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Geophysical Significance of the Senegalo-Mali Discontinuity: Evidence from Secondary Structures, Kédougou-Kéniéba Inlier, Western Mali

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Abstract

The present study focuses on the analysis and description of lineaments interpreted as secondary structures to describe the nature of Senegalo Malian Discontinuity. These lineaments cross-cut the large north-south oriented transcurrent lithospheric structure known as the Senegalo Malian Discontinuity (SMD). Two lineaments were selected oriented NNE (N15˚ to N25˚), one at Dialafara and one at Sadiola. Four profiles on each lineament of these 2 zones, so that there were 2 on each side of the SMD. The ground data collected were processed using proper parameter and software. Some filters were applied to enhance the signal level. These ground data were later compared to the existing airborne magnetic data for consistency and accuracy using the upward continuation filter. The results show that the quality of ground data is good. In addition, the ground magnetic data show the presence of certain local anomalies that are not visible in the regional data. The analytical signal was also used to determine domain boundaries or possible contact zones. The contact zone can be highlighted on certain profiles such as L300 and L600. The study showed that the west and east sides of the SMD are not the same. Secondary structures become wide when approaching the SMD on both sides. They are also duplicated to the east of the SMD when we move progressively away. In the Dialafara area, the ground magnetic data intersect an interpreted fold. The results of this work confirm the presence of the secondary structures and their evolution in relation to the SMD. The relationships between the secondary structures in the Dailafara and Sadiola zones and their relations with the SMD are highlighted. The technique used in this study, is an important approach to better description and interpreting of regional structures using the secondary structures and proposing a structural model.

Keywords

Kédougou-Kéniéba Inlier, Senegal Malian Discontinuity, Secondary Structures Mapping, Magnetic Data

1. Introduction

The increased demand for mineral resources for human needs in the world also implies the increase in techniques for the exploration of these resources. The mineral exploration is complicated as most of the minerals on the surface are exhausted, which implies deep exploration methods. However, deep exploration requires a strong investigation and heavy financial means for mining exploration companies and it takes a lot of time. So, the knowledge of the geology at depth becomes a major challenge for researchers and mining exploration companies. To achieve this challenge, the use of geophysical method combination to build depth model is the main tool [1]-[3].

The geophysical methods are the greatest tools in sub-surface exploration especially when there is a thick overburden (lateritic cover) that hides most of the outcrops. These data methods constitute critical sources of information for geology mapping and resource exploration [4] [5]. These data are useful at all stages of regional mineral exploration programs and offer the chance to explore the subsurface distribution of geological properties [6]. The integration of geophysical data with the regional geological data have been proved to be useful for the reconstruction of the lithotectonic evolution of an area [7]-[10]. As the architectural configuration of a region takes its source from the structural models, it will be efficient to focus more on the search for large structures at the regional scale as these structures are considered as the primary plumbing systems for magmas and mineralizing fluids migration from deep crust leading to deposit formation in the upper crust [11] [12].

The Malian part of the KKI (**Figure 1**) hosts many exploration and mining companies. With these potentialities, this part of KKI becomes a good area for characterizing potential structures. The characterization of the regional structures is generally based on geophysical data analysis. It helps to better understand the regional tectonics of the area. The analysis of previous aeromagnetic data has made it possible the detection of certain magnetic signatures [13] [14], the largest of which was reported by [15] from field and satellite data called the Senegalo-Malian discontinuity (**Figure 1**). The Senegalo-Malian discontinuity is a magnetic signature visible on the regional magnetic data (**Figure 2**). This signature has been interpreted by several studies with different descriptions and interpretations

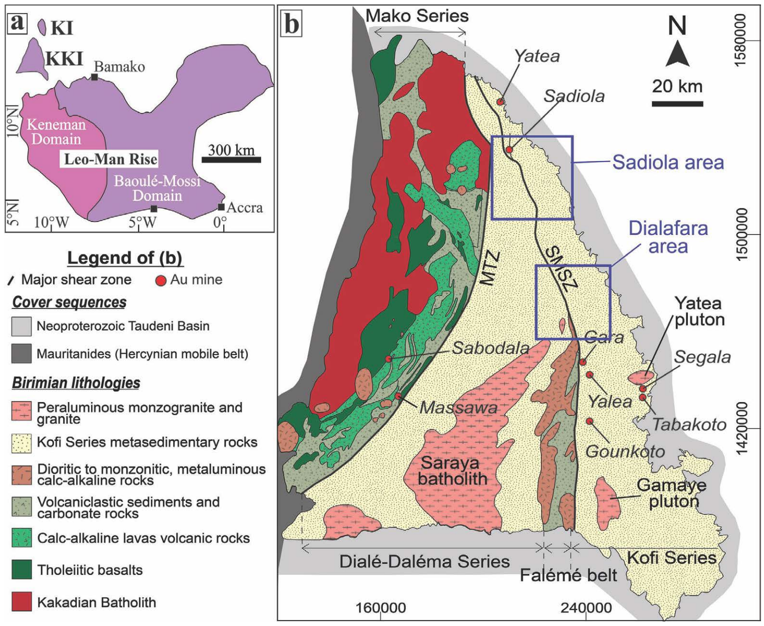

Figure 1. (a) Simplified geological map of the Leo-Man Shield. (b) Geologic map of the Paleoproterozoic Kédougou-Kéniéba inlier (modified from Lambert-Smith et al., 2016 [18]).

