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Processing and Analysis of aeromagnetic data of North-Eastern Morocco

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Abstract: The North-Eastern of Morocco was widely known for its mining potential, so discovering new structural guidelines was indispensable to find out new mineralization. Indeed, applying airborne magnetic techniques proves its efficiency in underlining new tectonic accidents and highlighting magnetic sources mostly hidden by Quaternary sedimentary covers. A magnetic anomaly map was established to attain this goal, basing on powerful operators (reduction to the pole, upward continuation, and Euler deconvolution), made on airborne data surveys of the study area. The elaborated map shows: (1) zones of strong magnetizations related to the Tertiary and Quaternary volcanic lavas partly outcropping in the Oujda and Saka regions to the iron and manganese mineralization concentrated in the Triassic beds. (2) Zones of relatively low magnetic response came from basaltic cones filled in a small graben at Oujda region. (3) Zones of low magnetization corresponded to the Quaternary and Tertiary cover or the Triassic-Jurassic deposits. We have established a magnetic lineaments map that emphasized deep faults, two main trends have been identified: NE-SW with ENE-WSW and E-W, they are considered as a major's accidents because their depth reach to 2 km, as much as they inherited from the Hercynian and Alpine tectonics.

Key words: Aeromagnetic surveys, magnetic anomaly, structural mapping, interpreted lineament, hidden faults, North-Eastern Morocco.

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1. Introduction

The study area belongs to North-Eastern of Morocco (NEM), it exciting fieldwork of several researchers [1, 2, 3] because of its mining potential, for instance the valley Mississippi deposit of Touissit-BouBeker known worldwide [4] and due to its crucial geodynamic position as a part of the African margin. The geological fieldwork seems insufficient because deep accidents were masked by a significant sedimentary cover at the plains level. Therefore, geomagnetic methods' contribution could be crucial to identify hidden faults, trends, and extensions underground [5,6].

Three airborne magnetic surveys have been made in the junction among the Middle Atlas' eastern limit, the Rifain foreland in the North, and the high plateaus in the South to conduct the geomagnetic study successfully. The three surveys were different in terms of altitude, flight line orientation, and survey period. Previous geomagnetic studies in this area have always eliminated the high plateaus, probably because of the vital difference of altitude between the three airborne surveys that result in an inappropriate residual magnetic map. This elimination identifies lateral extensions of accident impossible on the Middle Atlas and the Rifian foreland in the East to the South. Hence the purposes of our work are:

- Producing a unique residual magnetic map were the three sectors' information is presented by recalculating the maps at the same altitude and interpolating the overlapping bands.
- Manipulating airborne magnetic techniques (reduction to the pole, upward continuation Euler's Deconvolution) to detect the hidden magnetic structures underground and discover their geological interpretation in a regional context.
- Enriching the subject area's structural map with new magnetic lineaments highly correlated to geological structures and defining its depth. The established structural map will be a cornerstone paper that guides mining prospection and helps establish the study area's geodynamic model.

2. Geological setting:

The NEM zone belongs to the Moroccan Eastern Meseta [7]. Bni Snassen Mountains (BSM) surround it to the North and the High Plateaus (HP) to the South. The Guercif Basin also borders it to the East and by the border Algero–Morrocan to the West. The study sector contains a succession of mountain ranges (the BSM, the Oujda-Taourirt Mountains (OTM)) and a depressed corridor called the Taourirt-Oujda corridor (TOC), The Bni Snassen and Oujda-Taourirt Mountains. They are formed by Meso-Cenozoic series attributed to the Triassic-Upper Jurassic times, those series overprint by discordance the Paleozoic basement dated Combro-Ordovician to the Carboniferous times [8].

The Paleozoic terrains were intensely deformed and granitized and cropped out in inliers such us Jerada, Debdou and Mekam, Zekkara, Tannecherfi, Bourdime and Narguechoum. Those inliers are covered by subtabular secondary and tertiary formations, which were weakly deformed and were inclined 10° W under the recent deposits of the Middle Moulouya [7].

