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CHARACTERIZATION OF MINERAL MEPOSITS USING THE MAGNETIC METHOD: THE CASE OF THE AÏN BEIDA MINE IN BOUARFA, MOROCCO

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Abstract

Geophysical methodologies represent a paramount approach for assessing the mining potential of a given area. Among these methodologies, the magnetic method stands out as indispensable for the exploration of metalliferous deposits. This method facilitates the characterization of both the lateral extent and vertical depth of anomalous bodies within the surveyed region, as discerned from their influence on the total magnetic field. In the case of the manganese-rich mining zone situated in Bouarfa, particularly in Aïn Beida, the mineral deposit genesis typically involves the association of manganese with ferruginous minerals, significantly perturbing the total magnetic field. However, the initial findings necessitate meticulous corrections to isolate the exclusive impact of anomalous bodies on the magnetic field. Accordingly, correction procedures must address diurnal variations prior to executing a Reduction to the Pole (RTP), enabling the identification of well-defined and unipolar anomalies crucial for precise delineation of potentially mineralized zones. Integration of spatially interpolated data yields comprehensive maps delineating areas of mining significance and elucidating pertinent geological phenomena within the study area. Subsequently, employing 2D modeling techniques on magnetic survey results facilitates accurate estimation of mineralized horizon extents and thicknesses. Ultimately, these synthesized maps serve as valuable guides for subsequent mechanical prospecting endeavors aimed at corroborating findings derived from geophysical methodologies.

Keywords:

Geophysics;
Magnetic method;
Mining;
Manganese;
Mining Geology.

1 Introduction

In the realm of subsurface exploration, the utilization of advanced geophysical methods has become indispensable for unraveling the secrets hidden beneath the Earth's surface. Among these methodologies, magnetic prospection stands out as a powerful and versatile technique, offering a unique window into the subsurface environment. In the domain of geophysics, the examination of the Earth's magnetic and gravitational fields, both representative applications of the physics of potential fields, is collectively referred to as potential methods. These methodologies encompass two distinct approaches dedicated to scrutinizing variations within each field: magnetic methods and gravimetric methods. The current investigation emphasizes a predominant focus on the magnetic method within the context of our research pursuits.

In contemporary scientific practice, these disciplines find widespread application in the investigation of the shallow subsurface, serving dual purposes in the pursuit of anthropogenic artifacts and the examination of natural phenomena [1]. The focal subjects of interest in the present study primarily pertain to geological and structural aspects, particularly within the context of mining prospecting, with a specific emphasis on manganeseiferous formations [12], [13].

The objective of the present investigation is to proffer methodological directives for the recommencement of exploitation activities within the deposit. This endeavor entails the implementation of a comprehensive geophysical campaign within the previously exploited region of Ain Beïda at the

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Bouarfa mine in Morocco [2]. The initiation of this campaign conforms to established practice, wherein a preliminary geological examination [14], [15] of the designated area precedes the execution of geophysical measures.

2 Context and Methodology

2.1 Geological and mining context

The Bouarfa manganese deposit is located in the province of Figuig, two kilometers north of the town of Bouarfa. The study area thus belongs to the northern border chain of the eastern high atlas, it is bordered to the north by the Jbel Bou Arfa, see fig. 1. It is a folded structure dating from the Jurassic to the Cretaceous which ensures the junction between the Central High Atlas and Saharan Atlas in Algeria. Its extensive tectono-sedimentary style in tilted blocks has generated a structure of ripples and depocenters.

