Deconvolution applied to aeromagnetic data of the Debbagh massive, neritic Constantinois (north-eastern Algeria)

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ABSTRACT The Debbagh massive represents the most important massive of the eastern Constantinois neritic zone (NE Algeria) and is characterized by its potential mining resources, with two types of mineralization (kaolin and gossans). It consists of autochthonous formations of Triassic to Miocene age, which are hosted in carbonate formations from the Cretaceous. In the present study, Euler deconvolution has been applied to real aeromagnetic anomalies data of the Debbagh area reduced to the pole to locate the magnetic sources and estimate their depths using a structural index of 0.25 for contacts and 1.25 for faults, a moving window size (grid points) of 11x11 cells and a tolerance of 15%. The depths obtained by Euler solutions range from 0.047 to 5 km for contacts, and about 0.128 to 8 km for faults. The synthesis of the results deduced from the modelling of aeromagnetic data has tracked and highlighted major events, as well as major tectonic and lithological contacts, and delineated the magnetic sources of this area.

Key words: Debbagh massive, north-eastern Algeria, Euler deconvolution, aeromagnetic data, tectonic, contacts.

1. Introduction

Geophysical investigation is applied to investigate various fields of Earth sciences: hydrogeology, petroleum exploration, and mapping.

Particularly in mining, geophysical methods are essential to characterize different types of deposits. The magnetic method is one of the best geophysical techniques to delineate subsurface structures. Geophysical mapping with magnetic field methods is a very effective tool for the detection of magnetic anomalies, and it reflects the spatial variations in the magnetic field of the Earth.

Euler deconvolution is one of the optimal methods for delineating different structural and lithological features (Thompson, 1982; Keating, 1998; Asfirane-Haddadj and Galdeano, 2000) by integrating the Euler homogeneity equation that relates the magnetic field and its gradient components using three parameters; structural index, on a moving window size, and threshold tolerance. The structural index must be assumed as a priori information because the choice of the optimum structural index provides the best solutions.

In the present study, Euler deconvolution has been applied to real aeromagnetic data collected in the Debbagh area, the most important massif of neritic eastern Constantinois in north-eastern
Algeria, aims to determine the magnetic anomalies. It also aims to develop a structural and lithological characterization of the study area representing the most important mineralization guide, because basement faults can influence and identify the overall field structure, tectonic history, and can control mineralization sites.

2. Geological and mining setting

In north-eastern Algeria, the massives of the neritic Constantinois series are divided into three groups (Vila, 1980): the southern group around Ain M’lila, the central group around Constantine, and the north-eastern group around Guelma, where the Debbagh massive is located, 17 km east of Hammam Debbagh and 35 km NE of Guelma (Fig. 1).

In the Debbagh area, from the west to the east, the north-eastern neritic Constantinois is mainly composed of the Kef Hahouner, Grar, Taya, and the Debbagh massive, which is the most important one among them.

The Debbagh massive is part of the external zones of the Maghrebides belt; it is the eastern extension of the northern neritic Constantinois. It is surrounded by Djebel Bou Asloudj and the Roknia depression in the north (Vila and Magne, 1969; Vila, 1980), Roknia in the west, Hammam Debbagh basin and Mechtet Labaïda in the south, and the hills of Fedjoudj and Bou Zitoune in the east (Fig. 2).

The geology of the Debbagh has been the subject of important revisions by Blayac (1912), Deleau (1938), Durand-Delga (1969), Vila (1980), and Lahondère and Magne (1983). The Debbagh massive is characterized by autochthonous formation of neritic limestones from the Triassic to the Miocene (Vila, 1980; Lahondère and Magne, 1983). Details about lithology are presented in Fig. 2.

The autochthonous units are topped by four allochthonous geological units: Numidian unit, the lower Cretaceous Tithonic flysch, Senonian flysch with micro breccias, and the Tellian unit (Vila and Magne, 1969).