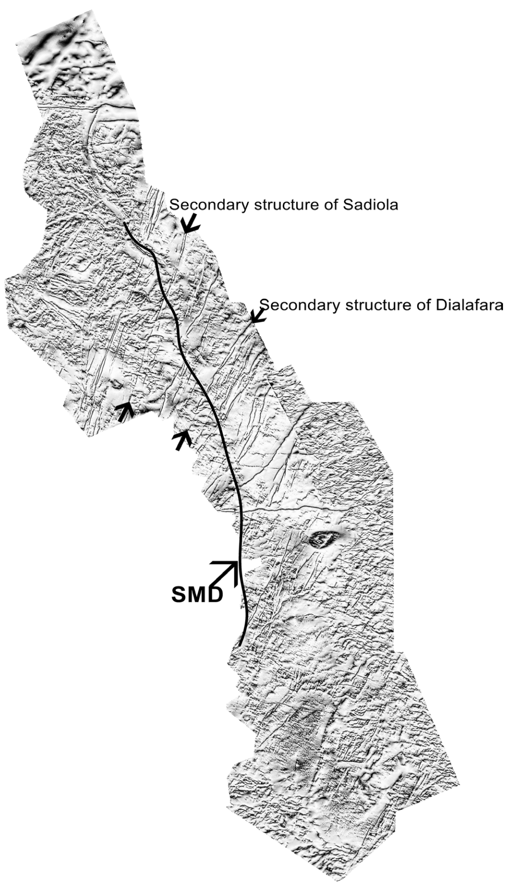

Figure 2. The selection of the secondary structures (apophysis) of the Senegalo-Malian discontinuity on the regional magnetic total field gradient map.

based on geological and geophysical data [13] [15]-[19]. This magnetic signature was firstly named Accident Senegalo-Malian. Recently the name assigned is the Senegalo-Malian Shear Zone. This signature is designated here as the Senegalo-Malian discontinuity (SMD).

Other researchers have also questioned the existence of this structure, and the qualifiers attributed to the signature [20]. Nevertheless, the structure seems to be the control of useful substances in this zone with the arrangement of several deposits along this magnetic signature [17]-[19]. In light of all preceding, this study will allow the confirmation of the existence of the SMD by using the ground and airborne geophysical data in order to clearly define the secondary structures and their relation with the SMD.

2. Regional Geological Setting

The Kédougou-Kéniéba Inlier (KKI) corresponds to a window through Paleoproterozoic terranes of the West African Craton (WAC). The KKI straddles Senegal and Mali and is subdivided into four distinct parts [21]: the metavolcanic belts of Mako and Falémé, and the metasedimentary series of Dialé-Daléma and Kofi (**Figure 1**).

The Mako belt, a predominantly tholeiitic volcano-plutonic complex, is a 20 - 40 km band of greenstone that forms the western part of the KKI. It is elongated NNE-SSW to NS (**Figure 1**). Its eastern border is defined by a major tectonic structure, the MTZ (Main Transcurrent Zone) [16] marking the limit with the Dialé-Daléma series. The Dialé-Daléma series is tectonically juxtaposed with the eastern margin of the Mako belt along the MTZ (**Figure 1**). The series includes the old Dialé and Daléma series, separated by the Saraya batholith [22]. The Falémé belt has been recognized as a metavolcanic entity in its own right [21]. The Falémé belt (**Figure 1**) is an NNE-trending belt of metavolcanic and intrusive rocks about 16 km wide. Plutonic intrusions of the Falémé series are represented by the Balangouma, Falémé Sud and Boboti plutons [21] [23]. The Kofi series (**Figure 1**) is located east of the Senegalo-Malian discontinuity [15]. The Koffi series is composed of detrital metasedimentary units, carbonate rocks and breccias and is crossed by monzodiorite and monzogranite massifs [23] and mafic dykes [24].

The organization of the Paleoproterozoic greenstone belts and metasedimentary series as well the granitoid plutons of the KKI were deformed and metamorphosed during the Eburnean orogeny [25]. A polycyclic evolution has been described within the KKI [13] [16] [19] [26]-[28]. Thus, most studies agree in describing an early period of shortening characterized by crustal thickening (D1), followed by a period of transcurrent tectonics (D2-D3) and fracturing (D4) with progressive evolution from a ductile to a brittle regime.

The D1 phase is marked by crustal thickening, as a consequence of NE-SW to ENEWSW horizontal shortening which is associated with SE verging thrusts and stratigraphic stacking with associated folding [26] [28]. The D1 phase is synchronous with the intrusion of granitoids within the Mako belt [28] [29]. The D2 and D3 transcurrent phases structures mark the main tectonic footprints of the KKI and mark a change in tectonic style from collisional to transcurrent deformation [28] [30]. According to the authors [19] [28] the deformation D2 and D3 are described such as 1) The D2 is characterized by large N-S strike-slip faults and shear zones. 2) D3 is the reactivation of early structures and the activation of ductile-brittle N-S to NE-SW trending sinistral shear zones accommodating NNW-SSE horizontal shortening. These transcurrent phases are associated with the widespread granitoid plutonism throughout the KKI [29].

3. Hypothesis

The size, extent and complexity of the magnetic signature, which correspond to the Senegalo-Malian discontinuity (SMD), has been the subject of several debates since the work of [15]. The existence of this structure is often questioned by some researchers [20]. However, other studies consider that the Senegalo-Malian discontinuity is probably responsible for the distribution of gold mineralization and other precious metals in the area [17]-[19].

Based on these considerations, this research project was established to find out whether:

- The significance of the highlighted magnetic signature. Is it a lithological contact zone or a regional structure?
- What are the significances of the secondary signature secant to the main signature? Are they apophyse or independent structures?
- Can the magnetic variations on either side of the main signature have concrete explanations?

This study focuses on secant secondary signatures to the large signature. It aims to realize the ground magnetic survey on a series of parallel profiles when moving away from the main signature. The main objective is to make 2D profiles to portray the characteristics of the secondary structures on both side of the signature. This article will focus only on the approval of the presence of these secondary structures and their relation with the SMD.

4. Materials and Methods

4.1. Ground Magnetic Survey Profile Determination

The choice of the areas was made on the basis of airborne magnetic data from the SYSMIN program. The SYSMIN project was carried out between 1997 and 2001 by the Malian government with the support of the World Bank in Mali South and Mali West [31]. During this survey, the plane was flying at an average altitude of 80 m. The survey lines direction was 180 degrees North and also the other at 335 in order to intersect all the existing structures in the area. The control lines were oriented 245 degrees North. The lines were spaced 200 and 400 m apart. These airborne data were corrected for diurnal effects and the 1995 IGRF model updated to 1996 was applied.