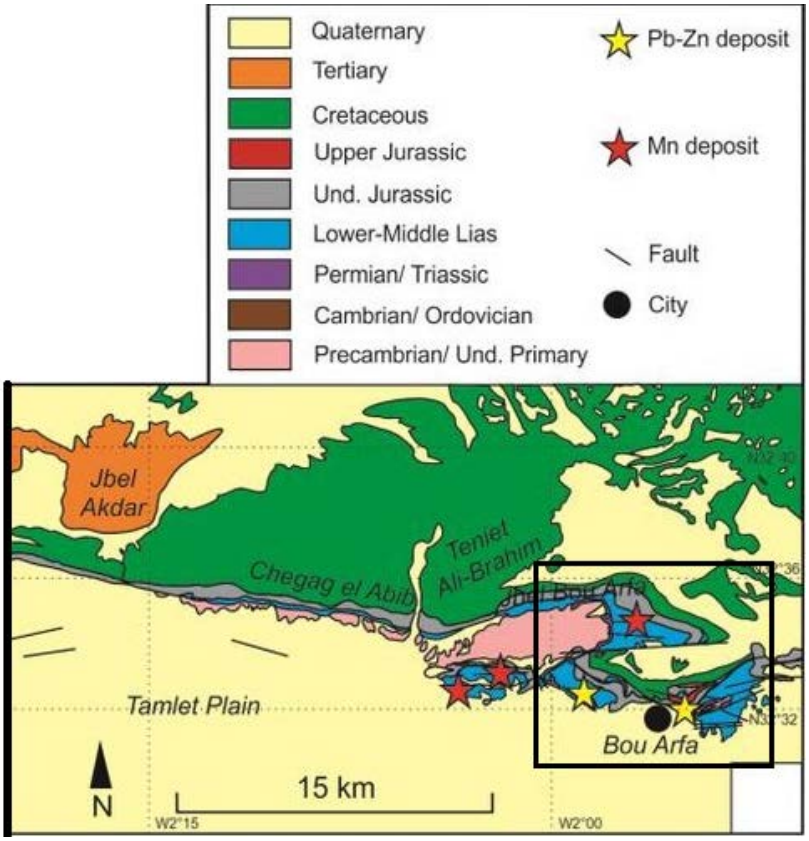

Fig. 1: Extract from the geological map of the Bouarfa Region [2], [14], the study area is framed.

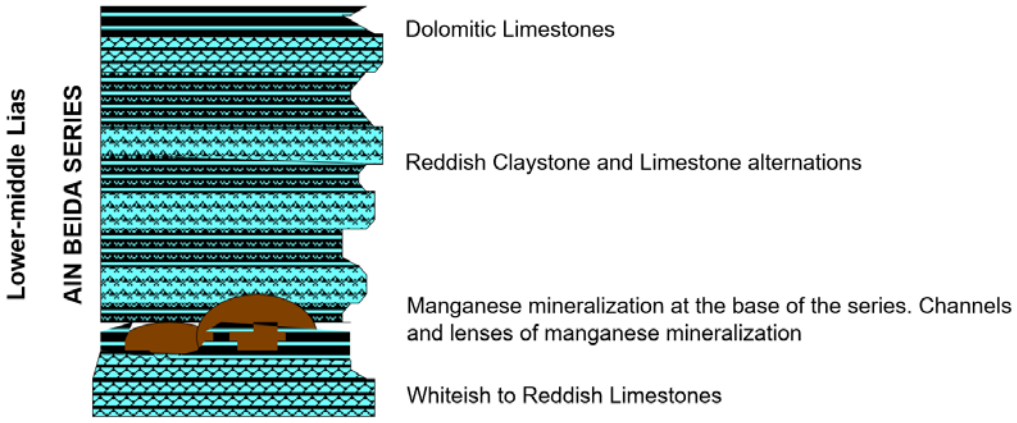

Fig. 2: Synthetic stratigraphic log of the Ain Beida formation.

The lower limit of the Aïn Beida formation, which interests us in our study, is defined by the arrival of a well-regulated and rhythmic alternation, of limestone with a whitish patina, in centimetric beds then in centimeter to decimeter beds and reddish argillites. The limestone beds are stromatolite, algal carpet with manganese and iron oxide. The beginning of this formation is characterized by metric to decametric On Lap synsedimentary tectonics. At the base of the Formation, mineralized manganese lenses or “manganese channels” are intercalated.