![Fig. 1 - Location map of study area.](image-url)
The Debbagh massive is bounded by normal faults trending NW-SE, intersected by older faults trending E-W in Mechtet Brahima. N-S oriented faults also intersect the E-W ones and affect sandstones in the Numidian unit. South of Mechtet Brahima, the event trending N75° is intersected by the NW-SE faults. Finally, the large event post-Miocene oriented E-W (Raoult, 1974) limits the Debbagh massive in the south and connects the neritic Constantinois series with the Mio-Pliocene formations of the Hammam Debbagh basin. The biggest fault crosses the Kef Hahouner, Grar, Taya, and Debbagh.
With regard to economic geology, the Debbagh massive is more important than Kef Hahouner, Grar, and Taya. It is characterized by the presence on its territory of well-known kaolin and gossans deposits, which are hosted in carbonate formations of Aptian and Albo-Cenomanian limestones. This area is characterized by a well-developed karst phenomenon.

In the three parts of the Debbagh massive (eastern, central, and western) the kaolin deposit is divided into three categories. The first category is the most important because of its high quality, and is located in karst and in outcrops of kaolin. The gossans (surface formations rich in secondary iron minerals such as goethite and hematite) cap a deeper mineral body represented by sulfur, carbonate, or iron silicate. This secondary mineralization capping the kaolin is characterized by limonitic outcrops dominated by iron and silica deposited mainly as goethite and hematite. The limonite textures observed present an exotic type, indicating a migration of iron in acid solution. The gossans are of a small size in the central part, are hosted in sandstone formations of the Tellian unit, and are composed of hematite. However, those from the eastern and western parts are large and contain goethite.

In the Taya massive, the mineralization is sulfuric, represented mainly as a stebine with a trace of cinabre. Other oriental Constantinois massives (Kef Haouner and Grar) do not present an important economic interest.

3. Methodology

In the present study, the Euler deconvolution method has been applied to real magnetic data to determinate the depth and location of magnetic sources. The aeromagnetic data collected were subjected to mathematical processing (reduction to the pole, derivative grids, and application of Euler deconvolution) using Oasis Montaj software.

The aeromagnetic data are represented as contour maps of the total magnetic field. These maps are part of the results of a survey covering all parts of Algeria. For this study, the aeromagnetic data used were extracted from a regional-scale aeromagnetic survey of northern Algeria realized by Aeroservice Corporation in 1975. The survey was designed to describe the regional geology of the country and its mining and petroleum potential. The survey consisted of profiles perpendicular to the general geological structures in the study area at an average ground clearance of 150 m and a line spacing of 2.5 km for traverses and 50 km for tie lines. The data were collected at an interval of 46.2 m. The technical characteristics and the results of this survey are detailed in Fig. 3.

The map of the residual aeromagnetic field (anomalous magnetic field) is obtained by subtracting the regional field from the total magnetic field; the residual magnetic field varies between a minimum of -13 nT and a maximum of +13 nT. The maps of magnetic anomaly fields are shown in Figs. 4, 5, and 6. From the residual map, we calculated the field map of the anomalous magnetic field reduced to the pole. Here we adopted the parameters of the magnetic field of the study area which are mentioned in the report of the contractor (Aeroservice Corporation, 1975), i.e.: total field $T = 42,900$ nT, Inclination $I = 51^\circ$ N, and declination $D = -2.6^\circ$, by using the geomagnetic model IGRF 1975 (International Geomagnetic Reference Field). The values of the magnetic field vary between a minimum of 33,774 nT and a maximum of 33,807 nT, with an average value of 33,788 nT. This treatment is intended to eliminate the distortions of the anomalies caused by the inclination of the magnetic field. It allows the definition of the anomalies whose maximum is centered on magnetic sources.
3.1. Euler deconvolution method

The Euler deconvolution method is used for rapid interpretation using potential field derivatives to image subsurface depth of a magnetic or gravity source (Hsu, 2002). It allows the localization and determination of the parameters of magnetic sources, delineation of contacts and rapid depth estimation. It is based on a mathematical process represented by Euler homogeneity equation, which can be written for magnetic data (Reid, 1980; Thompson, 1982) in the form:

\[
(x - x_0) \frac{\partial T}{\partial x} + (y - y_0) \frac{\partial T}{\partial y} + (z - z_0) \frac{\partial T}{\partial z} = N(B - T)
\]

(1)

where \( (x_0, y_0, z_0) \) is the position of a magnetic source whose total field \( T \) is measured at \( (x, y, z) \), \( B \) is the regional magnetic field and \( N \) is the structural index; it is the degree of the homogeneity...
Fig. 4 - Map of total magnetic field of the Debbagh area.

