MAPPING STUDY OF GEOTHERMAL RESOURCES BY ANALYSING GRAVIMETRIC AND MAGNETIC DATA: THE CASE OF THE MAHABO DISTRICT, SOUTH-WESTERN MADAGASICAR

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ABSTRACT

The Morondava sedimentary basin in the Mahabo district is one of the major geothermal zones. This work involves processing the magnetic and gravity data available in this area using GEOSOFT/GM-SYS and ArcGis software. Anomaly maps and profile models were created in order to visualise the structure of the subsoil in the study area if it fulfils the conditions required to be classified as a hot-spring region. The results confirm the possibility of the existence of geothermal resources.

Keyword: - *Morondava, geophysics, geomodelling, geothermal resources, profiles et sedimentary basin*

1. INTRODUCTION

Geothermal resources in fault zones are now coveted, even though they represent only 10% of the geothermal resources currently exploited worldwide. To better develop this type of resource, we need a better strategy for exploring geothermal systems. Of course, energy is a key factor in a country's economic development. However, new perspectives have been included in Madagascar's energy policy, taking into account its effects on the economy without considering its environmental impact [1].

Madagascar currently has 117 thermal springs listed on the island, with three types of energy: medium to high energy, low enthalpy and low medium enthalpy [2] . In this work, we are particularly interested in geothermal energy, which studies the Earth's internal thermal phenomena. These internal thermal phenomena are located in the Earth's crust and require geophysical analysis to facilitate their exploitation. This study focuses on the south-western part of Madagascar, in the Menabe region, which is located in a major geological structure.

Geoscience and geothermal energy are playing an important role at international level in scientific research and in the development of our future energy independence: geothermal energy for domestic uses such as heating or cooling, and also the exploitation of all forms of geothermal systems [3].

2. PRESENTATION OF THE STUDY AREA

Despite the work that has already been done in Madagascar, the renewable energy development project, in particular the exploitation of energy from geothermal sources, is not yet well advanced.

2.1 Geographical location

Our study area is located in the district of Mahabo, in the Menabe region, more precisely close to the communes of Malaimbandy and Ankilizato. Its geographical coordinates lie between 44.45° and 45.75° East longitude and 19.95°

and 20.75° South latitude according to the Laborde coordinate system. This area is linked by the RN35 Bis national road linking the two urban communes from Malaimbandy to Morondava (Fig 01).