Rough sea facies (external platform or proximal slope) were encountered in this Formation: presence of oolites, pisolites and grainstone. From halfway up the Ain Beida Formation, the limestone beds become thicker. Dolomitization affects the decimetric limestone beds by giving fine-grained dolomitic limestones, then these are welded together to form reinforcements of 2 to 3 m. At the top of the Formation, horizons of iron and manganese oxides are well individualized in the beds of oolitic limestone. The series experiences a lateral variation since its power decreases to disappear completely towards the North-West of the sector; it can reach 50 to 70 m to the East of the sector. The upper limit of the Formation is made by lateral passage west of Hammraouet, from carbonates to arkoses of the Bouarfa Formation. The age of the Ain Beïda Formation is attributed to the Pliensbachian [2].

The type of mineralization found in this formation is by far the most important in the region, it is located in outcrop on the hillside of the Ain Beida anticline, it is linked to the base of the Formation of Ain Beida. This mineralization presents itself according to a morphology of channels about ten meters deep and wide, decametric in length and surface outcrop length of 1.2 km [3]. These channels are intercalated in the first benches of the carbonated and clayey rhythmic series and are submerged and seem to converge towards the North without disappearing towards the same source. The same paragenesis (without quartz and barite) of the Barre de Hammraouet is found in Ain Beida (manganite, pyrolusite, cryptomelane hausmanite) and iron (goethite, limonite and hematite) linked to the wall rocks (roof and side walls) by the means of a reddish clay joint.

2.2 Magnetic Method

The most intriguing technique for identifying the manganese deposit of Ain Beida is magnetic prospecting, which makes sense given the origins and characteristics of the mineralization [3, 4].

The magnetic method is based on measuring the total magnetic field, which will experience disruption in the presence of manganese ore, as in our case study, associated with iron oxides, due to the difference in magnetic susceptibility between the surrounding rock and the mineralization [5].

Therefore, magnetic prospecting is the process of looking for and detecting deposits, rocks, and formations using the anomalies or localized fluctuations in the earth's magnetic field that they cause.

Work carried out in situ:

The measurement work that was carried out in our study site consisted of:

6 Magnetic Profiles, spaced 50 to 150m apart, depending on the difficulties imposed by the relief, with a cumulative linear distance of 4.15 linear km with measurement stations 25m apart.

The details of this work are shown in Fig. 3.

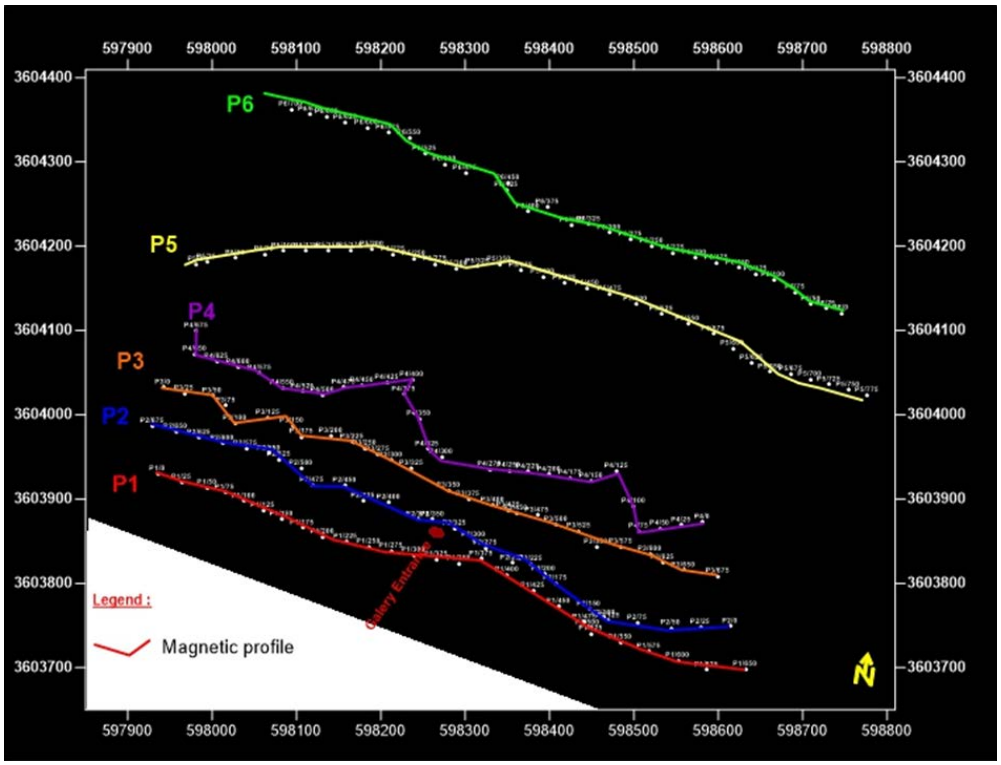

Fig. 3: Measurement profiles location map.