Some filters were applied on the raw airborne magnetic to select the secondary structures areas. The first derivative filter was applied on the airborne magnetic data afforded to choose the two secondary structures (**Figure 2**). The profiles have been chosen so that there are two profiles on each side of the Senegalo-Malian Discontinuity (SMD). The analytical signal filter applied on the airborne magnetic data was used to choose the profile on the secondary structures in the Dialafara and Sadiola areas (**Figure 3**). This choice is to better highlight the structural architecture when moving away from the SMD along these secondary structures. The analysis in this article focuses on 4 profiles in Dialafara and 4 other profiles in Sadiola. On each secondary structure, two profiles were placed on each side of the SMD. The technical survey characteristics of the profiles are described in **Table 1**.

4.2. Ground Magnetic Data Acquisition and Quality Control

The ground magnetic surveys were carried out in the two areas (Dialafara and Sadiola) in 2018. The reading magnetometers used were the GEM System (gsm-19w walking v 7.0 overhauser) with the novatel oemstar GPS for the survey. The base station magnetometer used was the gem gms-19. The continuous reading was used for the line magnetometers, and the reading for the base station was set at each 5 seconds. The profiles spacing were irregular due to the access in these areas. The characteristic description of ground magnetic survey profiles of Dialafara and Sadiola zones are presented in **Table 1**.

Table 1. Characteristics of the profiles Dialafara and Sadiola areas. Coordinates system used is based on the WGS84 and UTM map grid Zone 29N.

Profile	Azimuth	From		To		Total length (km)	Survey Zone
		X UTM	Y UTM	X UTM	Y UTM		
L0000	N345	223,307	1,470,966	220,862	1,478,553	7.4	Dialafara
L6000	N165	225,142	1,487,018	229,198	1,474,396	13.5	
L9000	N165	227,482	1,491,091	229,737	1,483,475	8.14	
L15000	N165	232,208	1,499,600	234,221	1,492,664	7.4	
L100	N345	211,749	1,490,601	209,973	1,498,454	8.3	Sadiola
L300	N345	215,245	1,508,273	213,079	1,516,461	8.5	
L400	N345	217,384	1,515,973	215,310	1,524,094	8.4	
L600	N345	222,250	1,529,700	220,800	1,535,450	6.3	
		TOTAL				**68.34**	

The data collected were corrected from the diurnal magnetic effect. The corrected data was imported into the software to create a database to perform the control quality.

Initially, this control was focused on the magnetometer signal quality (sq). The signal quality is measured by the sensor and named sq normally it is 99. At each

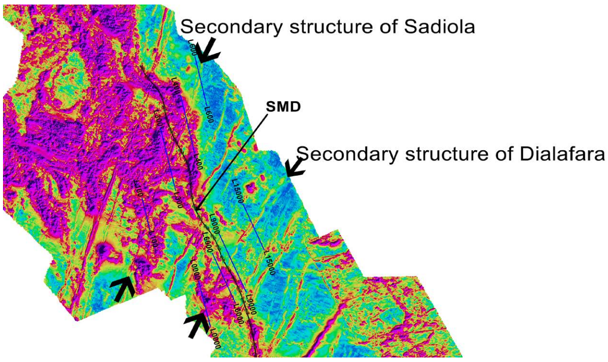

Figure 3. The ground magnetic survey profile on the secondary structures crosscutting the Senegalo-Malian discontinuity (SMD) on regional analytical signal map.

point measured the sq was checked. The sorting procedure was used to eliminate the values below 82. Secondly, the GPS position recorded was checked. The fourth derivative was also used to evaluate the noise level. Then an observation of the data variation curves was carried out in order to eliminate the irregular values of the magnetic field. The curve shape was the most important step of this quality control of ground data. These steps allowed to arrange and facilitate the comparison with the airborne magnetic data. After the data quality control, the data comparison was performed with the airborne magnetic data.

The corrected total magnetic field values in the database were presented in the form of amplitude variation (curve) (**Figures 4-11**). These figures represent respectively the total magnetic field of the profiles of Dialafara and Sadiola. On these same figures, the amplitude variation of the airborne magnetic data of the corresponding profiles are represented. The upward continuation of the ground survey was calculated to compare them to the airborne survey.

Filtering is a process of applying mathematical principles on geophysical data to improve the specifical feature [32]. The upward continuation and analytical signal filter were mainly used in this present project. The upward continuation filter [33], was proposed to facilitate the comparison between ground and airborne surveys. The 80 m value was chosen relative to the flight altitude used during the airborne survey [34]. The application of the upward continuation shows that the ground measurements were taken under normal conditions. The analytical signal filter described by [35] was also applied to the magnetic field data to determine the lithological boundaries that lie within the area.

5. Results

5.1. Profile Description and Analysis

5.1.1. Dialafara Area

The total magnetics field, the upward continuation as well as the analytical signal of the ground magnetic survey and the total magnetic field of the regional airborne magnetic data of the different profiles at Dialafara (L0000, L6000, L9000 and L15000) are shown on **Figures 4-7**. In addition to the secondary structure sought, others anomalies were cross-cut named Dialafara Anomaly (DA) and numbered.

The L0000 and L6000 profiles are in the western side of the Senegalo-Malian discontinuity (**Figure 3**). The results are represented respectively by **Figure 4** and **Figure 5**).

The profile L0000 (**Figure 4(a)**, **Figure 4(b)**) intersects the secondary structure at the station 2200 m and 3100 m which gives an approximate width of 900 m of the secondary structure at this point. In addition to the secondary structure intersected, there are at least two other anomalies (DA1 and DA2; **Figure 4(a)**). The highest magnetic amplitude value on the L0000 profile is 32645.25 nT at station 8000 m and the lowest value is 31,465 nT between 6000 and 6400 m. Homogeneous parts are also observed on this profile.

The L6000 profile (**Figure 5(a)**, **Figure 5(b)**) intersects the secondary structure between the 3000 m and 4400 m stations (about 1400 m wide). As for line L0000, there are other anomalies intersected by this profile. The DA3 is located between 4600 to 6800 m, DA4 is at station 9900 and DA5 between 12,000 and 11,700 m. The interval between station 1200 and 2400 m corresponds to a relatively homogeneous zone. The lowest value of the total field recorded is 31771.36 nT which is located at station 6500 m, whilst the highest field value recorded is 32200.44 nT located between the stations 6600 and 6800 m.

