

# Geomagnetic Investigation Method Using Iphone® Integrated Magnetic Sensor

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## ABSTRACT

We carried out a geomagnetic investigation using Iphone 4S® integrated magnetic sensor. The investigated area is a faulted sedimentary terrain crossed by basaltic volcanic veins. The obtained magnetic anomaly map shows the limits between the sedimentary rocks and a magnetic body at a given depth. These results are compared to the geometry of the magnetic body as shown by geological maps. The results seem to be accurate for the determination of geometry and the depth of the magnetic body.

## KEYWORDS

Geomagnetic; Magnetic Anomaly; Iphone 4S; Vein; Basalt

## 1. Introduction

The rapid expansion of mobile phone technology led to the emergence of smartphones. Nowadays, almost all smartphones include various accessories as cameras or GPS antenna. But one of the most innovative steps in smartphones evolution remains the integration of sensors [1]. Nowadays, many smartphones are equipped with gravity, light detection, or magnetic sensors. The competition context between manufacturers leads to embedding more and more sensitive sensors in the devices. While it is common to use these sensors in various domains [2]; [3] or to access their electronic specifications, it is still difficult to predict their efficiency in more specific domains, as in geophysical investigation. This is probably due to the complexity of geophysical objects where information about the physical property is encoded in the data in a complex way [4].

In this work, we explored a smartphone sensor, specifically magnetic sensor capability for geophysical investigation. We chose a geological context, favorable to geomagnetic investigations, with well contrasted magnetic properties, presenting volcanic veins surrounded with layered sedimentary rocks. Moreover, by comparing the obtained results with the existing geological data, it will be possible to validate obtained results.

## 2. Material and Method

We carried out geomagnetic investigation using Iphone magnetic sensor, recording data with Sensor Monitor mobile application [5].

Sensor Monitor is an iOS application allowing to show the current value of all the sensors included in the Iphone (GPS sensor, magnetic sensor, accelerometer, proximity sensor, etc.). We used Sensor Monitor free version on Iphone 4S. Many other free sensor data recording applications are available for Iphones. But they differ on the types of sensor data that can be recorded simultaneously, the format of the output file or the number of shown digits.

The explored area is located in Diack, a village South-east of Thies Region, Senegal, West Africa, between 16°43'W to 16°45'W and 14°40'N to 14°41'N. The geological framework of Diack is characterized by faulted sedimentary layers crossed by basaltic veins settled during the late Miocene fissural volcanism [6]. The radiometric ages ranges from  $7.8 \pm 0.50$  MA for basanites to  $10.30 \pm 0.50$  MA for dolerites [7]. The volcanic veins fill the intersection of N-S and E-W orthogonal faults [8]. Previously, two main veins referred as "pitons" and numbered P1 and P2 exist with secondary veins spread all around the region [9]. Since the eighteens, the basaltic

veins have been actively exploited as source of aggregates for roads and building materials. Nowadays, as it can be observed in the field, the main veins are merged and form a unique set.

The investigated area is located in the eastern part of the unified veins (**Figure 1**) with sedimentary rocks and no basaltic rock outcrops. The purpose of our choice was to take advantage of the contrast of magnetic properties to detect the underground limit between sedimentary and basaltic formations.

Using Sensor Monitor, we collected current time versus GPS location and current time versus magnetic field components through scan lines (**Figure 2**). Sensor Monitor saves this data in two distinct files. The current time allowed synchronization between location and magnetic data.

The magnetic data were collected as in standard magnetic survey choosing a base station where data were repetitively collected at given time intervals during the investigation, for magnetic data correction. Also the Iphone 4S was held by a walking operator as the device sensor can update and record magnetic data at 30 Hz frequency. 4321 magnetic data with their positions were recorded.

The obtained data were processed to synchronize location and magnetic data. In fact, GPS and magnetic sensor update respectively when location and magnetic data change. As these changes are not always correlated, it was necessary to use the current time to synchronize the data. We coded a small script in java to synchronize the data.

The processed data were mapped using Surfer software. The obtained result is further replaced in the geological context using a GIS.

### 3. Results and Discussion

Using the implemented java code on magnetic and position files, we produced a unique output file with the current time, the position ( $x$ ,  $y$  and  $z$  in degrees) and the main components of the magnetic field ( $X_m$ ,  $Y_m$ ,  $Z_m$ ).

