomalies can now be well identified. Thus, N, K and D extremes *do not appear* on the map of T-transform. They are peripheral parts of the ΔT negative anomalies A-B. Anomalies P, Q, G, M are independent fields of their own sources. This is an *important conclusion* for the anomalies P and Q since they could be taken as peripheral extremes of their positive neighbors.

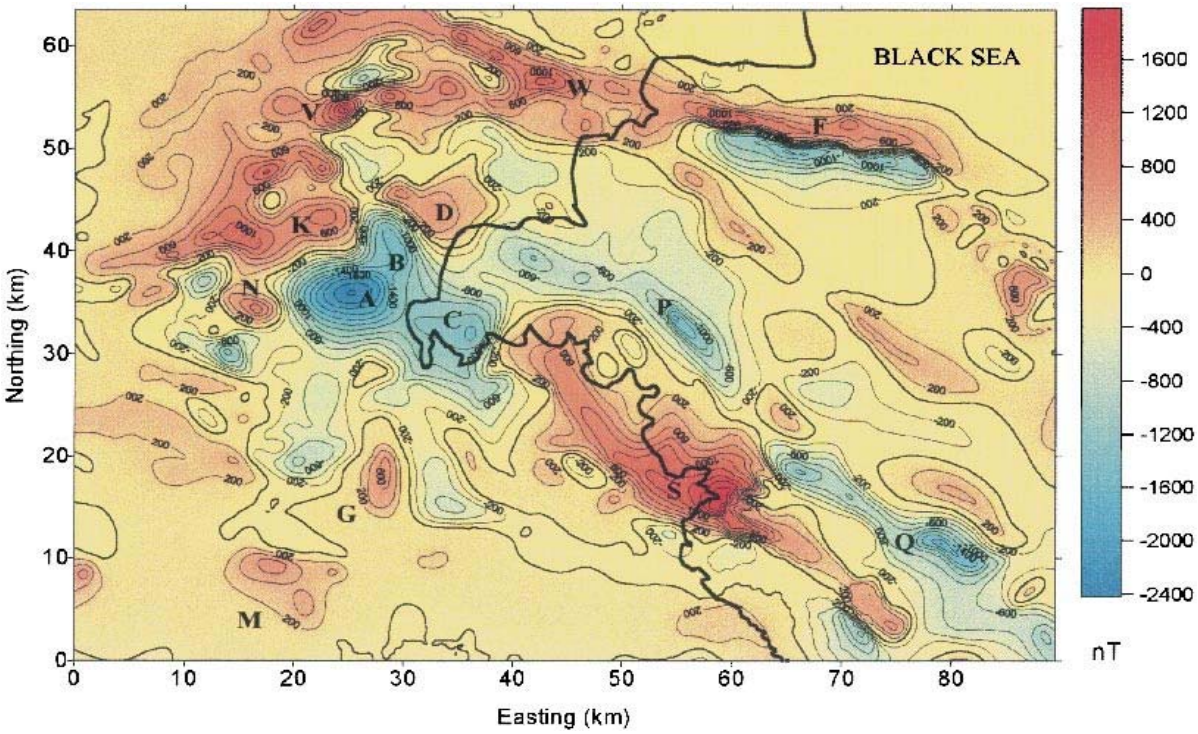


Fig. 2. Anomalous field ΔT in the Burgas area (after V. Pchelarov and L. Kerbelov)

Analysis of the magnitude transform T (Fig. 3).

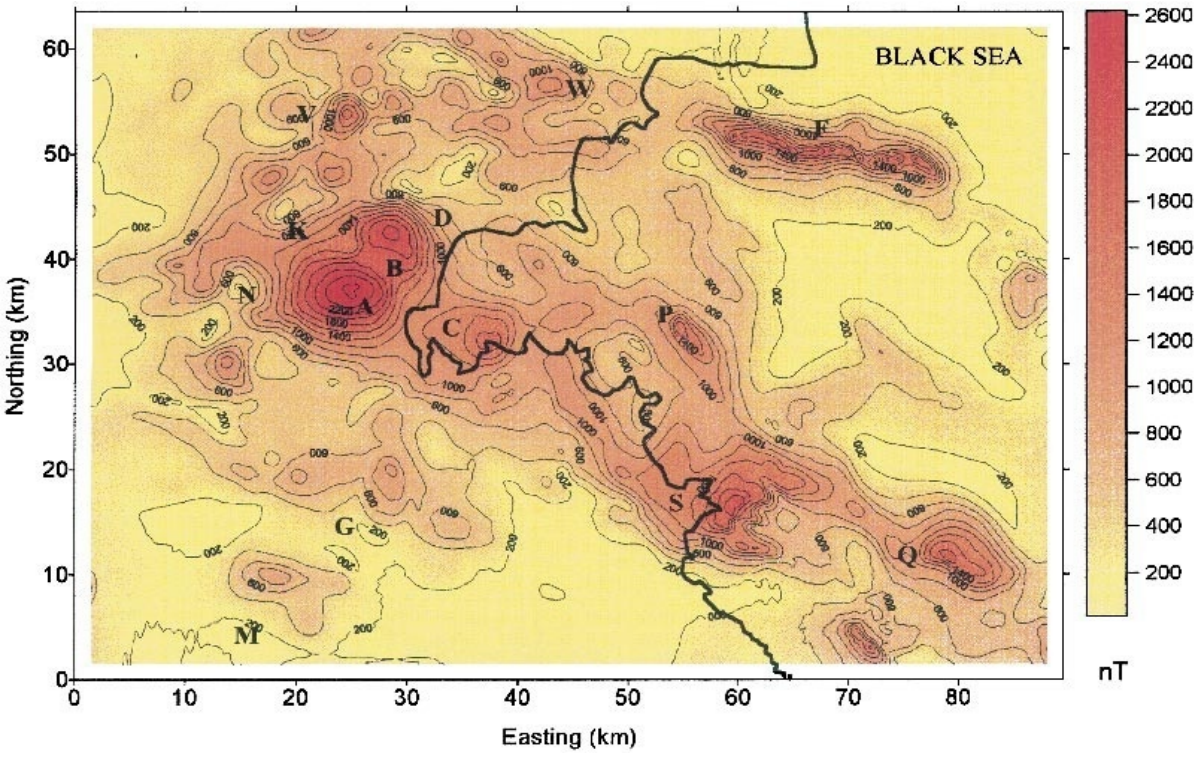


Fig. 3. Calculated transform T from the field ΔT in Figure 2 (after Stavrev and Gerovska).