The results of the profiles L9000 and L15000 are presented on **Figure 6** and **Figure 7**. These profiles are located to the eastern part of the Senegalo-Malian discontinuity in the Dialafara area (**Figure 3**) with the L9000 profile close to the SMD.

The profile L9000 (**Figure 6(a)**, **Figure 6(b)**) intersects the secondary structure sought between the stations 8800 and 10,350 m (about 1550 m wide). The other anomalies observed on the L9000 profile are located between stations 11,700 and 12,250 m (DA6; **Figure 6(b)**). The anomaly DA7 located at the station 12,850 m (**Figure 6(b)**) is observed. Between secondary structure and the DA6 anomaly, the magnetic field is relatively homogeneous. The lowest value of the magnetic field recorded on the L9000 is 31863.41 nT located at stations 12,800 m, whilst the highest value is 32163.72 nT located between 11,650 and 12,000 m.

The L15000 profile (**Figure 7(a)**, **Figure 7(b)**) intersects the secondary structure between the stations 2800 and 3500 m (DA6; **Figure 7(b)**) and between the station 3700 and 4350 m (DA7; **Figure 7(b)**). These two anomalies represent the secondary structures at this part of the SMD (with 700 m and 650 m wide respectively). The lowest value is 31943.65 nT at station 4000 m, whilst the highest value is 32201.64 nT at station 3350 m. Between stations 1000 and 2000 m, the magnetic field is disturbed with weak signal (**Figure 7(b)**). The magnetic total field value is low but more heterogeneous for the two closer profiles to the SMD on the western and eastern sides.

5.1.2. Sadiola Area

The ground magnetic profiles as well as the airborne magnetic profile at Sadiola area are located in the west and east of the Senegalo-Malian discontinuity (**Figure 3**)

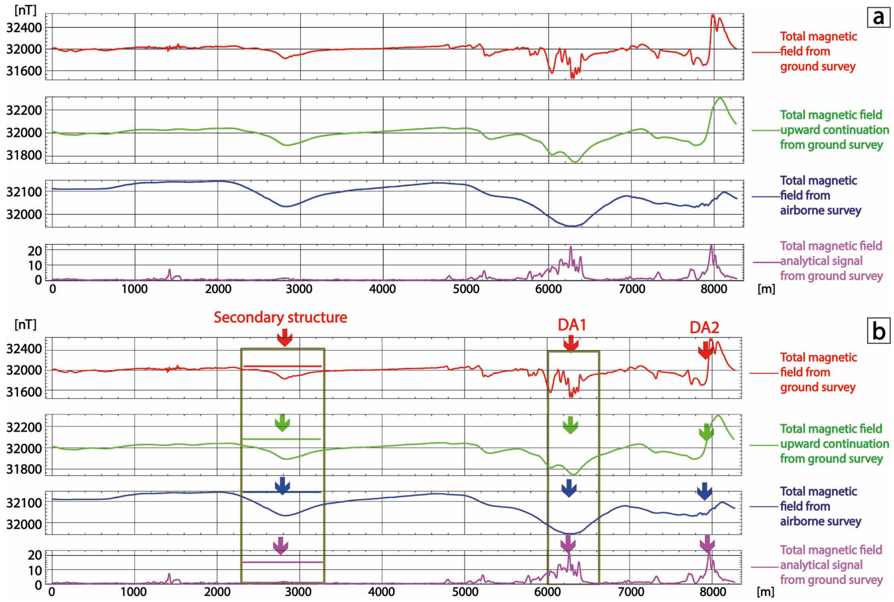

Figure 4. Curve of amplitude variation of magnetic survey profile on L0000 from Dialafara Zone. (a): Result of the profile in curve form; (b): Result interpretations. **DA**: Dialafara Anomaly.

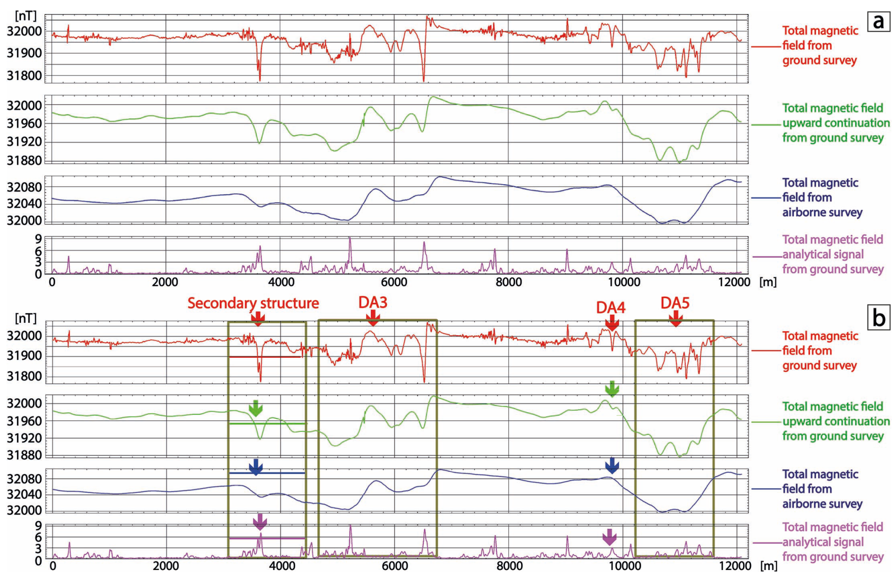

Figure 5. Curve of amplitude variation of magnetic survey profile on L6000 from Dialafara Zone. (a): Result of the profile in curve form; (b): Result interpretations. **DA**: Dialafara Anomaly.

as for Dialafara area. The results of these profiles are presented in **Figures 8-11**). On these profiles, other anomalies were cross-cut named Sadiola Anomaly (SA) and numbered from 1 to 8.