3 Results and discussions

3.1 Total magnetic field map

The Drawings of iso-gamma maps will be possible thanks to the data from the magnetic investigation. This will display the gradients of the magnetic anomalies, which will subsequently provide information about the locations of the mineralized zones on the map as well as the likelihood that they exist.

The whole field's magnetic map is the outcome of graphically representing the total field's values that have been measured and adjusted for the diurnal variation effect—a solar position-related influence. The direction of the body with respect to magnetic North, the magnetic susceptibility of the material constituting the body sought, its shape and extent, its depth, and other factors all play a major role in how magnetic anomalies arise.

The map of the total field shows a succession of bipolar anomalies whose axis is East-West. The minima are located to the north in profile 4 from station P4/0 to P4/275 and to the south of station P1/300 to station P1/550.

The maximums are found at the level of profiles P2 and P3 from stations P2/300 to P2/0 and from P3/350 to P3/650. Similarly, a large unipolar anomaly is located throughout the extreme western part of profiles 2, 3 and 4.

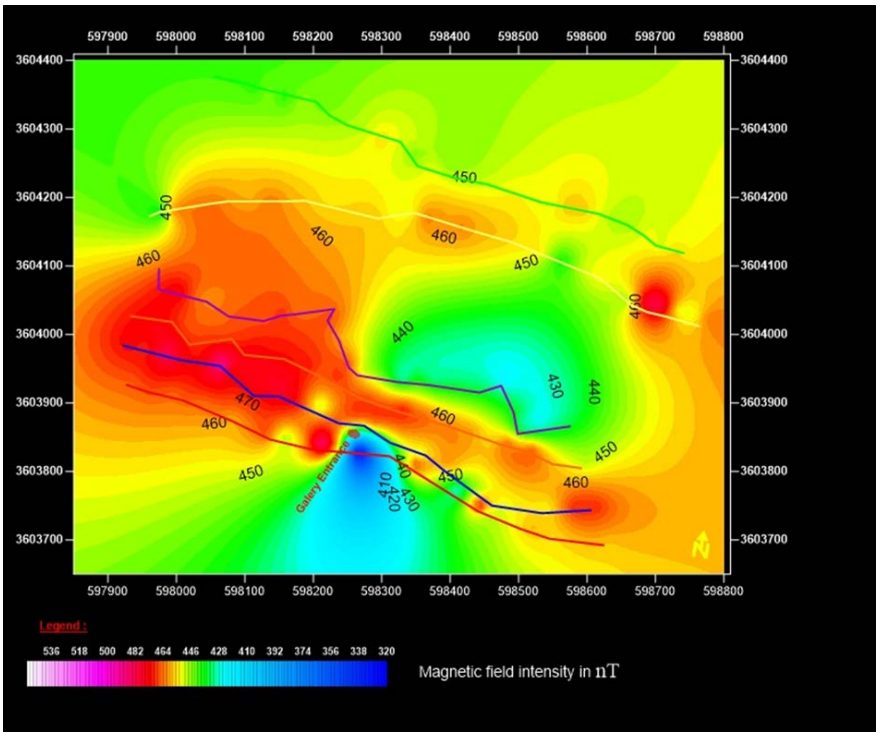

Fig. 4: Total Magnetic Field Map.

3.2 Reduced to the pole magnetic map

The reduction to the pole (RTP) transformation is a commonly used method to remove the dipolar effects of magnetic data that are not at the Polar Regions [7].

The resulting map is the so-called magnetic map reduced to the pole (see fig. 5), which will allow us to have well individualized and unipolar anomalies [5, 8, 9].