The tectonic history of the zone has been produced during two orogenic cycles (Hercynien evolution and Alpine cycle), we present the essential events briefly;

Firstly, during Eo-variscan phase, the oldest Carboniferous terrains were strongly deformed, and three trends were noted NNE–SSW, N-S, and NW-SE with vergence towards the West [9, 3]. Next, they were covered by a volcano-sedimentary series mixed with Carboniferous coal levels, which are well known in the Jerada coal basin [10]. Then comes the last Hercynian cycle event that was marked by the come up of syn to late-tectonic granitoids in inliers (Zekkara, Tancherfi Tarhilest) rooted in the crust [11].

Secondly, the alpine cycle began with the rifting system that started in the Triassic and continues during the Jurassic [12, 13]. The cycle continued with the syn-rift period that involved clastic, continental Triassic deposits mainly formed by evaporates and red clays. Those formations are overlain by doleritic basalts everywhere in the NEM [14, 15]. Later, it ended with the inversion of the rift systems at Mesozoic–Cenozoic compressional–transpressional phases controlled under Africa–Europe continental collision [7]. In this period, the essential event was the apparition of shoshonitic volcanism in Gourougou and Guilliz mounts (Northern Morocco) and basalts' apparition in basalts in the Oujda area dated 4.8–1.4 Ma [16].

3. Materials and Methods:

3.1 Acquisition and processing of aeromagnetic data:

The aeromagnetic surveys used were measured during the airborne geophysical campaign made in NEM sponsored by the Ministry of Energy and Mines. Acquisition of data were done for three different zones: the Rif at the North, High Plateaus (HP) at the East, and Middle Atlas (MA) at the West. Moreover, aeromagnetic surveys were flown at different flight altitudes; Guercif at 2600 m, Dedbou at 1700 m and Mekkam at 1829 m and along with different flight directions. The primary goal was to draw a unique residual magnetic field that contains the three sections' information. First, the steps to achieve this goal are digitizing the intersection points between the iso-values curves and lines and traverses for each aeromagnetic survey. Second, the Debdou and Mekkam panels were upward continued (UC) to the Guercif altitude of about 2600 m. At the junction between the three surveys, we could connect the overlapping zones' profiles to eliminate the artifacts initially observed. Each value of the junction area's anomalies was calculated based on a mathematical formula (Eq.1), the last five points of each panel profile, and the first five adjacent ones. This results from a standard line that passes from one profile to another, the formula is:

$$M = M_1 \frac{N_T - np}{N_t - 1} + M_2 \frac{np - 1}{N_t - 1} \qquad (1)$$

Where N_T: Total number of collection points, np: is the recovery point, M_1: is the value of the first point of P_1 on the overlay, M_2: is the value of the first point of P_2 on the overlay, P_1 and P_2: profiles 1 and 2 (which may in our case be North-South or East-West). The final step was interpolating and smoothing intensity values using the 'minimum curvature' function to the regular grid nodes of 93 rows and 117 columns. Consequently, a representative residual map with continued magnetic profiles was mad.

3.2 Filtering techniques:

The main filtering techniques released in this work are:

- Reduction to the pole (RTP): It is a powerful method that solves the difficulty of reading residual field maps because of its bipolarity. The RTP allows positioning the observed aeromagnetic anomalies on the top of their source's bodies [17].
- Upward continuation (UC): It is a low-pass filter and a convolution of the original map with a geometric operator of upward continuation at the field's vertical continuity [18].
- Euler deconvolution (ED): To assess the depths of the magnetic sources, ED was used. It is based on the equation of Euler homogeneity; to scan through the gridded field, it uses a deconvolution window. By repeatedly solving Euler equations' linear system, the window is pushed over the aeromagnetic anomalies to obtain the required solutions [19, 20, 21].

4. Results and Discussions:

Sophisticated technics were utilized for aeromagnetic data. It provided geological and structural details that enormously helped to understand the morphology of the NEM zone. In the coming paragraphs, we will shed light on our work's fruits and give our interpretations.

4.1 Residual magnetic anomaly:

The residual magnetic field (RMF) map (Figure 1) of this sector presents different shapes and intensities of magnetic anomalies. Those variations are reflecting the magnetization contrast of the subsurface. The intensities range from -170 to +230 nT, and sizes range from a few kilometers to 60 km. The polarity illustrated in the map was generally normal since the axis joining the two lobes (negatives and positive) was oriented North-South.