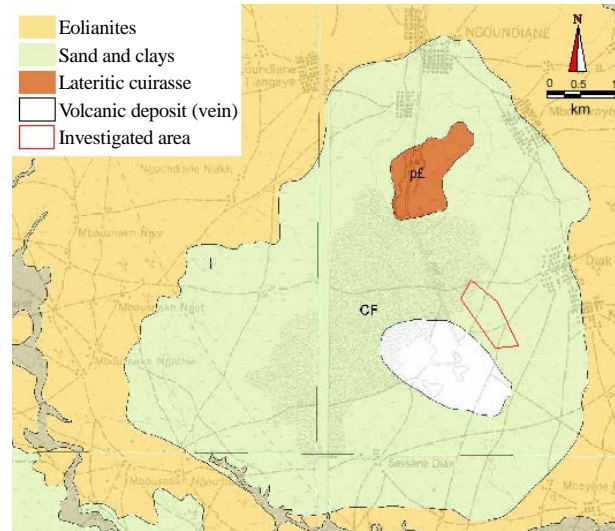
The positions were converted to UTM WGS 84 Zone 28 for compliance with geological data. The components of the magnetic field were used to compute the total magnetic field  $T_m$ .

The base station data (**Table 1**) allowed computing the drift, necessary for diurnal correction (**Figure 3**).

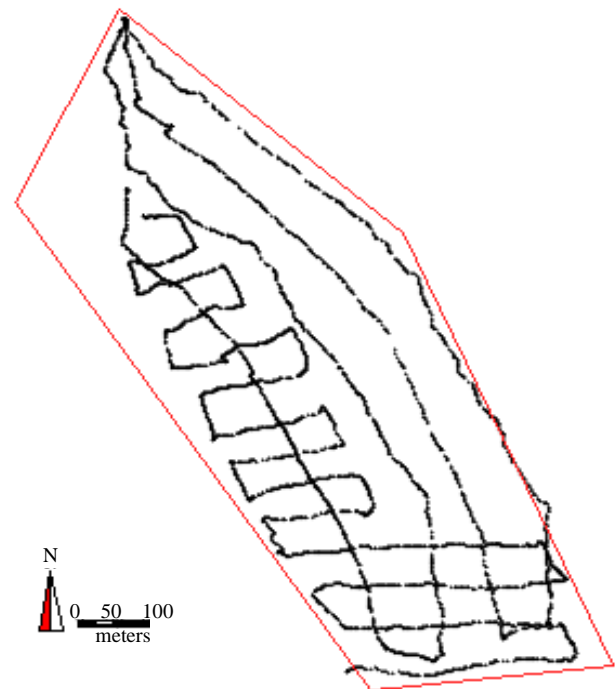
The diurnal correction was done considering the drift of  $-0.2377$  nT/s computed from the base station data. Thus, the correction formula for a value  $V$  read at a time  $t$  within the starting time (11 h 57 min 22 s) and the ending time (14 h 17 min 12 s) is:

$$V_{\text{corrected}} = V_{\text{read}} + 0.2377(t - t_0) \quad (1)$$

where  $V_{\text{corrected}}$  is the value of magnetic field after diurnal



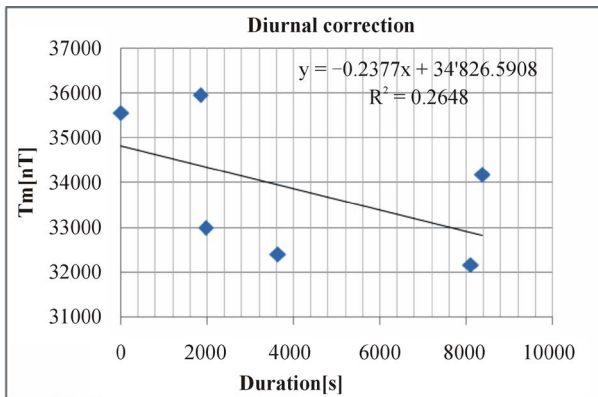
**Figure 1.** Geological setting of the investigated area ([10], Modified).



**Figure 2.** Scan lines used in geomagnetic investigation.

**Table 1.** Magnetic field measure at base station.

Base	x [m]	y [m]	$T_m$ [nT]	Duration [s]
1A	313,837	1,624,724	35553.6237	0
1R	313,842	1,624,723	35952.7422	1840
2A	313,842	1,624,723	32998.7754	1958
2R	313,842	1,624,723	32408.4254	3637
F1	313,842	1,624,723	32177.6049	8107
F2	313,842	1,624,723	34180.6022	8383



**Figure 3.** Plot of base station data showing a decrease in magnetic field value in time.

nal correction,  $V_{read}$  is the measured magnetic field at time  $t$  and  $t_0$  is the starting time of the magnetic survey.