The L100 profile (**Figure 8(a)**, **Figure 8(b)**) intersects the secondary structure between the station 8400 and 8900 m with an approximate width of 500 m at this point. The other structures intersected by this profile are SA1 and SA2, with certain homogeneous zones (**Figure 8(b)**). The most important are located at

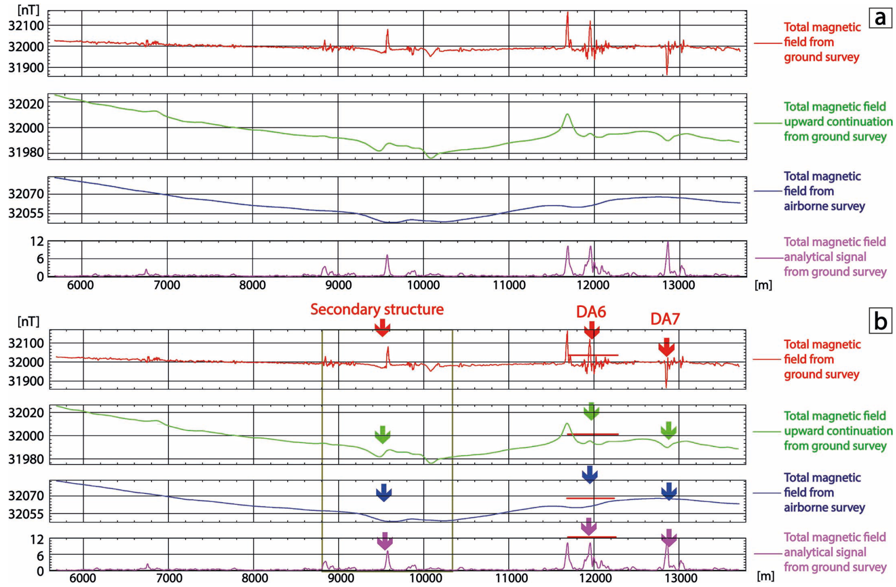

Figure 6. Curve of amplitude variation of magnetic survey profile on L9000 from Dialafara Zone. (a): Result of the profile in curve form; (b): Result interpretations. DA: Dialafara Anomaly.

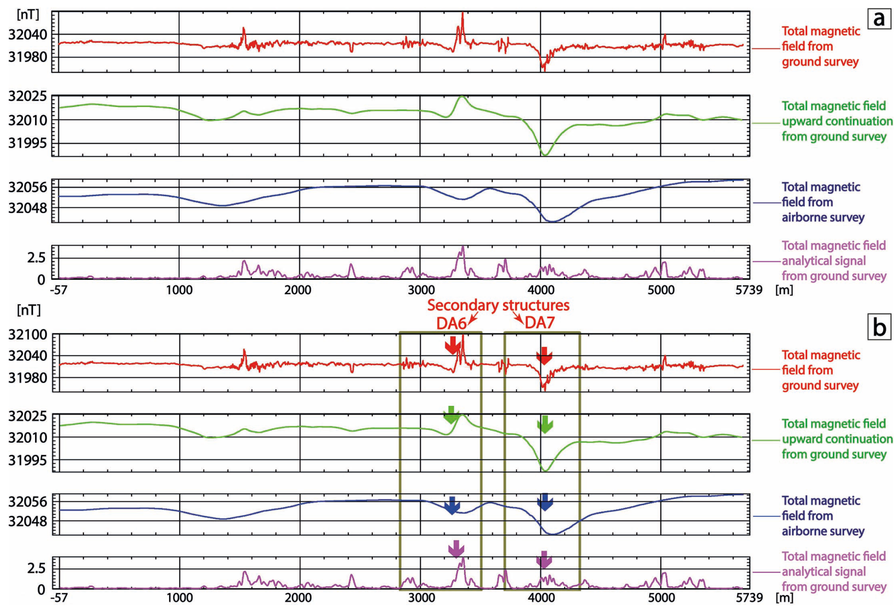

Figure 7. Curve of amplitude variation of magnetic survey profile on L15000 from Dialafara Zone. (a): Result of the profile in curve form; (b): Result interpretations. **DA**: Dialafara Anomaly.

station 600 m (SA1) and at station 2600 m (SA2). In addition to these anomalies, there are E-W oriented structures along the secondary structures between the stations 1000 and 2400 m. The L100 profile is the far most from the SMD at its western side. The strongest magnetic total field amplitude on L100 is about 32071.36 nT at the stations 150 and 1400 m, whilst the lowest amplitude is about 31598.75 nT at the station 2800 m. Apart from these points, the magnetic field is

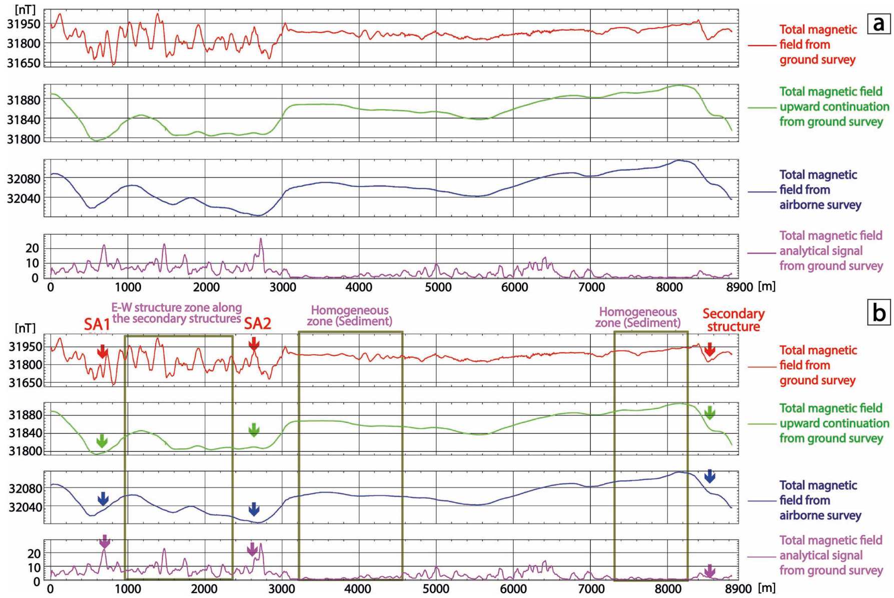

Figure 8. Curve of amplitude variation of magnetic survey profile on L100 from Sadiola zone. (a): Result of the profile in curve form; (b): Result interpretations. **SA**: Sadiola Anomaly.

relatively homogeneous with two main domains (**Figure 8(b)**). The average value of the magnetic field on the concerned structure is 31861.68 nT.