Three types of anomalies were shown: sub-circular anomalies. The first one is located above Guercif town, it possesses a significant size extending over 26 km and a peak of 120 nT, and the second anomaly is even closer to Rchida town, it has the same intensity of Guercif anomaly but elongated in East-West direction and extends over 67 km in length and 12 km in width. Then complex low amplitude anomalies are found in the TOC. Other anomalies situated between Tourirt and Jerrada interfere with each other registering high intensities 120 nT to 160 nT and line up in a WNW-ESE trend. Although, Central High Plateaus lands presented in the extreme southeast of RMF map and area between Guercif and Taourirt are magnetically calm.

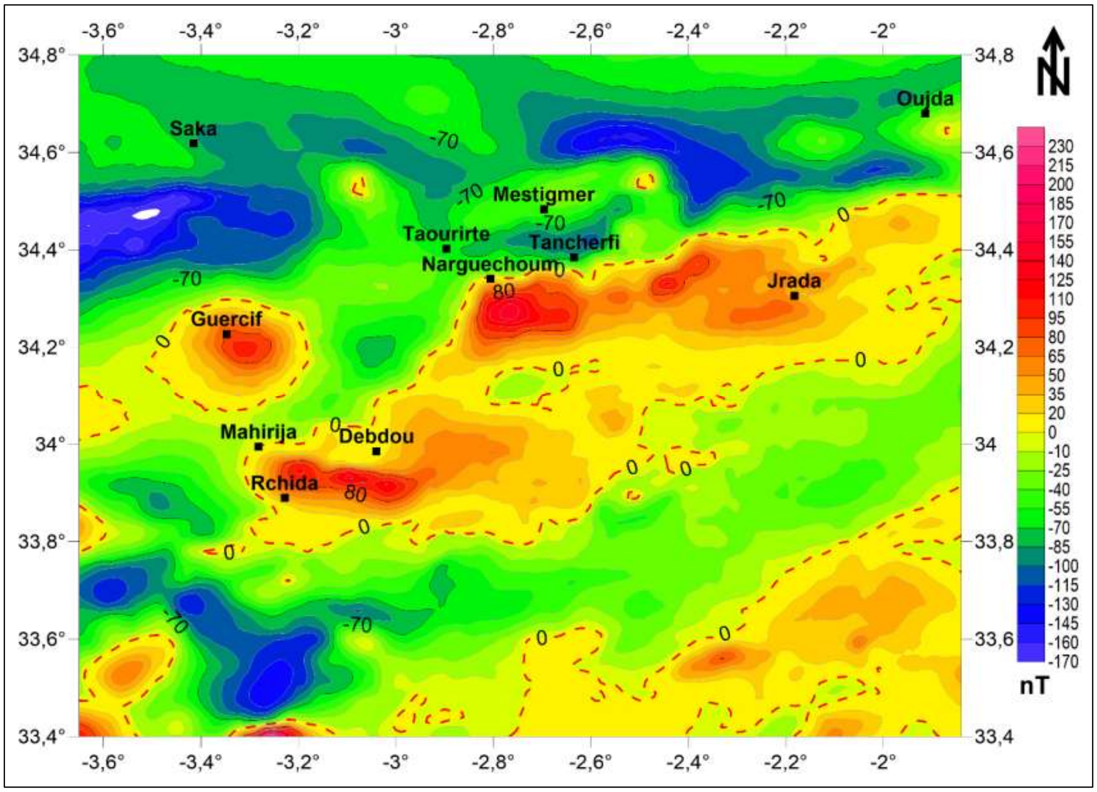

Figure 1: Residual magnetic field map of the study area, the red curve corresponds to 0 nT.

4.2 Reduced to the pole (RTP) magnetic anomaly

An augment of intensities was mentioned in the RTP map (Figure 2) in addition to a minor northward displacement of the lobes. The established map shows different intensities, shapes and orientations of anomalies. The positive ones are labeled P1, P2, P3, P4, P5, P6, P7, P8, P9 and P10, they are concentrated in the center of the zone, or the negative ones (N1, N2, N3, N4 and N5) are located in the north, northwest either southwest of the Saka.

To associate etch magnetic anomaly to its geological expression, we have digitized geological formations referring to Morocco's geological map at a scale of 1/1000 000 and projected them to the RTP map (Figure 2).