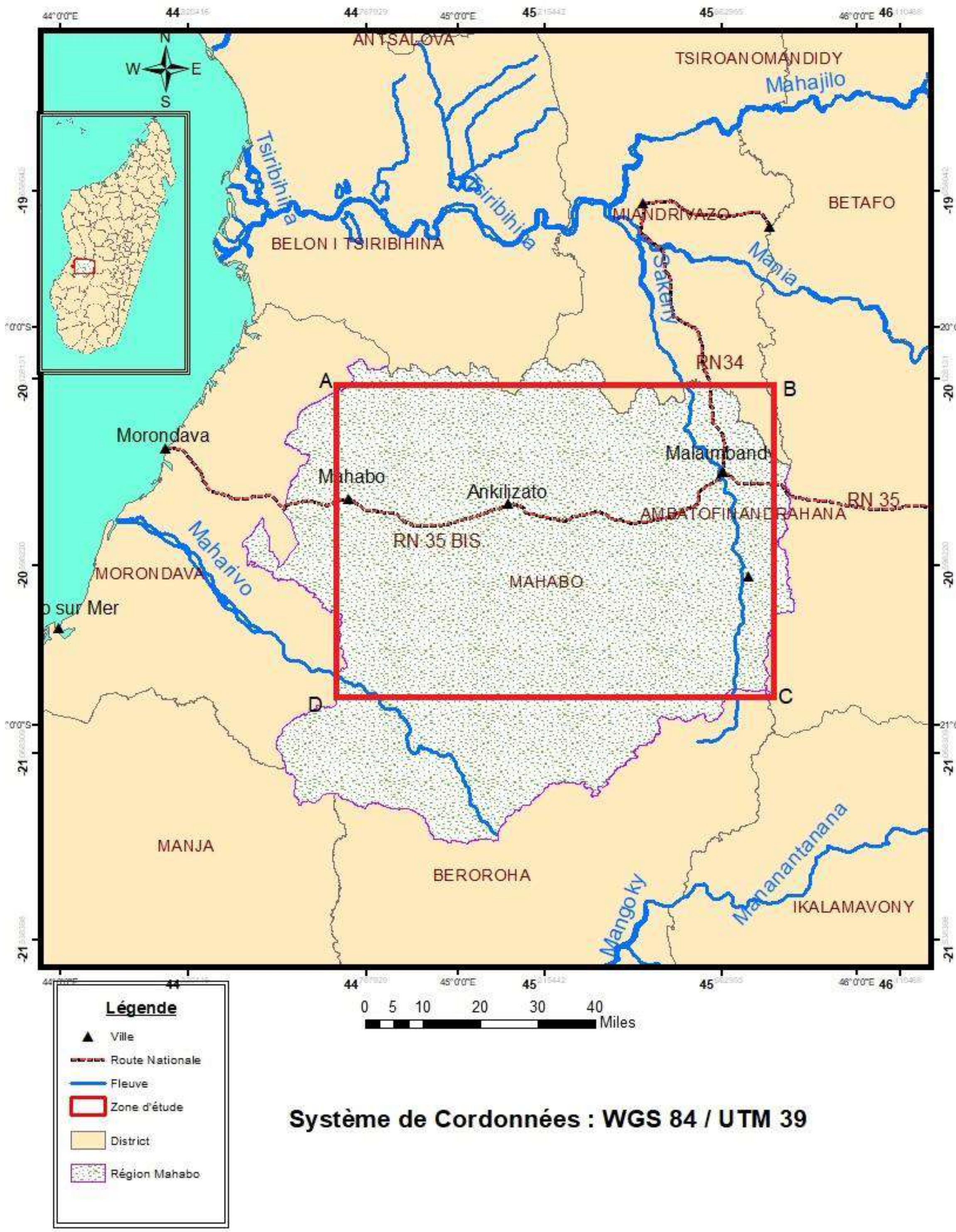

Fig -1: Location map of the study area in the Mahabo district

To better focus the study in the district concerned, we delimited the area from four respective points A, B, C, D in the WGS 84 geographic coordinate system (Fig-1).
The District of Mahabo, where our interest lies, has a hot, dry desert climate. The average annual temperature is 26°C. In December, the average temperature is around 28.5°C, which is the hottest month of the year, and in July it is 22.5°C, which is colder at this time of year.

2.2 Rainfall and hydrology

May has an average rainfall of 6.4 mm, which is low and the driest month of the year. January has the highest annual rainfall, with an average of 233.9 mm. There has been a certain increase in rainfall in the west-east direction. In fact, the number of rainy days increases from west to east, with a 90% chance of rain falling during the 5 months of the rainy season.

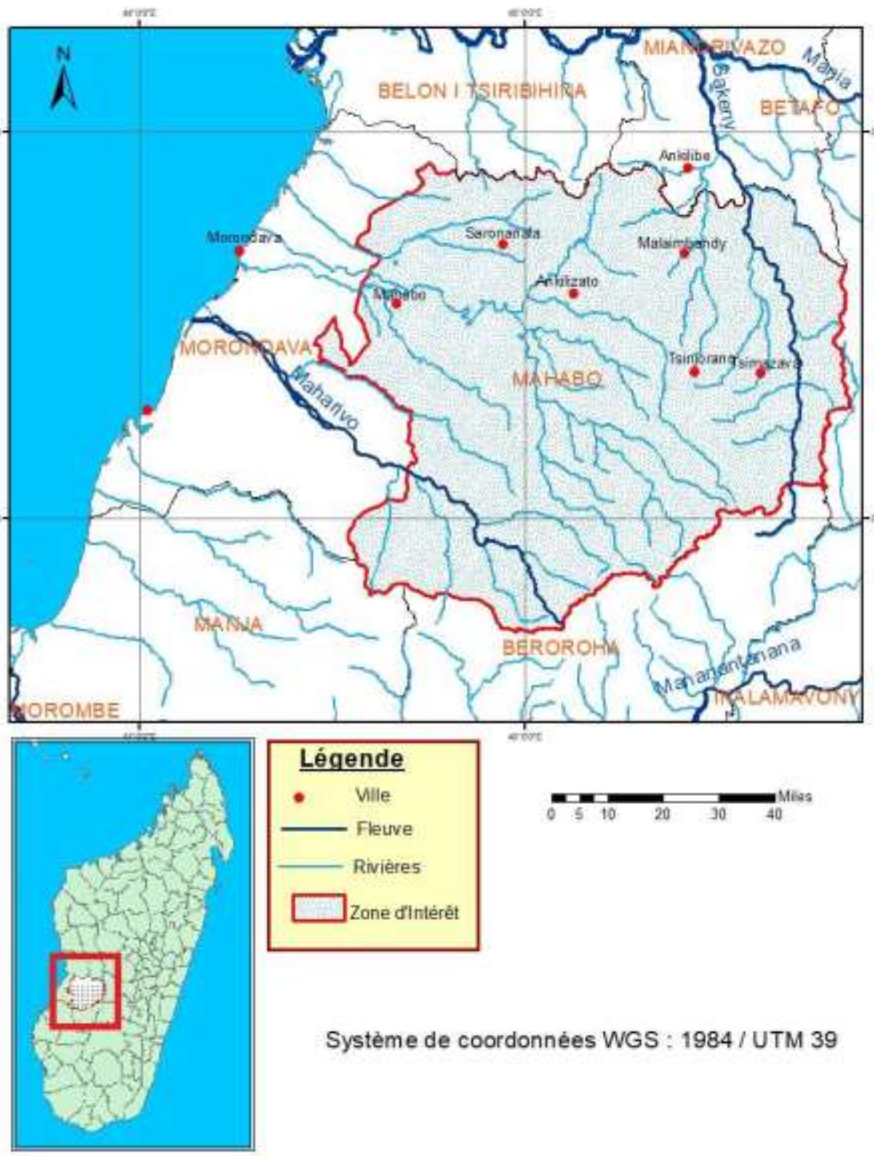

Fig-2: Hydrographic network of the Mahabo district

The sea wind will be influenced by the Bongolava massif in the centre, which is the reason for the persistent humidity in the western part of Madagascar, and our district will be affected. Between October and September a drying wind blows and lowers the levels of the rivers, thus reducing the water table. Consequently, this season could

be a good time to dig wells. But in high tide, there is the existence of periodic winds that blow from north to south during the rainy season. During the dry season the opposite happens.
The Morondava river, which originates in the Makay massif, waters the central part of the district and flows towards the Morondava district (Fig-2). It is therefore known as the long Morondava river, which mainly runs parallel to the RN 35. Various tributaries occupy the district before flowing into the Morondava river. The central part is watered by the distribution of the various rivers. The Tsiribihina river in the north has its source in the Bongolava massif and arrives at Miandrivazo, separating the Sakeny, Mahajilo and Mania rivers. The Maharivo river waters the southern part of our district, while the eastern part of the district is represented by the Sakeny river.