The map reduced to the pole shows three large magnetic anomalies positioned as follows:

The most important is located on profile 3 from station P3/350 to P3/650 with a high probability of an extension towards the SE. The axis of this anomaly is oriented NNW-SSE.

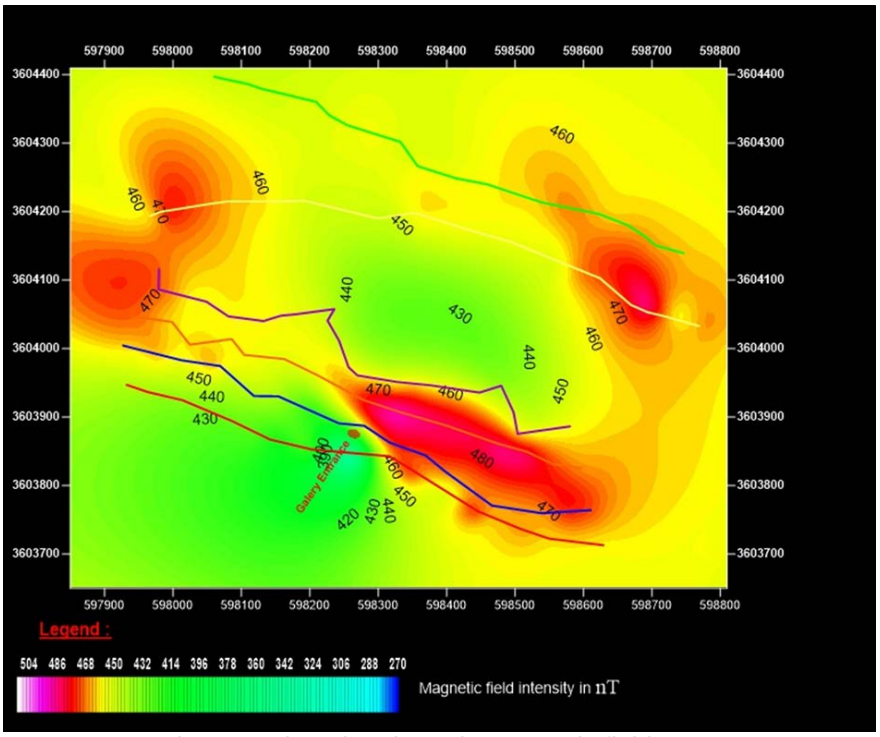

Fig. 5: Reduced to the pole magnetic field map.

The second anomaly is located NE of the area between stations P5/575 and P5/700 with a NW-SE axis.

The extreme NW zone is limited by a large anomaly with two maxima, one towards profile P5/25 and the second at the end of profile 4 towards station P4/650.

4 Modeling of Reduced to the Pole Magnetic Profiles

In order to deduce the geometric characteristics and the physical properties of each anomaly, a numerical modeling proves to be the best recognition tool.

Euler deconvolution was chosen as a method for inferring the location and depth of subsurface sources of magnetic anomalies from a measured magnetic field. It is based on the assumption that the observed magnetic field is the convolution of the magnetization of the subsurface sources with the response function of the Earth's magnetic field. By using the Euler equations, which describe the relationship between the magnetization and the magnetic field, it is possible to deconvolve the observed magnetic field to estimate the subsurface sources of the magnetic field [10].

The magnetic profiles modeled are P3 and P5, (see fig.6). Their choices were based on the fact that they come across the most important anomalies detected.