The field variation of profile L300 (**Figure 9(a)**, **Figure 9(b)**) with the same orientation as L100, intersects the secondary structure between the stations 2650 and 3600 m leading to 950 m wide. As for the L100, there are other structural anomalies intersected by the profile L300. These structures are SA3 at the station 75 m, and SA4 located between the stations 5800 to 6250 m. The magnetic total field is relatively homogeneous along this profile. The lowest value of magnetic total field is 31560.17 nT located at the station 100 m, whilst the maximum value is 32078.25 nT at the stations 5900 m. In addition to these structures, two main homogeneous zones can be highlighted. The first zone is located between the stations 1600 to 2550 m, and the second is located between the stations 4200 to 5600 m. The profile L300 is the closest to the SMD in its western part.

The profile L400 (**Figure 10(a)**, **Figure 10(b)**) is the closest to the SMD in its eastern part. The profile L400 intersects secondary structures between the stations 500 to 1600 m with 1100 m wide. The anomaly SA5 is located at the station 6800 m. The large area with homogeneous amplitude is between the stations 2400 and 3700 m. Some zones with high disturbance can be highlighted between the stations 4200 to 5600 m. The lowest value recorded on this profile is 31652.12 nT corresponding to the anomaly SA5, whilst the highest value is 3210.57 nT between 4200 m and 4600 m.

The profile L600 (**Figure 11(a)**, **Figure 11(b)**) oriented N345˚ and intersects the secondary structure between the stations 1250 to 1750 m with about 500 m wide and between stations 2050 to 2700 m which gives about 650 m wide. In addition, the anomalies SA6, SA7 and SA8 are highlighted and located respectively

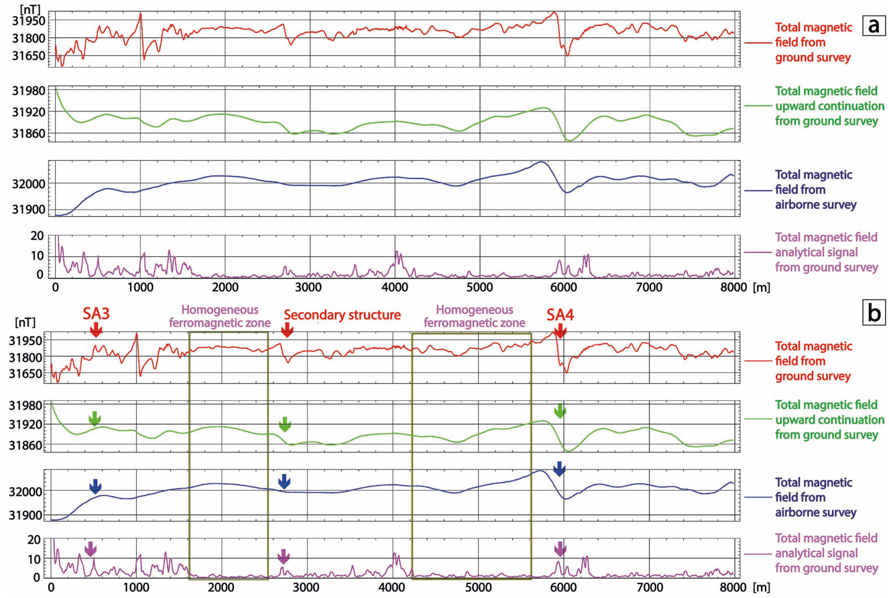

Figure 9. Curve of amplitude variation of magnetic survey profile on L300 from Sadiola zone. (a): Result of the profile in curve form; (b): Result interpretations. **SA**: Sadiola Anomaly.

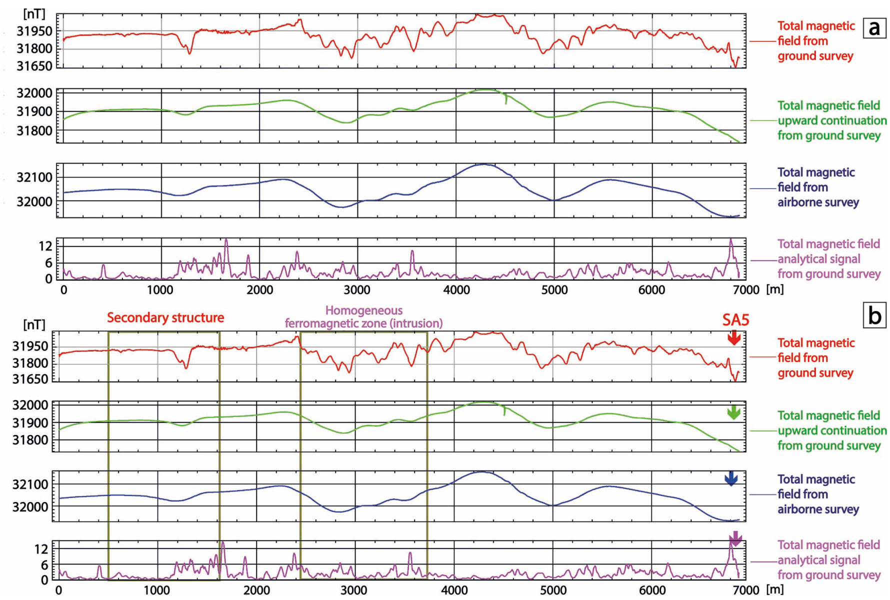

Figure 10. Curve of amplitude variation of magnetic survey profile on L400 from Sadiola zone. (a): Result of the profile in curve form; (b): Result interpretations. **SA**: Sadiola Anomaly.

at the stations 30 m, 1500 m and between 4300 to 4450 m (**Figure 11(b)**). A homogeneous zone is located between the secondary structure and the SA8. The similar zone can be described between SA6 and SA7 anomalies. The lowest value on L600 is about 31876.17 nT at the station 0 m (SA6 zone), whilst the highest is 32013.18 nT at the station 4480 m the anomaly SA8; (**Figure 11(b)**). The total magnetic field along with this profile seems to be relatively homogenous.