The IGRF field for Senegal,  $T_{IGRF}$  is 32755.1 nT [11]. We can therefore compute the magnetic anomaly  $\Delta t$  using the relation:

$$\Delta t = T_m - T_{IGRF} \quad (2)$$

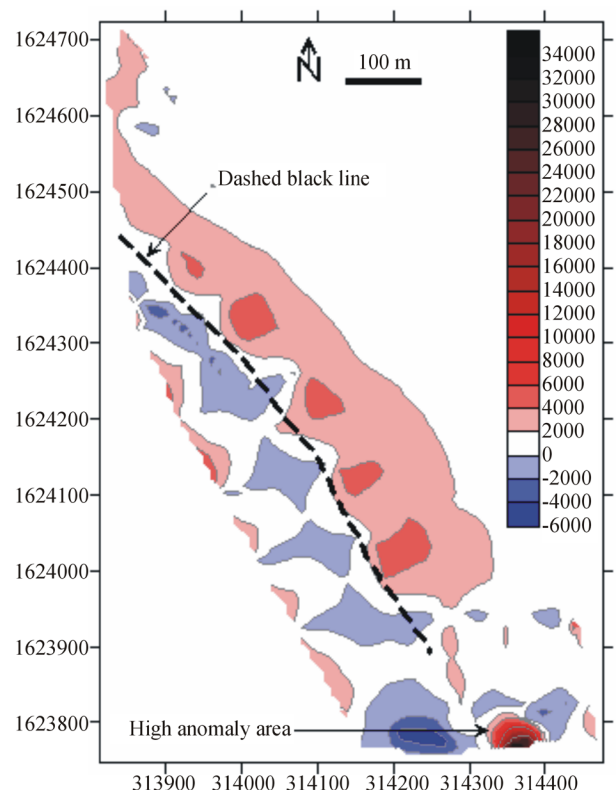
where  $T_m$  is the corrected value  $V_{corrected}$ . Therefore we have:

$$\Delta t = V_{corrected} - 32755.1 \quad (3)$$

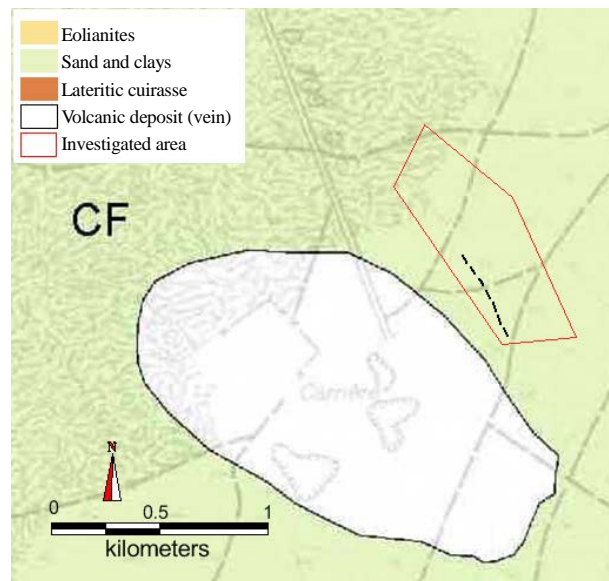
Finally we filtered the high frequency noise corresponding to soil surface magnetic variations using moving average method [12]. The corrected and filtered data were mapped in Surfer using natural neighbor interpolation. The results are shown in **Figure 4**.

The magnetic anomaly map (**Figure 4**) shows a dipolar magnetic anomaly with a maximum and a minimum with geological structures slightly oriented NW-SE. In fact, the magnetic anomaly shape depends on magnetic inclination which depends on the location. When we are out of the Earth poles, magnetic responses are always dipolar in relation to magnetic inclination and the presence of two opposite poles in all magnetic objects. The position of the magnetic object is slightly at the inflexion point of the anomaly profile for an inclination of  $30^\circ$  [13]. Thus we interpreted the dashed black line as the limits of the magnetic object with extension to the western side. The depth of the magnetic object responsible for the anomaly is determined by the tangent method [14] and gives 61.5 meters.

To compare the magnetic anomaly data with other datasets, we reproduced the dark line corresponding to magnetic object limit (ie basaltic vein) on the geological map (**Figure 5**). The extension and the orientation of the magnetic anomaly seem to be relevant to geometry of the unified vein as represented on the geological map. The vein slopes in the eastern direction and may reach 61.5 meters depth under the dashed dark line.



**Figure 4.** Magnetic anomaly map obtained by interpolation using natural neighbor method.



**Figure 5.** Representation of the interpreted magnetic object limit (dashed black line) on geological map.

In the southern part of the magnetic anomaly map, we observed a small area of around 1 hectare, with very high anomaly values. This anomaly zone is unknown on existing geological maps and previous investigations. An excavation or mechanical drilling of the area should lead

to know the underground object responsible for the anomaly.

#### 4. Conclusions

The geomagnetic investigation carried out using iPhone 4S magnetic sensor with Sensor Monitor application, shows that the geometry and the depth of the basaltic vein can be retrieved from the magnetic anomaly data. The reliability of the result has been confirmed with existing geological maps.

It should be important in a next stage to interpret the geomagnetic anomaly using inversion techniques in 2D in order to retrieve a model of the magnetic body.

The method seems to be accurate in geometry and depth determination but it will be worth in the next steps developing a standalone mobile application that should process the acquired data, map the magnetic anomaly and later give the depth and shape of the magnetic body.

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