2.3 Geological context

Generally speaking, Madagascar is made up of crystalline and sedimentary rocks, with the former occupying almost two-thirds and the latter a third of the country. Crystalline rocks have gradually undergone intense metamorphic transformations, which have changed their structural appearance. As a result, these phases are accompanied by volcanic activity.
Our study area is located in the Morondava sedimentary basin, so it is necessary to gain a better understanding of the formation and classification of the existing sediments. The sedimentary formation of the basin defines two distinct fundamental series: the Karoo and the Post-Karoo (Fig-3).

- The Karoo

The Karroo is particularly continental, extending from the Upper Carboniferous to the Lower Lias. It is transgressive and also has an unconformity on the crystalline basement. It lies in the southern part of the sedimentary basin and is estimated to be 6 to 7 km thick. It is divided into three groups.

- The Sakoa

From the Upper Carboniferous to the Permian, it occupies the southern part of the Morondava basin and is unconformable with the Malagasy Pecambrian basement. It is composed in ascending order, from the deepest to the highest, of : The glacial series, the coal series, the lower red series and the Vohitolia limestones.

- The Sakamena

From the Upper Permian to the Middle Triassic, it is essentially continental. These deposits are composed from bottom to top by: schistosandstone series and clay-sandstone series.

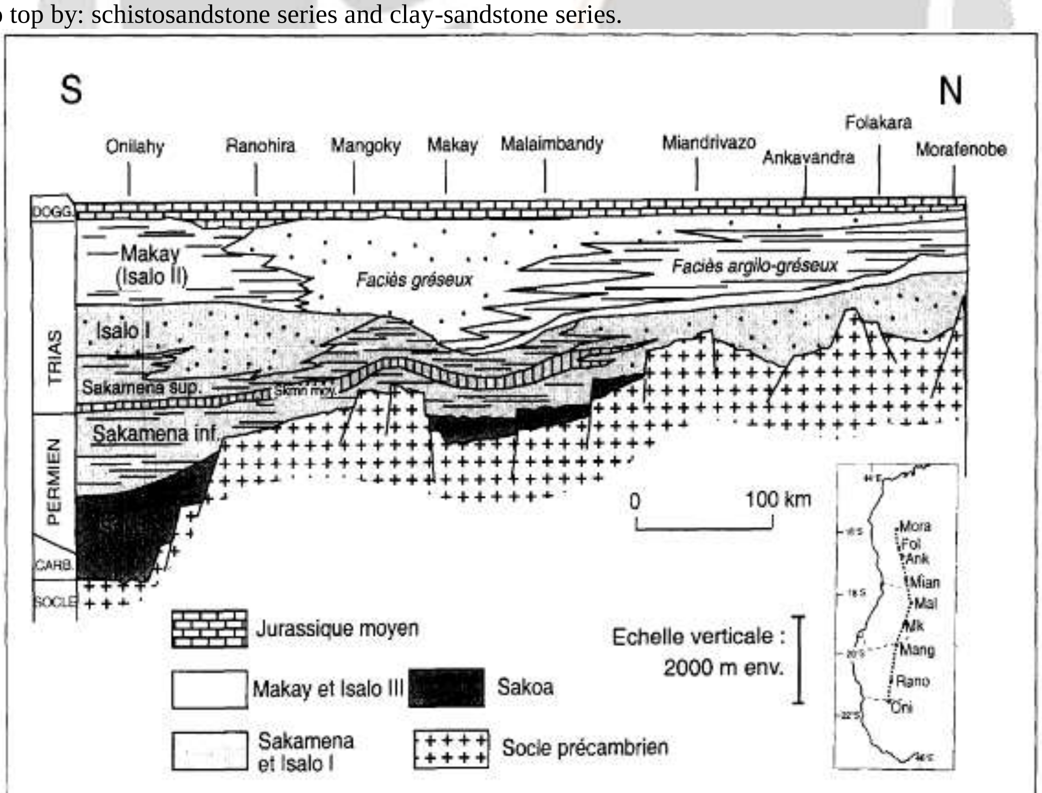

Fig-3: Lithological cross-section of the Morondava basin from north to south [4]

- The Isalo

From the Upper Triassic to the Middle Jurassic a major unconformity links the Isalo and the Sakamena (Besairie 1972) The Isalo is made up of three groups: -Isalo I, - Isalo II or the Makay, - Isalo III. The Makay is composed in succession from bottom to top by : Makay I (coarse sandstone), Makay II (sandstone-limestone clay complex) and Makay III (sandstone-limestone clay).