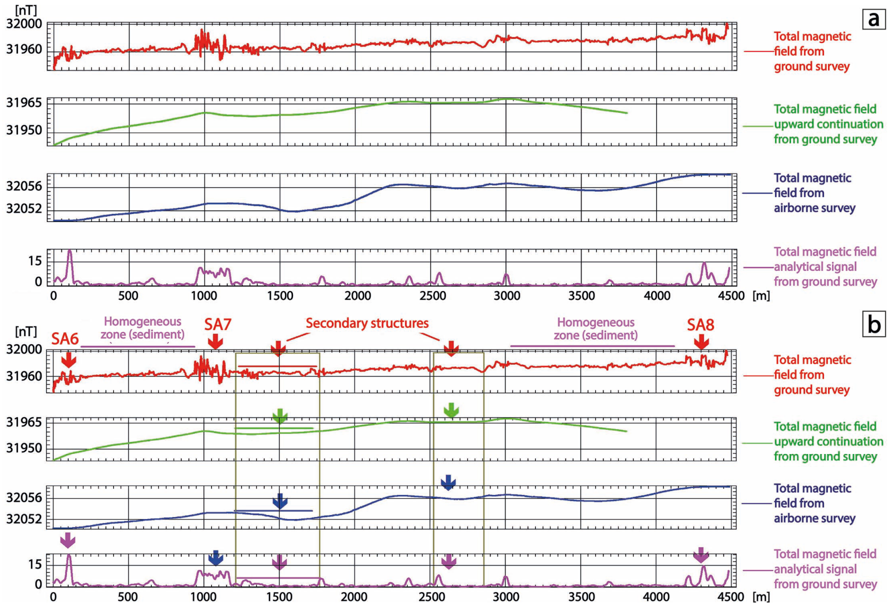

Figure 11. Curve of amplitude variation of magnetic survey profile on L600 from Sadiola zone. (a): Result of the profile in curve form; (b): Result interpretations. **SA**: Sadiola Anomaly.

5.2. Qualitative Interpretation

5.2.1. Dialafara Area

The comparison of the two sides profiles of the SMD in Dialafara area afford to determine the amplitude of the magnetic field and to evaluate the apophyses behavior relative to the interpreted SMD. The amplitude variation of Dialafara zone can be described from West to East. The magnetic average amplitudes recorded on the anomaly intersected by the profiles show that the average field value is 31985.08 nT for L0000 and 31964.76 nT for L6000 in the western part of the SMD. In the eastern part of the SMD the average values are 31996.56 nT for L9000 and 32013.08 nT for L15000. At Dialafara, the total magnetic field amplitude increases when we move from the SMD (L0000 and L15000). This amplitude is lower in the west than the east along the same structure. This can be explained by the variation of geological environment along the profile. The fact that the zone is located near the magnetic equator; so, the eastern side (L9000 and L15000) can be considered as sedimentary rocks or sediments compared to the western zone of Dialafara area.

It appears that the L6000 and L9000 profiles close to the main structure are more disturbed (heterogeneous) than the L0000 and L15000 where the field is relatively stable specially for L15000. Finally, the magnetic field is relatively homogenous in the east of the SMD than the western part.

The observation of the amplitude variation shows that the magnetic susceptibility is stronger to the west than to the east of the SMD. This involved that the western part of the SMD could be the fresh rocks likely the magmatic or metamorphic rocks. In the east the rocks are generally sedimentary rock type with low magnetic minerals. As the study area is close to the magnetic equator, the lowest values of the magnetic field could generally correspond to the high magnetic susceptibilities.

The width of the secondary structure investigated (**Figure 2**) is about 900 m for the profile L000 and 1400 m for L6000. To the east of the SMD, the width is 1550 m for the profile L9000 and 500 m for L15000. This shows that the secondary structure is wider to the west than to the east of the SMD. The magnetic susceptibility of the secondary structure is weak in the east, especially on L9000. On the other hand, it is strong in the west, and more highlighted in the west than east. This visibility could be due to the presence of tick sedimentary layer to the east of the SMD. Also, the western part is probably the weak weathering zone with high susceptibility rocks.

The application of the upward continuation filter on the raw ground survey data reveals some anomalies that are not visible in airborne. These anomalies can be due to the existence of superficial or residual structures and could show the accuracy of the ground data.

The variation curve of the analytical signal for the profiles (**Figure 4(b)**, **Figure 5(b)**, **Figure 6(b)** and **Figure 7(b)**) shows the domain limit with the different rock types. It shows that the secondary structure and their environment present almost the same rocks groups to the west of the SMD as the anomaly is not well expressed for both western profiles, especially the L6000. On the profile L6000, the secondary structure and its surroundings do not have the same magnetic susceptibility. Then, it can be highlighted that the structures in the west are not too much affected by weathering than those in the east.

The station 6000 m on the profile L0000 (**Figure 4(b)**) shows the anomaly DA1 which corresponds to an outcrop of dolerite dykes and the field amplitude is weak. This amplitude weakness could probably have the effect of the secondary structure. The secondary structure cross-cuts the rocks with moderate magnetic susceptibility compared to the DA1 anomaly. The position of the DA1 anomaly can be the contact zone, probably the physical or chemical change in the rock composition.

5.2.2. Sadiola Area

The analysis of the ground magnetic survey field amplitude on the profiles of Sadiola zone shows certain variations. The profiles (L100 and L300) in the western part of the Senegalo-Malian discontinuity (**Figure 3**). The result shows an average magnetic field amplitude that can reach nearly 31861.68 nT for L100 and 31844.47 nT for L300 (**Figure 8** and **Figure 9**). The results of the profiles to the east (L400 and L600) show an average amplitude that can reach 31919.02 nT for L400 and 31971.02 nT for L600. In the Sadiola area, the magnetic field is weaker for the western profiles than those in the eastern part of the SMD. The profiles in the west intercepting the structure show the high magnetic susceptibility than those to the east of the SMD. The secondary structure wide is about 500 m for L100, 9500 m for L300, 1100m for L400 and 550 m for L600.