As a first observation, an anomalous zone (AZ) was highlighted on the map, it joins three anomalies P2, P3 and P6, generally has NE-SW direction and separates the Guercif-Tafrata Basin from the HP. So AZ certainty reflected the fault corridor, which separated the Middle Atlas Basin to the NW from the Jurassic Platform to the SE of HP.Then N1, N2, N3, N4, and N5 anomalies record a low magnetic response, and they are probably related to the Tertiary and Quaternary coverage and/or Triassic-Jurassic deposits.

P1 and P5 situated respectively above the Guercif town and near the Saka region may relate to the Tertiary and Quaternary volcanic occurrences outcropping in the study area's vicinity. Next, The P2 anomaly near Mahirija is positioned on the top of the Variscan granites of Debdou. We suggest that iron oxides are referred to in the Devonian basement since granites do not produce appreciable magnetic anomalies. Following the East of Debdou, P3 and P4 anomalies are maybe caused by the Triassic basalts that enveloped Debdou and Mekkam inliers. Now, the P6 and P7 anomalies, which are striking in NE–SW and ENE-WSW directions respectively, are indeed explained by Paleozoic metamorphic basement structures (Tancherfi, Bourdine inliers) and P8 anomaly is oriented E-W supposed to be related to the Visean volcanogenic complex of Jerada, and/or iron and manganese mineralization. Finally, the P10 anomaly positioned above on Oujda town is most likely the source of volcanic emissions distributed around the Oujda region. P9 anomaly has no evidence on the surface.