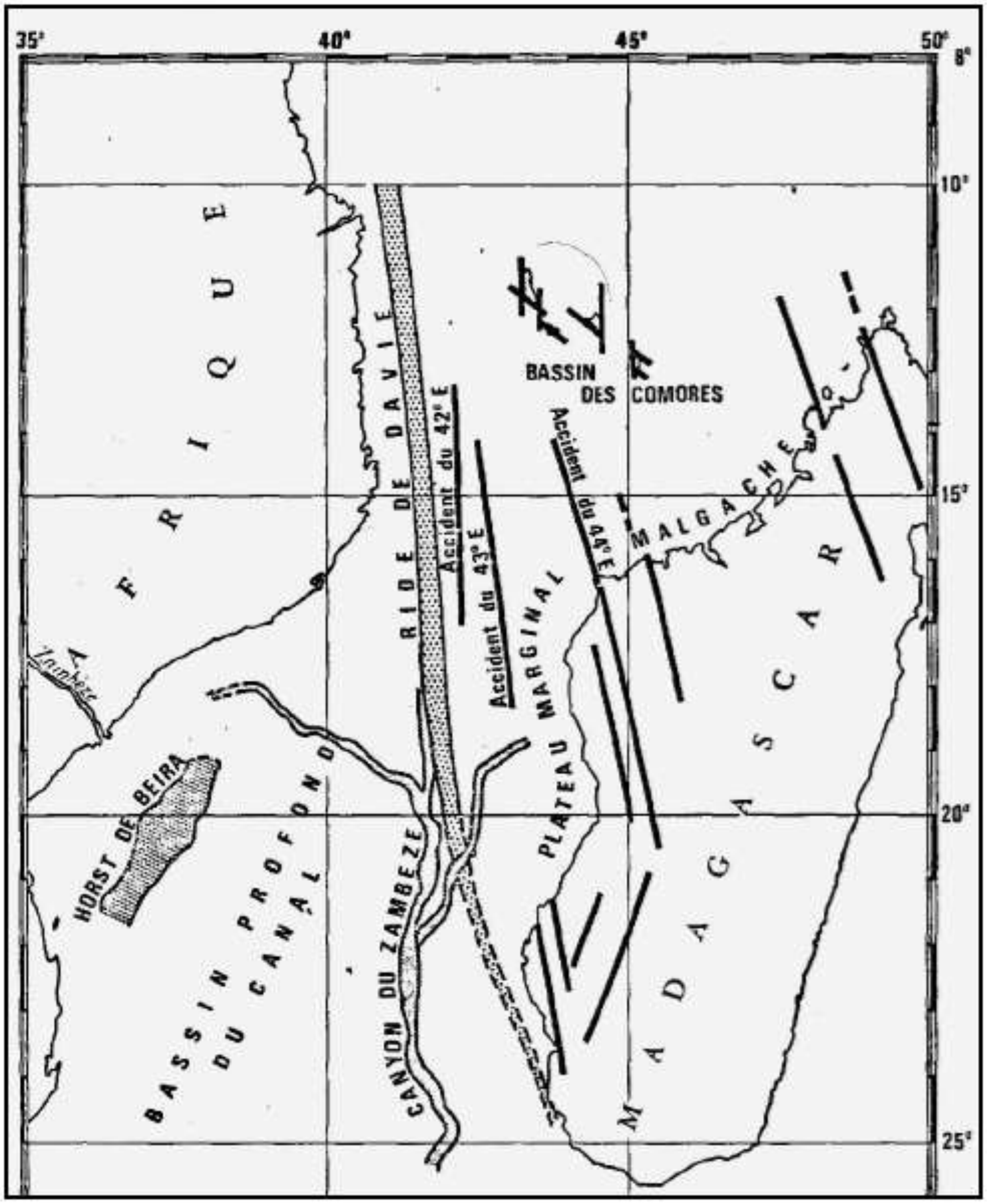

Fig-4: Map of the structural aspect of Madagascar's sedimentary basins [5]

- The post-Karoo era

The post-Karoo is a formation due to the marine level in general, from the Jurassic to the Quaternary, with the following transformations: - The Jurassic, which is composed of clay-limestone series from bottom to top, the Bemaharaha and Besabora limestone plateau, calcareous sandstone facies and marl. The marine transgression marked the deposition of a level composed of Ammonites, - The Cretaceous from bottom to top by marls, limestones, sandstones, clays and volcanic flow, - Tertiary transgressive and discordant on the upper Cretaceous favoured by the composition of limestone and marly limestone known as Paleogene, the Neogene with ferruginous sandstones, and the Pliocene by sand shells.

2.4 Tectonics

Brittle tectonics are very prominent in Madagascar's sedimentary basin. In this case, the Morondava basin is marked by brittle tectonics and can be represented in two distinct parts: A sub-basin marked by the West Coast fault (Toliara-Ilova) oriented NNE-SSW and another by NNO-SSE faults such as the Bongolava-Ranotsara shear (Fig-4).

3. MAGNETIC AND GRAVIMETRIC DATA AND METHODOLOGICAL BASES

2.4 Magnetic prospecting method

The magnetic method is a method which consists of studying the disturbance of the magnetic field and the distribution of rocks on the basis of their magnetic susceptibility. The magnetic method is a geophysical method that was applied a long time ago and remains one of the first methods to be used in various exploration disciplines such as mineral exploration and also in the search for geothermal resources. This method can be used at all scales and from the same measurement system.

- Fundamental law of magnetism (Coulomb's Law)

The magnetic method is based on Coulomb's law. This law states that: "two charged particles or two magnetic poles separated by a distance r attract or repel each other by a force proportional to the product of their mass and inversely proportional to the square of their distance".

$$\vec{F} = \frac{m_1 m_2}{\mu r^2}\vec{r} \qquad (1)$$

μ : Magnetic permeability (value 1 in a vacuum and in air)

m_1 and m_2 : respective masses of the particles

r : Distance between particles and $\vec{r}$ the unit vector

$\vec{F}$: Magnetic force in dynes

- Magnetic susceptibility

The ambient magnetic field and the magnetic susceptibility of the rocks depend on the value and orientation of the induced magnetisation. On the other hand, the value and orientation of the remanent part depend on the age and geological history of the rocks. Induced magnetisation runs parallel to the ambient magnetic field. Its value is proportional to the ambient field, and the proportionality constant k is in fact the magnetic susceptibility, hence the equation :