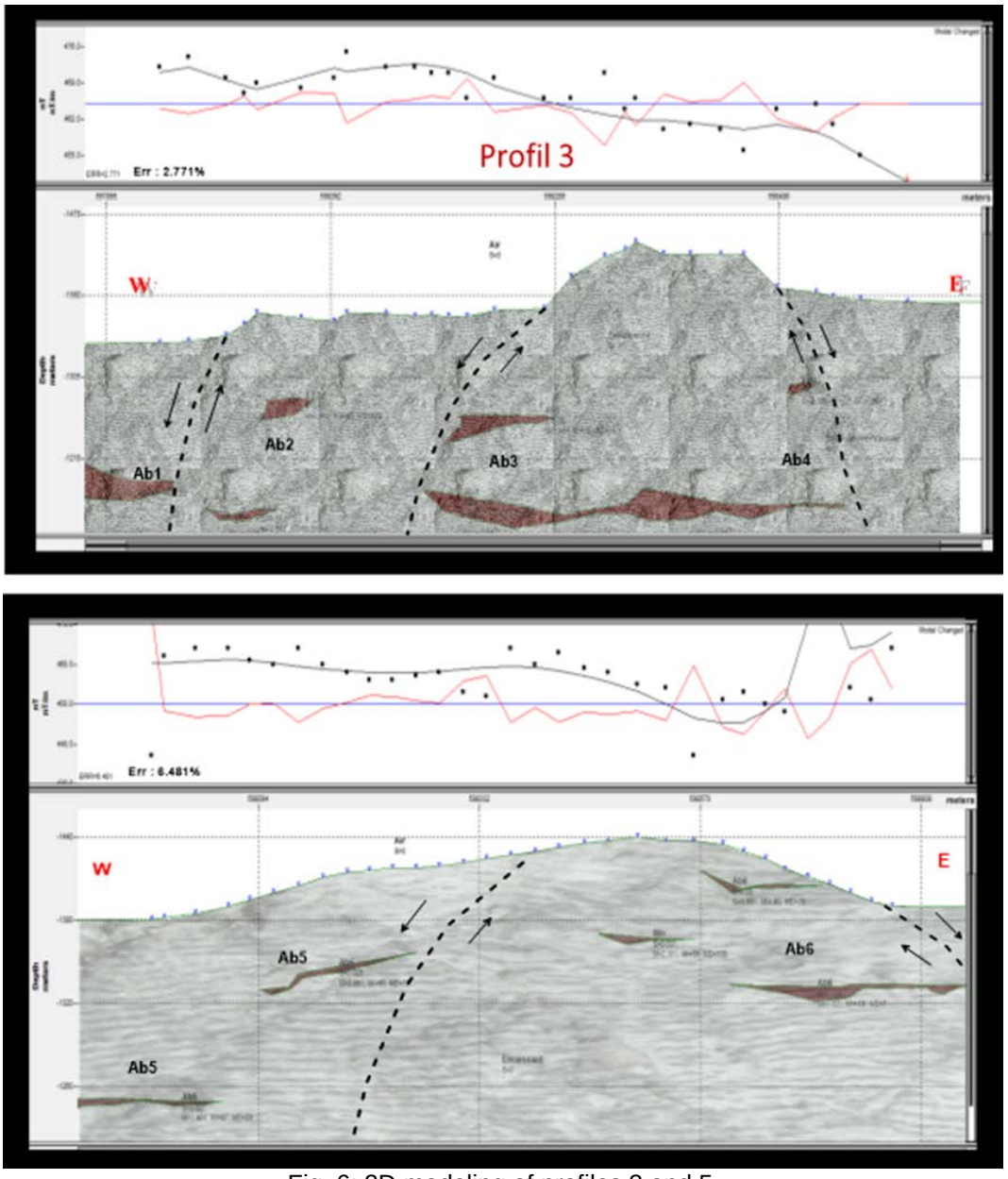

Fig. 6: 2D modeling of profiles 3 and 5.

The modeling of the P3 and P5 profiles (Fig. 7) shows a series of anomalies similar to mineralized lenses formed in two mineralized levels, which will later be named Level 1, and Level 2.

Level 1 is the shallowest and thinnest compared to level 2. The calculated depths are very variable. The explanation of the ascents and descents of these levels are explained by the set of faults schematized in fig. 7 by dashes in black color.

Only the Ab6 anomaly, located to the northwest, is considered to be formed by a single shallow mineralized level.

4.1 Interpretation and Synthesis

Anomalous areas are distributed as shown and named in the map below (Fig.7).