Fig. 5 - Map of regional (normal) magnetic field of the Debbagh area.
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(Yaghoobian et al., 1992), interpreted physically as the fall-off rate of the field with distance from the source and geophysically as a Structural Index [SI: Thompson (1982)]. The SI depends on the geometry of the source: $N = 0$ for a contact; $N = 1$ for a thin layer, dyke, fault; $N = 2$ for a homogeneous cylinder, and $N = 3$ for a linear source, or line of dipoles or poles (Thompson, 1982; Barongo, 1984; Reid et al., 1990; El Dawi et al., 2004).

By considering four or more neighboring observations, source location $(x_0, y_0, z_0)$ and $B$ can be computed by solving a linear system of equations generated from Euler homogeneity equation. Then, by moving the operated window from one location to the next over the anomaly, multiple solutions for the same source are obtained.

The successful application of Euler deconvolution is conditioned by the best choice of the SI, which has been extensively discussed by Reid et al. (1990) and Thomas et al. (1992). An incorrect choice of the SI leads to errors in estimated source depths (Ravart, 1996; Barbosa et al., 1999; Nogueira, 2008) and dispersed solutions associated with isolated anomalies (Silva et al., 2001). Two other parameters should also be cautiously selected to obtain reliable results (the window size and the tolerance). The choice of the spatial window size is an important parameter for the successful implementation of the method (Munis, 2009). The window size determines the area in grid cells used to carry out Euler deconvolution. All points within the window are used to solve Euler equation for source location. It should be large enough to incorporate the entire anomaly being interpreted and small enough to avoid significant effects from adjacent or multiple sources (Bournas et al., 2003). The depth tolerance controls the accepted solutions with an error estimate less than this tolerance. If the depth error is greater than this value, the associated depth will be automatically rejected.

Fig. 6 - Map of residual magnetic field of the Debbagh area.
The application of Euler deconvolution is well known and has been applied successfully by Beasley and Golden (1993), Salem et al. (2005), Saheel et al. (2010), Amigun and Adelusi (2013), and Saraiva Rodrigues et al. (2014).

In the present study, Euler deconvolution has been applied to real aeromagnetic data from the Debbagh area. It is sensitive to noise, because it is based on the derivatives of the magnetic anomaly. This method uses the magnetic field and its horizontal and vertical gradients to compute anomaly source locations (Keating and Pilkington, 2004). The Euler method has been applied assuming two models (contact and faults), for the location of magnetic sources (fault and lithological contacts) and estimation of their depths by integrating the Euler parameters: SI = 0.25 for contacts and SI = 1.25 for the faults, window size W = 11x11 cells, and tolerance TZ=15%.

4. Results and discussion

From the residual map (Fig. 6), in general, the positive residual anomalies observed are the effect of outcrops and of the heterogeneous basement complex. These positive anomalies are located in the north and the south parts of the map, and are related with the Cretaceous to Quaternary outcrops. The negative anomalies are located in different parts of the map and coincide with the Jurassic to Cretaceous outcrops.

The reduced map to the pole of the Debbagh area shown in Fig. 7 reflects the degree of distribution of both low- and high-frequency anomalies which characterized the magnetic field.
The variable distribution of magnetic anomalies is due mainly to the geological complexity of the study area. In the Debbagh area, the magnetic structures coincide with the limits of the geological structures. The map of the field reduced to the pole (Fig. 7) allows the identification of the various structures, such as faults and lithological contacts. The different faults observed throughout the area are regionally associated with the positive anomalies which are moved slightly to the north. The most important one is slightly angled to the NW and coincides with Cretaceous outcrops (NE of the Kef Er Zaounia structure). In the SE and the SW parts, a positive anomaly distinguishable by its high amplitude is located SE of Jebel Abd Allah and from the east to the NW to the Kef El Hadjedje respectively, corresponding to the Miocene and Quaternary sedimentary units, with Numidian sandstone and alluvions.

The negative anomalies occupy the major parts of the map, and extend from the west to the east, corresponding to Kef Haouner, Jebel Grar, Jebel Taya, and Jebel Debbagh respectively, and coincide with the Jurassic and Lower Cretaceous limestone and dolostone occurrences with a diamagnetic character with low or negative magnetic signature. Especially in the Jebel Debbagh, the negative anomaly coincides with the gossans outcrops which topped the Cretaceous formation, agreeing with the results of geological study and confirming the origin of exotic textures of limonite of the Debbagh massive. This indicates that the gossans are not autochthonous; they are transported (Ouaddah and Assassi, 2008).