$$\vec{I} = k\vec{H} \qquad (2)$$

$\vec{I}$: Intensity of magnetisation

k : proportionality constant or magnetic susceptibility

$\vec{H}$ **:** Inducing field

- Geomagnetic field

The Earth's magnetic field or geomagnetic field measured at a point O at a time t is the sum of three fields:- the main field (this is the field that accounts for more than 90% of the field measured at the Earth's surface), - the anomaly field (this is the field generated by the magnetised rocks in the surface layers), - the transient field, which results from the superposition of an external field, the primary sources of which correspond to the interaction between solar radiation and the environment at the Earth's surface, and an induced internal field. Hence the Earth's magnetic field is expressed as a function of time at point O by the equation :

$$B_p(O,t) + B_a(O,t) + B_t(O,t) = B(O,t) \qquad (3)$$

Table -1: Source of the magnetic field at a point

Field	Origin	Value
Main field $\vec{B}_p$	Earth's inner core	Thousands nT
Anomaly field $\vec{B}_a$	Rock in the earth's crust	>1000 nT
Transient field $\vec{B}_t$	Ionosphere of the atmosphere	Tens to thousands nT

- Magnetic card filtering operation

Mathematical tools are used as digital filters. The aim is to transform the maps from the raw data to obtain appropriate maps that facilitate interpretation tasks depending on the area to be studied.
Numerous filters are used to process magnetic data, each with its own manipulations and calculations. The most commonly used are: the pole reduction filter (equator); the upward extension filter; the horizontal derivative filter; the analytical signal filter; and the pseudo-gravimetry filter [6].

3.2 Gravimetric prospecting method

Gravimetry is the science that studies the Earth's gravity field. It provides useful and important information about the distribution of the masses of bodies on the Earth's surface.

- Fundamental law of gravimetry (Newton's Law)

Notre Globe Terrestre représente différents variation des phénomènes comme les chute des corps, marées,…Pour mieux expliques ces phénomènes, Newton ont énoncé des lois fondamentales en 1967. C'est en fait le Principe de base de la gravimétrie.

Newton's first law shows that a force F between two bodies of respective masses m_1 and m_2, of distance r corresponds to an attractive force whose value is expressed by the equation :

$$F = \frac{m_1 \cdot m_2}{r^2} G \qquad (4)$$

G : Universal gravitational constant, G = 6,673 10^{-11} $N \cdot m^2 kg^{-2}$

Newton's second law shows that a force F must be exerted on a mass m to cause it to undergo an acceleration a.
Hence the relationship: F = m.a

And the acceleration of a mass m is expressed by: a = g = G $\frac{m_T}{r_T^2}$

With,
m_T : Earth's mass 5,97 10^{24} kg
r_T : Radius of the Earth 6370 km

The acceleration of gravity is therefore g, which is equivalent to 9,81 m. s^{-2}
The unit of gravitational acceleration is generally expressed in Gal
We have the following relationships: 1 Gal = 1 cm. s^{-2} = 10^{-2} m. s^{-2} et 1 mGal = 10^{-3} Gal = 10^{-5} m. s^{-2}

- Density

Rocks are generally heterogeneous, with bodies in liquid, solid or gaseous states. In this case, compared with the other petrophysical parameters of the rock, the variation in density on the global scale of the different materials is very small.

The average density of rocks covering the Earth's crust is around 2.67, whereas the average density for the whole of the Earth is 5.5**.** The density of different rocks generally depends on three properties: - The density of the seeds of the minerals that make up the rock, - The porosity (volume of empty parts in relation to the total volume), - The density of the fluids that fill the interstices of the rocks.
It can be said that the variation in the density of the subsoil leads to a variation of in the force of gravitational attraction, as shown in fig-5**:** The anomalies are due to the contrasts in density. For example, salt has a relatively low density and presents negative contrasts with the usual sedimentary rocks. In contrast, metamorphic rocks in contact with the same rocks show a positive density contrast.

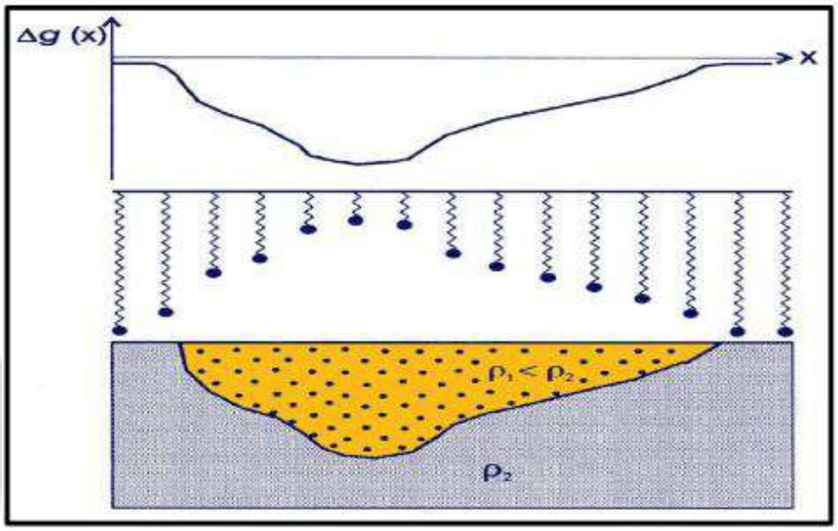

Fig-5: Simplified schematic diagram showing gravimetry

- Interpretation of gravimetric data

Although it is difficult to measure the physical properties of subsoil rocks on the surface, interpretation by gravimetric methods is generally theoretical. Geological and structural problems are studied and resolved using gravimetric approximations. The main aim of the measurements is to gain a better understanding of the appearance of a supposed discontinuity (distribution) in the average density based on gravity "g" at the surface, using the density contrast. Many interpretations can be made from the same series of data by varying the density contrast. The Bouguer anomaly map is derived from the results obtained by superimposing the effects of geological structures, whether at superficial, medium or great depths. The map provides important information about discontinuities in the subsurface. Depending on the analysis with the associations of the anomalies observed, many observations can be generated: - Positive anomalies may be related to dense sedimentary rocks, basement uplift or intrusions of high-density (heavy) rocks into the crust. - Negative anomalies are related to deposits of low-density (light) rock in the crust, to thickening of the crust, to collapse of the basement - Anomalies represented by iso-anomals are consistent with features of cylindrical or spherical (three-dimensional) structures in the form of elliptical figures or nearly circles. These conceptual models correspond to the study of anticlinal and synclinal structures, veins and galleries in the case of cylindrical structures and, in contrast, to the study of domes, basins and clusters in the case of spherical structures.