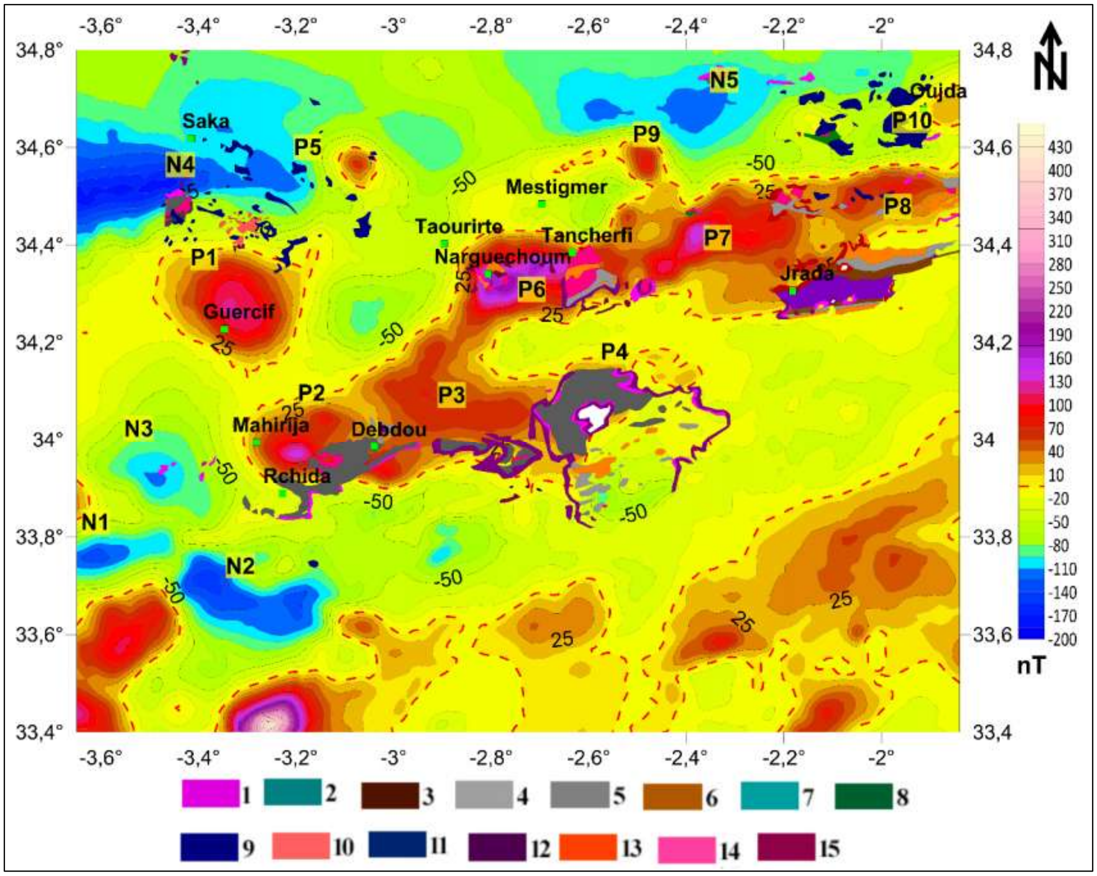

Figure 2: The residual magnetic anomaly reduced to the pole superposed on the study area's simplified geological map (Px: Positive anomaly, Nx: Negative anomaly. The red curve corresponds to 0 nT. 1=Trias 2= Westphalian Namurian and / or Paralic Stephanian 3= Bashkirian Namurian (Béchar) 4=Viseen 5= Devonian Dinant 6=Middle and Upper Devonian 7= Silurian 8= Ordovician 9= Plio-quaternary Ankaratritis Basalts 10= Messinian Trachytes- Rhyolites 11= Pontico-Pliocene Ankaratrites and Diatremes 12= Triassic with undivided basalts 13= Rhyolites Dacites latites Primary Trachy-Andesites 14= Granites of the Hercynian massif 15= Hercynian Dolerites.

4.3 Euler deconvolution

Structural mapping of magnetic lineaments was achieved due to Euler solutions (Figure 3). They were obtained for the structural index value of 0 to represent two-dimensional features (linear fault or a high throw contact). We use a window size of 10x10 and a maximum depth tolerance of 10 % data points to identify the possible subsurface accidents from the observed aeromagnetic data. Consequently, ED source locations are represented with four different symbols depending on the estimated depth values. The depths values range from 0 to 2 km, 80 % are less than 1.5 km.

The interpreted lineaments basing on ED solutions indicate major elongated E-W and ENE-WSW faults. They characterize the deep structure setting of the Taourit-Jerada-Oujda zone and their depth reaches 1.5 km. We also note N-S and NE-SW small trends that we interpreted as satellite faults that record the same depth but do not exceed 10 km of length. Those faults follow Alpin logic directions except for the major ENE-WSW Hercynian fault. It traversed Jerada basin and presented the extension of a mapped fault. From Narguechoum to Rchida (including Horst belt and Debdou region), this area was characterized by ENE-WSW, NE-SW and E-W trending faults. We can thus advance that accidents affect the basement and be inherited at least from Hercynian orogenies.