Method TREL for a magnetic map automated inversion. This is a method for interpretation of a full set of magnetic anomalies over a large area using models of simple sources as approximations to the real sources. The results come from ratios between the magnitude transforms T, R, E, and L (Stavrev 2001, 2006). For the *depth inversion* and imaging it is suitable to form the spatial functions

$$q(x,y,0) = -T_h/T_z = x/d, \quad s(x,y,0) = T_z/R = d/(x^2 + d^2)^{1/2},$$

and for the *shape inversion* and imaging to form the functions

$$b(x,y,0) = -T_h/L = x/N, \quad c(x,y,0) = L/T_z = N/d,$$

where (x,y,z) are the coordinates of observation points, T_h is the horizontal derivative along the line normal to the T-transform axis, T_z is the vertical derivative of T transform, d is the depth of the source, and N is the structural (shape) index (SI).

The table below shows results for the depth and shape of the marked anomalies in Figure 4:

Ano-maly	Depth d (km), на	Structural index N	Shape of the source's normal vertical section
J	1.7, center	1.9	isometric
F	1.6, center	1.8	elliptical
Y	0.7, top	0.9	dike
P	1.5, top	1.0	dike
S	2.1, top	0.9	dike
X	3.5, center	2.1	isometric
Q	1.5, center	1.9	isometric

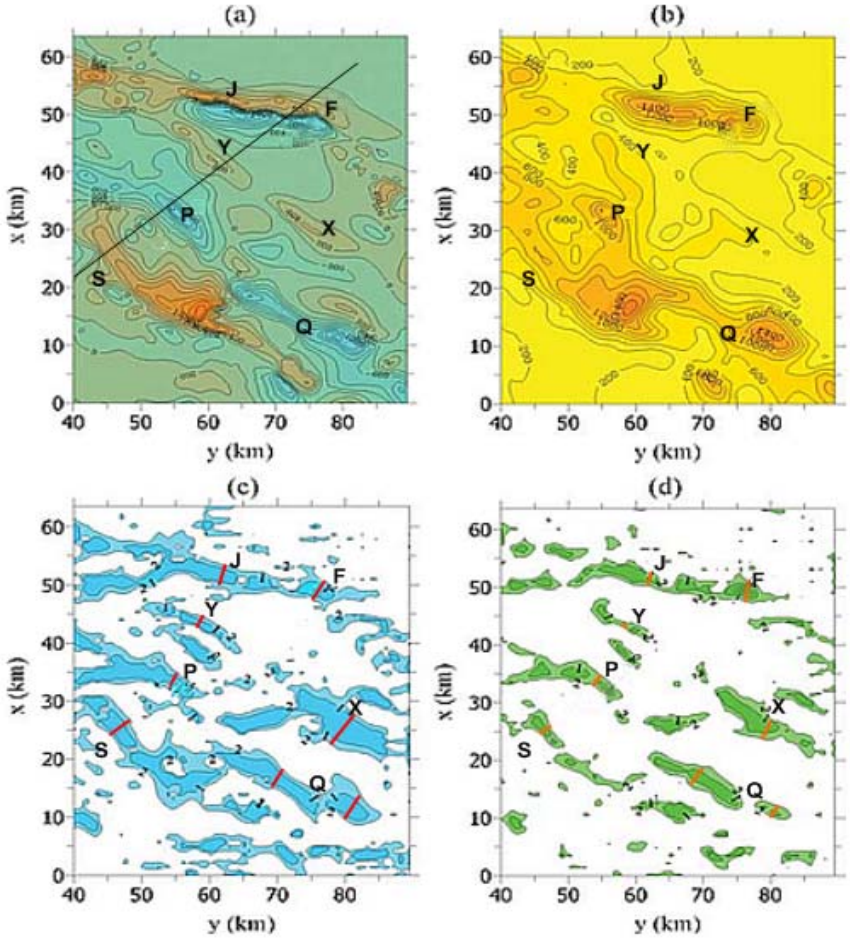


Fig. 4. (a) Original magnetic field ΔT of the Burgas shelf area;
(b) Magnitude transform T;
(c) Depth-converted map of ΔT; (d) Shape-converted map of ΔT.

Note. In Figure 4 the cross-width of the contours of value 1 is equal to the depth d (on the left) and to the shape index N (on the right) in the scale units of the map, while the width of contours 2, shown by red lines, gives the value of $2d$ and $2N$, respectively (after Stavrev 2006).

Geologic inferences. The top of dike-like magnetic bodies appears at a depth corresponding to the boundary of the Tertiary/Cretaceous layers. The intensity of elongated magnetic anomalies shows basic intrusions along major joints. The observed linear distribution and the intensity of magnetic anomalies, as well the results for the sources depth and shape confirm the assumption of Yossifov et al. (1986) about a possible spreading phase during the Upper Cretaceous period in this area of the southern Bulgarian shelf.

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