3.3 Modelling principle

- Gravimetric data

There are a number of different gravity survey methods, including terrestrial, marine, aerial and satellite (Fig-6). The latter method is used in this study, and the data used comes from the BGI (Bureau Gravimétrique International) archives at http://bgi.omp.obs-mip.fr. These archives can be downloaded as ASCII data (American Standard Code for Information Interchange).

```
plot_bouguer_20230731103214 - Bloc-notes
Fichier  Edition  Format  Affichage  Aide
# BGI - BUREAU GRAVIMETRIQUE INTERNATIONAL / INTERNATIONAL GRAVIMETRIC BUREAU
# WGM2012 - Complete spherical Bouguer gravity anomaly
# Model : WGM2012_Bouguer_ponc_2min
# Grid Limits : LON [44.4/45.8] - LAT [-20.8/-19.8]
#      LON(Deg)       LAT(Deg)  GRAVITY(mGal)
   44.400000000  -19.800000000        179.00
   44.433333333  -19.800000000        171.83
   44.466666667  -19.800000000        164.93
   44.500000000  -19.800000000        158.53
   44.533333333  -19.800000000        151.65
   44.566666667  -19.800000000        141.68
   44.600000000  -19.800000000        131.52
   44.633333333  -19.800000000        122.00
   44.666666667  -19.800000000        117.23
   44.700000000  -19.800000000        117.99
   44.733333333  -19.800000000        117.93
   44.766666667  -19.800000000        114.17
   44.800000000  -19.800000000        103.50
   44.833333333  -19.800000000        106.09
   44.866666667  -19.800000000        117.36
   44.900000000  -19.800000000        110.85
   44.933333333  -19.800000000        112.90
   44.966666667  -19.800000000        102.91
   45.000000000  -19.800000000        116.36
   45.033333333  -19.800000000        113.24
```

Fig-6: Gravity anomaly data extract

- Magnetic data

The Earth's magnetic field is measured by satellite using the on-board magnetometer. All the magnetic anomalies detected reflect major geological features such as the composition and temperature of the rock formation, remanent magnetism and geological structure on a regional scale (Fig-7).