The second negative anomaly connected the first one, coincides with the Upper Eocene formation with marls and sandstones series of Jebel Mermera (SE of Jebel Taya), Jebel Bou Aslouge, and Jebel Betoum and Jebel Arara (NE and south of Jebel Debbagh respectively), Kt. Er Ras in the northern part of Jebel Grar, and Kt. Toumiat between Kef Haouner and Jebel Grar.

The lineaments identified represent sub-meridian magnetic structures which coincide with the outcrop of sedimentary units (marl and sandstone).

Fig. 8 (panels a, b, and c) shows respectively the maps of the X, Y, and Z derivative grids of the aeromagnetic data of the study area. Based on the analysis of the three maps, it can be noticed that the Y derivative is the most representative map, because the lithological contacts in the Debbagh area generally follow the E-W direction. The Y derivative also presents a clear differentiation in the intensity of the magnetic anomalies characterizing the different lithological and structural domains. The X derivative represents the NE-SW trending which interested the E-W lineaments. The Z derivative shows that the study area is characterized by shorter wavelength anomalies.

Euler solutions obtained (contacts and faults), using SI of 0.25 and 1.25 respectively, and keeping a constant window size (W = 11x11 cells), as well as threshold tolerance (TZ = 15%), are spread out in three ranges, each one representing one of the estimated depths. These solutions have been projected on the geological map of the Debbagh area and presented in Figs. 9 and 10.

Fig. 9 shows that magnetic sources detected are shallow to deep, with ranges between 0.03 and 1.25 km. The results correlated with the known geological contacts in the study area evidenced that the groups trending E-W to NW-SE in the western, central, and eastern parts are related to the Jurassic to Cretaceous outcrops of the Kef Haouner-Debbagh unit. In the northern and southern regions, the solutions indicate the presence of deep geological structures of Miocene and Quaternary formation which are bordered by shallower contacts, and show major E-W to NE-SW trending, corresponding mainly to the Eocene and Miocene outcrops.

Fig. 10 shows that the computed depths range between 0.43 and 6 km. The northern and southern parts of the Debbagh area are characterized by a relative abundance of deep structures...
Fig. 8 - The derivative grid of aeromagnetic data of the Debagg area: a) X derivative, b) Y derivative, and c) Z derivative.
which are limited by the shallower NW-SE and NNE-SSW fault systems. The lowest depths of the faults are observed in the eastern, central, and western parts of the map and show major E-W and WNW-ESE trending features that delimit the kef Haouner-Debbagh unit and relate to the important fault which aligned these massive from the west to the east and bordered the Jurassic to Cretaceous outcrops. This is explained by high extensions of anomalies characterized by short wavelengths and justified by the absence of significant magnetic sources in this part of the study area. The N-S faults intersected the E-W faults and affected the sandstones in the Numidian unit in the central part of the Debbagh area.

The consolidation of positive anomalies along faults and lithological formations can be explained by the presence of strong magnetic sources located in the sub-surface. These tectonic structures are traps for polymetallic concentration in the Debbagh and Taya massive.

The comparative study of the map of magnetic anomalies reduced to the pole (Fig. 7) and the geological map of the Debbagh area (Fig. 2) showed a strong correlation, indicating that the
magnetic structures generally follow the direction of the geological structures. The subvertical magnetic sources indicate a good agreement between magnetic signatures and the transported gossans in the Debbagh massive.

5. Conclusion

Through this study, we attempted to provide new insight into the structural setting of the Debbagh area using real magnetic data. The application of the Euler deconvolution method seems very effective for the detection of magnetic sources and the estimation of their depths. It is a fundamental method of geological and structural characterization, that allows the location of lithological contacts and faults and proves the existence of anomalies associated with outcrops of transported gossans. The Euler solutions obtained are valid and are consistent with the geological and structural studies in the investigated area. This confirms that the value of the structural index and moving window were well chosen.
The Euler deconvolution method of magnetic anomalies highlighted the presence features trending similarly to the tectonic lineaments and geological formation in the Debbagh area: the WNW-ESE, SW-NE, WSW-ENE, W-E, N-S and NW-SE trends characterize the shallower structural setting of the study area.

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