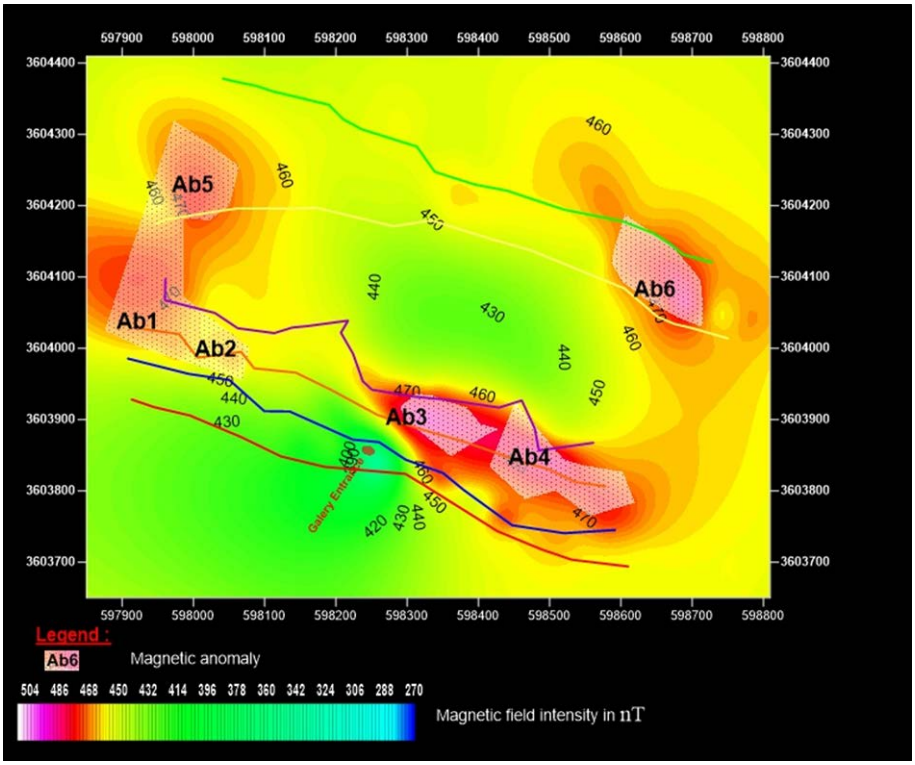

Fig. 7: Location of anomalies from the reduced to the pole map.

The latter summarizes the locations of the main anomalies. We note that the anomalies Ab1, Ab2, Ab3 and Ab4 are aligned but seem to be caused by sources of the same nature but dissociated. Certainly, they are affected by the interplay of several faults or metallogenic phenomena.