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*Magnetic_Anomaly - Bloc-notes
Fichier  Edition  Format  Affichage  Aide
*****Data Magnetic Anomaly-EMAG2
Long   Lat        AM(nT)
44.4  -19.866667  39.160089
44.433333  -19.866667  23.595269
44.466667  -19.866667  8.416787
44.5  -19.866667  -5.743479
44.533333  -19.866667  -18.433332
44.566667  -19.866667  -29.528256
44.6  -19.866667  -39.549929
44.633333  -19.866667  -48.365714
44.666667  -19.866667  -55.989993
44.7  -19.866667  -62.368990
44.733333  -19.866667  -67.182731
44.766667  -19.866667  -70.413193
44.8  -19.866667  -71.946119
```

Fig-7: Extract of magnetic anomaly data

The satellite magnetic data comes from the global EMAG2 grid (Earth Magnetic Anomaly Grid 2) by the NOAA (National Oceanic and Atmospheric Administration). These data are compiled from a ship's satellite and airborne magnetic measurements. In our case, the EMAG2 data has already been reduced to the pole, so we can already interpolate it to obtain the magnetic map.

- Processing software (Fig-8)

The manipulation of geophysical data requires the use of very specific software. For most of our study, we used Géosoft Oasis Montaj software and ArcGis 10.4.1 software to represent the study area.

Fig-8 : Oasis Montaj V8.4 software

- Resolution concept (Fig-9)

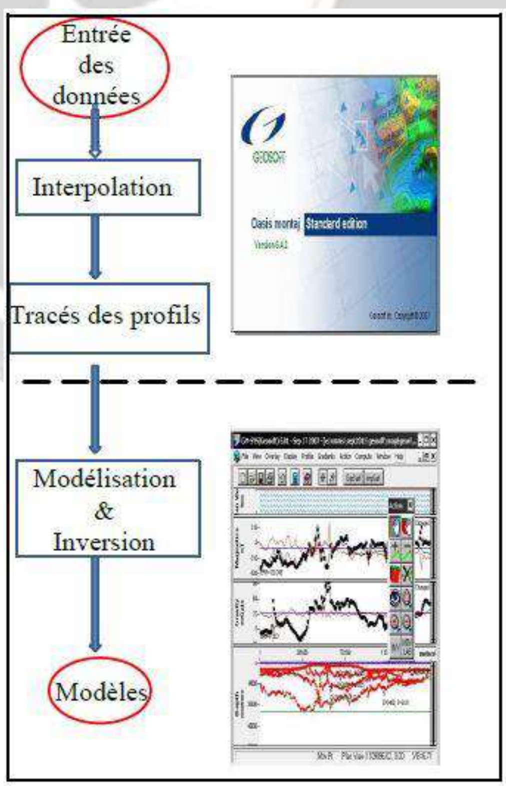

Fig-9: Geophysics data processing flowchart by Géosoft/GM-SYS

It is a representation of the subsoil in plan form. The main aim of modelling is to determine the likely geological structures and formations in the area to be studied. This technique is necessary in principle to impose constraints to adjust our theoretical curves on the experimental points. The gravity and magnetic profiles are modelled simultaneously. We use the GM-SYS program from Géosoft Oasis Montaj 8.4 to model the gravity and magnetic profiles in 2D.

This application was developed by Northwest Geophysical Associates in 1999. The masses between 0 and 15 km deep will be taken into account from the calculation of anomalies, without neglecting the structures and geological formations of the region which are the basis of the concept. The flowchart below represents the data processing processes until the models are obtained.

4. RESULTS AND INTERPRETATION

4.1. Correlation of gravity data

The geophysical data is imported into Geosoft in ASCII format. The geographical coordinates are then transformed into planimetric coordinates (Laborde in Greenwich), and finally an interpolation is performed to obtain the anomaly map.

The gravity anomaly map is dominated by zones of positive anomalies with a range of 89 to 176 mGal (Fig-10). There is a high value in the western zone as far as Morondava, a low value in the east and a medium value in the centre. A high anomaly value indicates the presence of a high-density body, while a low value indicates a low-density body.