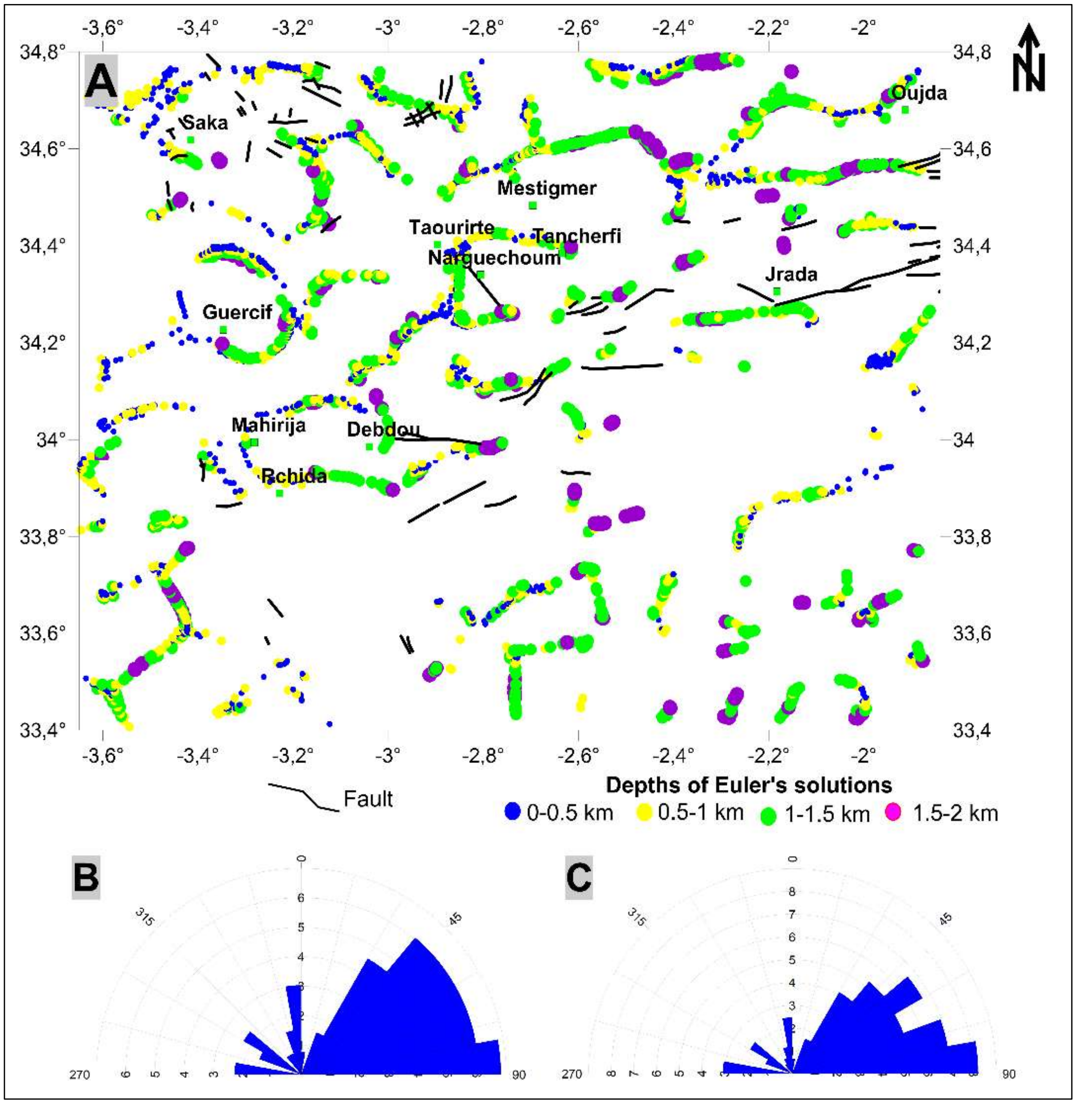

Figure 3: A) Synthetic structural map of the main lineaments and magnetic contacts obtained by Euler deconvolution. Directional rosette of B) Frequency C) Lengths.

5. Conclusions:

Tactic geological exploration highly demanded applying crucial magnetic techniques previously cited in addition to the challenging fieldwork. Those techniques allow displaying hidden accidents and provide missing information about geological structures of NEM for our case. Our main findings are:

- According to the RMF map, the Positive anomalies that recorded high intensity could be related essentially to (1) Tertiary and Quaternary age volcanic lava outcropping in the Saka and Oujda regions.(2) Paleozoic metamorphic basement (Tancherfi, Bourdine inliers...).(3) Iron and manganese mineralization, which are concentrated in the Triassic beds in contrast with negative anomalies, corresponded to superficial formations such as Quaternary and Tertiary cover and/or Triassic-Jurassic sedimentary deposits.
- From RTP and ED maps, we can notice; (1) E-W fault of Rchida-Debdou that can reach the tungsten mine belongs to Hercynian orogeny. As a result, it was a perfect guideline for new mineralization. This latter conclusion has been proved by the gravity study done on the Guercif-Debdou-Mekkam region [11]. It demonstrated that this interesting fault gave rise to generally uplift of the basement and either the establishment of granite (Alouana granites). (2) NW-SE

strike-slip faults and ENE-WSW to E-W folds, limited morpho-structural units of Taourirt-Oujda Corridor, belong alpine tectonic because they give rise to alkaline volcanic activities (Aïounites and Mestigmérites) and by Calcalkaline volcanic event well represented around Oujda area. (3) Boundaries faults construct basin boundaries like NE-SW long fault, which separate the Guercif-Tafrata basin and high plateaus. Also, NE-SW fault formed a triangle with E-W, N-S trending faults illustrated under Narguechoum. They participated in constructing small Jurassic triangular basins. (4) Most of those accidents did not exceed 2 km of depth and the extension of 80 % of them was less than 1.5 km underground.

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