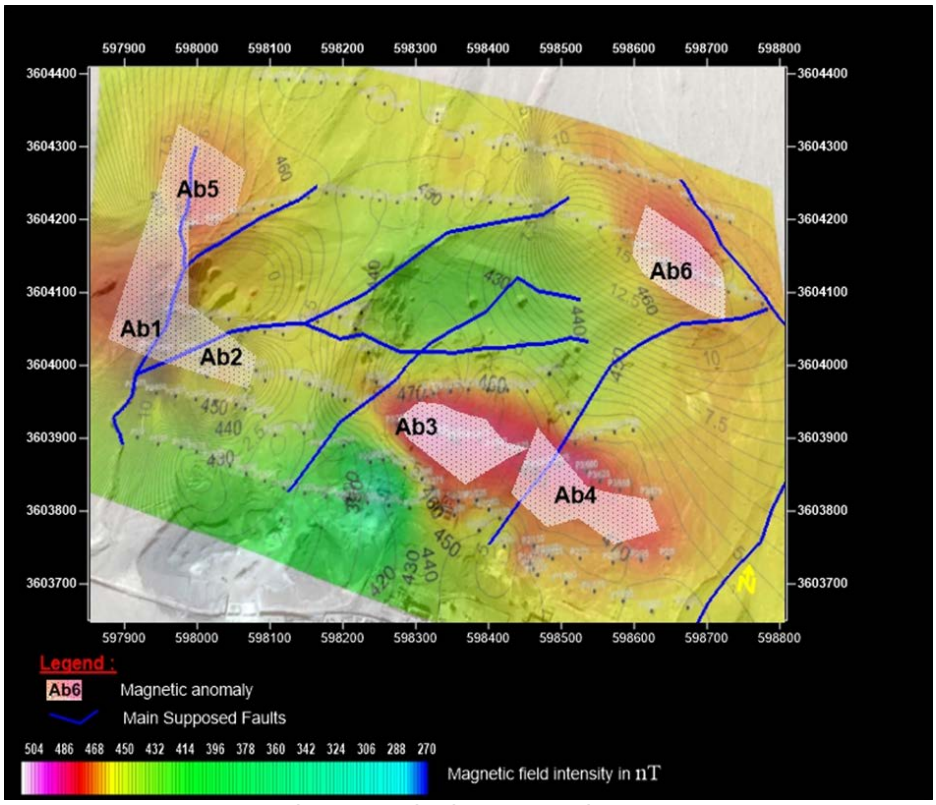

Fig. 8: Synthetic Structural map.

The map in fig. 8 summarizes the probable faults and the observed direction of play, which affected the mineralized zones. The importance of these faults will be useful in all direct research work such as drilling and/or execution of reconnaissance galleries.

The main faults subdivide each anomaly into dissociated mineralized portions. This is clearly seen for anomalies Ab1 and Ab2, Ab3 and Ab4 and the same for Ab1 and Ab5.

The modeling of the magnetic profiles gave us information on the depth range of each anomaly and probable thicknesses.

Table 1 summarizes the measurement stations close to each anomaly and the calculated depths as well as the vertical crossings of the mineralized levels.

Table 1: Estimated depths of inferred anomalies.

Anomalies	Stations	Stations Altitudes [mNGM]	Head Altitude [mNGM]		Floor Altitude [mNGM]		Depth [m]		Thickness [m]	
			Lvl 1	Lvl 2	Lvl 1	Lvl 2	Lvl 1	Lvl 2	Lvl 1	Lvl 2
Ab1	P3/0-P4/675	1344	X	1189	X	1180	X	155	X	9
Ab2	P3/100 - P3/125	1369	1278	1162	1269	1157	91	207	9	5
Ab3	P3/400	1375	1261	1169	1252	1154	114	206	9	15
Ab4	P3/575	1401	1296	1168	1289	1161	105	233	7	7
Ab5	P5/25-P5/50	1414	X	1347	X	1343	X	67	X	4
Ab6	P5/650-P5/675	1415	1406	1333	1402	1327	9	82	4	6

5 Conclusion

The application of practical modeling techniques for magnetic anomalies emerges as a significant methodology within the realm of geological investigations. This approach involves the quantification of magnetic susceptibility in both ore deposits and the encompassing rock formations. The measured values are subsequently employed as crucial parameters in the modeling process, facilitating the discrimination between ore bodies and their geological surroundings. The utilization of practical modeling, rooted in the precise measurement and interpretation of magnetic susceptibility, enhances

the accuracy and efficacy of characterizing subsurface structures, thereby contributing to a comprehensive understanding of geological formations and aiding in targeted resource exploration.

Hence, we were able to draw attention to the many mineralized axes and the faults that affect them thanks to the geophysical prospecting campaign we conducted using the magnetic approach. This has made it easier for us to identify various points of interest that will act as a foundation for the mechanical survey operations [11], which will eventually provide a clearer picture of the mineral reserves in the study region.

Nevertheless, the magnetic approach by itself is insufficient to assess a deposit's economic potential.

Consequently, the imperative for an integrated prospecting strategy arises. In order to substantiate the orientations of mineralized axes and ascertain the depths of anomalies gleaned from magnetic surveys, the incorporation of the grounding resistivity approach becomes requisite. This complementary methodology, grounded in electrical resistivity measurements of the subsurface, serves as a corroborative tool to augment the insights derived from magnetic surveys. The synergistic application of magnetic and resistivity data contributes to a more comprehensive characterization of subsurface features, enhancing the accuracy and reliability of mineral exploration assessments.

Finally yet importantly, it would be intriguing to execute electrical soundings above the discovered anomalies in order to have an even better understanding of the depths of the mineralized levels.

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