The application of the upward extension filter shows that: 1) The quality of the ground magnetic data is good, and it correlates well with the airborne data in the Sadiola area. 2) There is a correlation between the ground and airborne curves, whilst some anomalies appear on the ground surveys. These anomalies allow to see in detail some residual anomalies (structures) that are not visible on the airborne data. The anomaly of the secondary structure becomes clearer and correlates with the airborne survey data. Except for the L600 profile where the ground magnetic survey data is different compared to the airborne data. A large anomaly with low amplitude of the magnetic field (high magnetic susceptibility) is observed on the ground survey. For the same station (from 5800 m to 6300 m) a positive anomaly is observed on the airborne survey (low magnetic susceptibility). The increasing of the magnetic susceptibility for ground data is likely due to the fence of the Sadiola mine for SEMOS (Sadiola Gold Mine Exploitation Company). When moving away from this fence, the noise decreases and the anomaly curves of the two surveys coincide. This allows to highlight that the environment has greatly influenced our ground data from L600 to the east of the SMD.

By applying the analytical signal on the ground data, the horizontal contacts between the different domains (lithological change) have been highlighted. This corresponds to the change in the rock natures with different magnetic susceptibility. The anomaly corresponding to the secondary structure is well presented for all the different four (4) profiles. The magnetic field is more heterogeneous for the western profiles, and more magnetized, probably the signal is from basement structures. This affirmation coincides with the rock observed around the area. The eastern profiles show more homogeneous anomalies. These anomalies (structures) in the east of SMD present low magnetic susceptibility due probably to the thick sedimentary cover. Probably only the top of the structures was cross-cut by the western profiles of the SMD.

6. Discussion

The reworking of the airborne data combined with the ground geophysical data presented in this paper provides a new understanding of the secondary structures crossing the Senegalo-Malian discontinuity. The interpretation of these secondary structures along the SMD gives an indication of the presence of two compartments. According to the main indication from the previous studies, the eastern part of the SMD is mainly composed of Paleoproterozoic metasedimentary unit of Kofi series [23].

From this study, the width of the secondary structures becomes large when approaching the SMD in both areas (**Figure 12(a)** and **Figure 12(b)**). It appears that these structures are duplicated in the eastern part of the SMD. When we observe the far east profiles in the two zones, the magnetic field is more homogeneous, which may be due to fine sediments that probably cover the secondary structures to the east. It should be noted that secondary structures often correspond to structural contacts in the eastern part of the SMD. A fold along the SMD

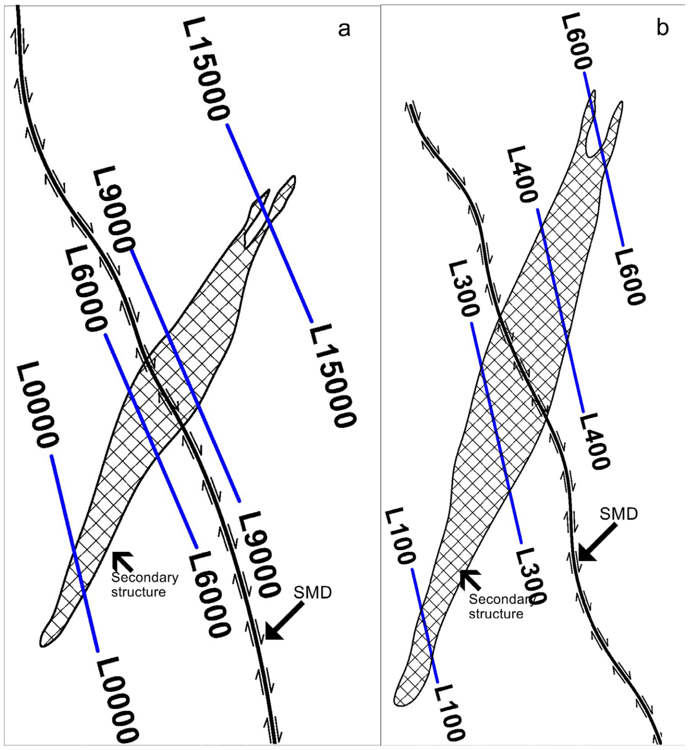

Figure 12. (a) The interpretation view of Dialafara secondary structure with the ground magnetic survey profile. (b) The schematic interpretation view of Sadiola secondary structure with the ground magnetic survey profile.

was highlighted in the Dialafara area [35]. This fold coincides with the anomaly DA4 on profile L6000. This profile seems to cross-cut another secondary structure interpreted as fold.

The regional structure trending northerly, which is considered as the sinistral strike slip structure referred to us as the Senegalo-Malian discontinuity (SMD). This structure is a first order structure and could be a lithospheric-scale transcurrent structures in the eastern of the KKI especially the Malian part of the KKI. The nature of this structure is still to be undescribed [17]-[21]. According to [22], the SMD is for exploration industry as an important structure controlling the major gold deposit in western Mali but it thinks that this is only a speculation in the literature.

In other hand, the SMD could be a limit between the Mako greenstone belt and the metasedimentary series of Kofi. According to [36], the NNE lineaments in western Mali are interpreted as fault which leads to name the secondary structures of this study as fault.

7. Conclusions

The work carried out during this study highlights the existence of a major regional structure using the cross-cut secondary structures. The description of the secondary structure allows to divide the SMD into two (2) different large compartments (west and east) in the Dialafara and Sadiola zones. One of the compartments is in the west and another is in the east. The combination of ground and airborne surveys becomes interesting in comparative studies and improves the data quality. The use of the upward extension filters on the ground data confirmed the good quality of the data. It should be noted that upward continuation of the ground surveys shows residual structures compared to the airborne survey.

The western profiles of the SMD are considered to be on the magmatic rocks and those to the east are on sedimentary rocks. The secondary structures are wider when approaching the SMD, which is due to the influence of the deformation of the SMD. This influence decreases when moving away. The study allowed to propose structural models which should be improved in the future.

In addition to this study, it is preferable to propose 2D models along with these selected profiles so that the geometries can be determined in depth. Another approach is to perform a resistivity survey on these profiles. These measurements will help to determine the thickness of the layer that covers the secondary structures, especially on the eastern side of the MDS.

The profiles in the Sadiola area afford to evaluate the secondary structure size around the SMD. The secondary structure is large in the west, and tends to disappear when moving to the far east.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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