The presence of major sediment layers can be determined from observations on the map by density contrasts. From a geothermal point of view, the study area is interesting for identifying thermal springs based on the physical properties of each layer.

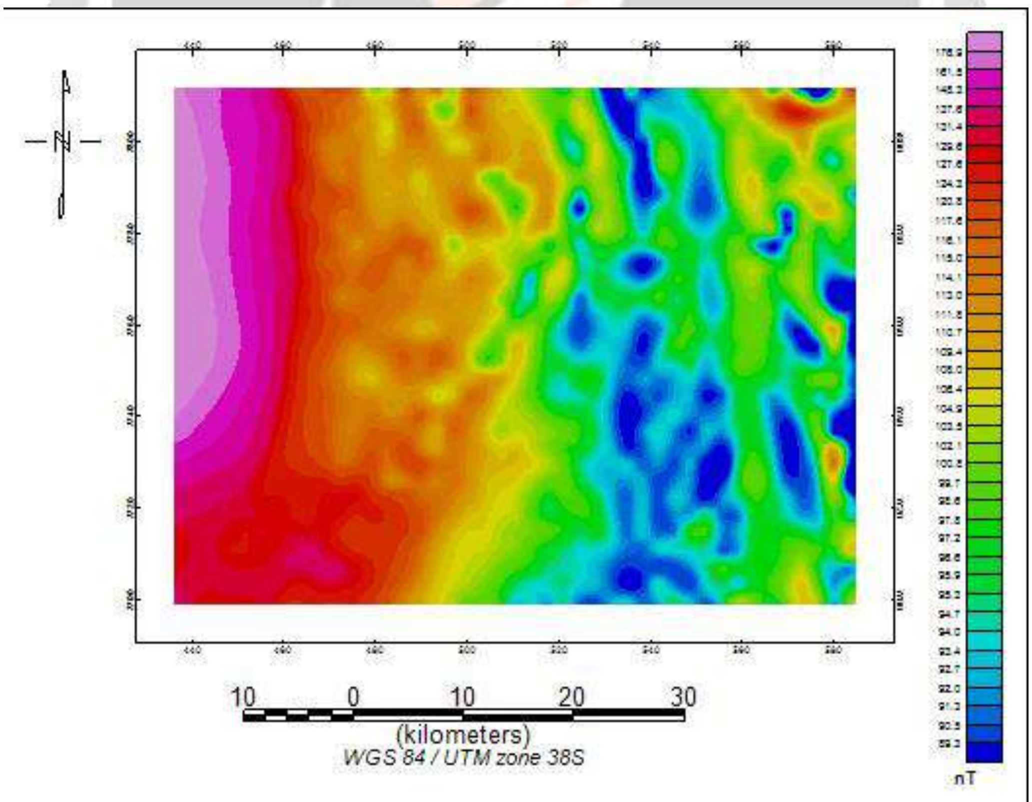

Fig-10: Gravity anomaly map

4.2. Correlation of magnetic data

The magnetic anomaly map is dominated by areas of negative anomalies with values around -85 to - 15 nT, and a positive anomaly of up to 125 Nt (Fig-11).

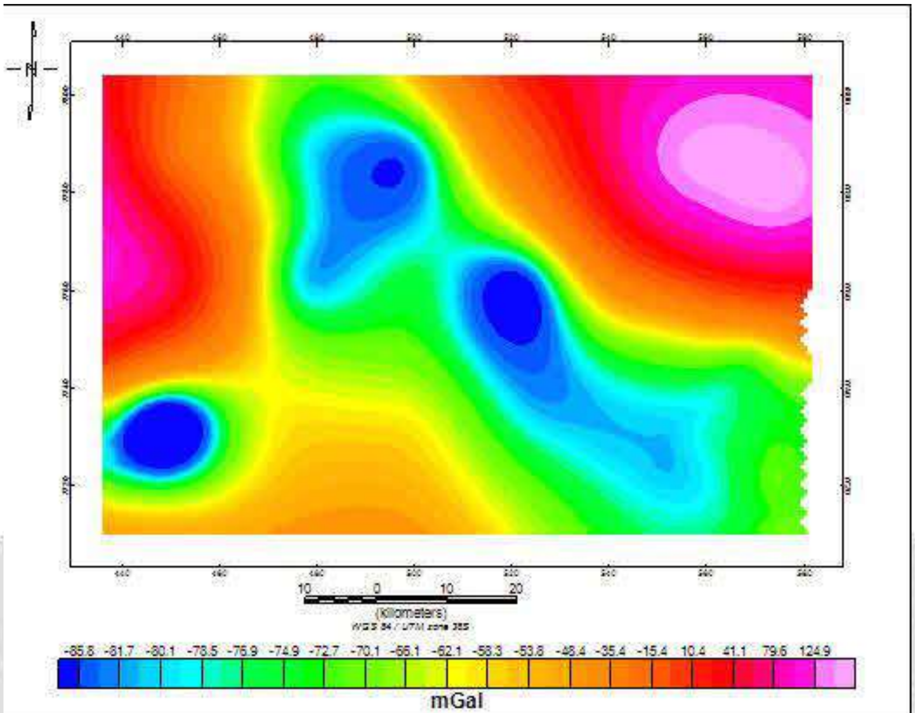

Fig-11: Magnetic anomaly map

In the centre, the anomaly is weak, as is the south-east and south-west. This negative anomaly is certainly caused by thick sedimentary formations with low magnetic susceptibility on the bedrock. The North-West and North-East parts are dominated by a positive anomaly value, which may be the effect of the bedrock with a high magnetic susceptibility.

4.3. Profile analysis and interpretation

In this section, we will attempt to make a joint quantitative interpretation of the gravimetric and magnetic data. These are two-dimensional (2D) models based on the profiles required according to the magnetic density and susceptibility parameters.

Interpretation is carried out using profiles run perpendicular to the main elongation of a structure to be studied. The profiles chosen must extend well beyond the area of interest. Our study focuses on the hydrographic networks to determine the connection between the reservoir rocks (geothermal) and the aquifers (groundwater system). The structure is assumed to be the source of the anomaly to take account of the effect of nearby or distant rocks.

- Choice of profiles

Our profiles were chosen so that they crossed hydrographic features that could represent porosities and permeabilities of interest to the groundwater system from the point of view of searching for hot springs (Fig-12 and Table - 2).

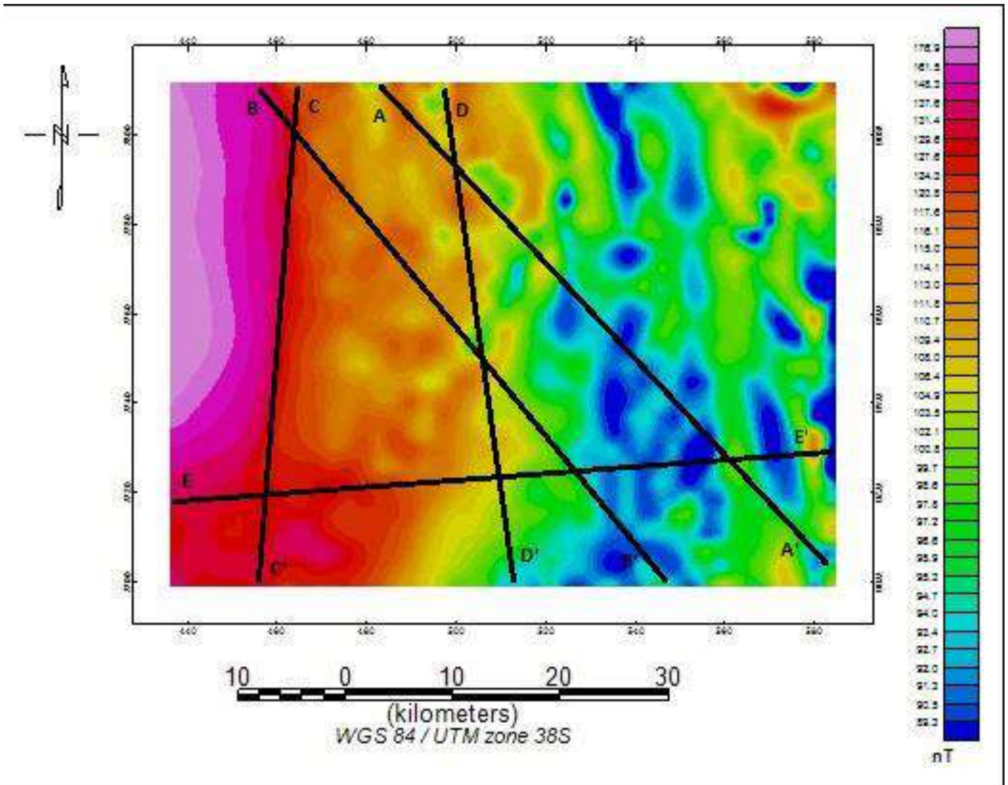

Fig-12: Gravity profiles to be modelled

Table-2: Profile coordinates in UTM

Profiles	**Orientation**	**Length (Km)**	**Start (Km)**	**End(Km)**
AA’	NNW-SSE	104	X = 481.82 Y = 7802.30	X = 581.32 Y = 7710.69
BB’	NNW-SSE	108	X = 464.51 Y = 7801.30	X = 543.3 Y = 7711.06
CC’	NNE-SSW	89	X = 469.19 Y = 7808.11	X = 459.15 Y = 7718.90
DD’	NNE-SSW	90	X = 498.11 Y = 7802.90	X = 513.08 Y = 7715.81
EE’	OSE-ENE	130	X = 439.81 Y = 7739	X = 580.16 Y = 7746.72

- AA' profile

Profile (AA') lies to the north of the study area and is 105km long. It is oriented NW and SEE. The resulting cross-section is shown in Fig- 13.

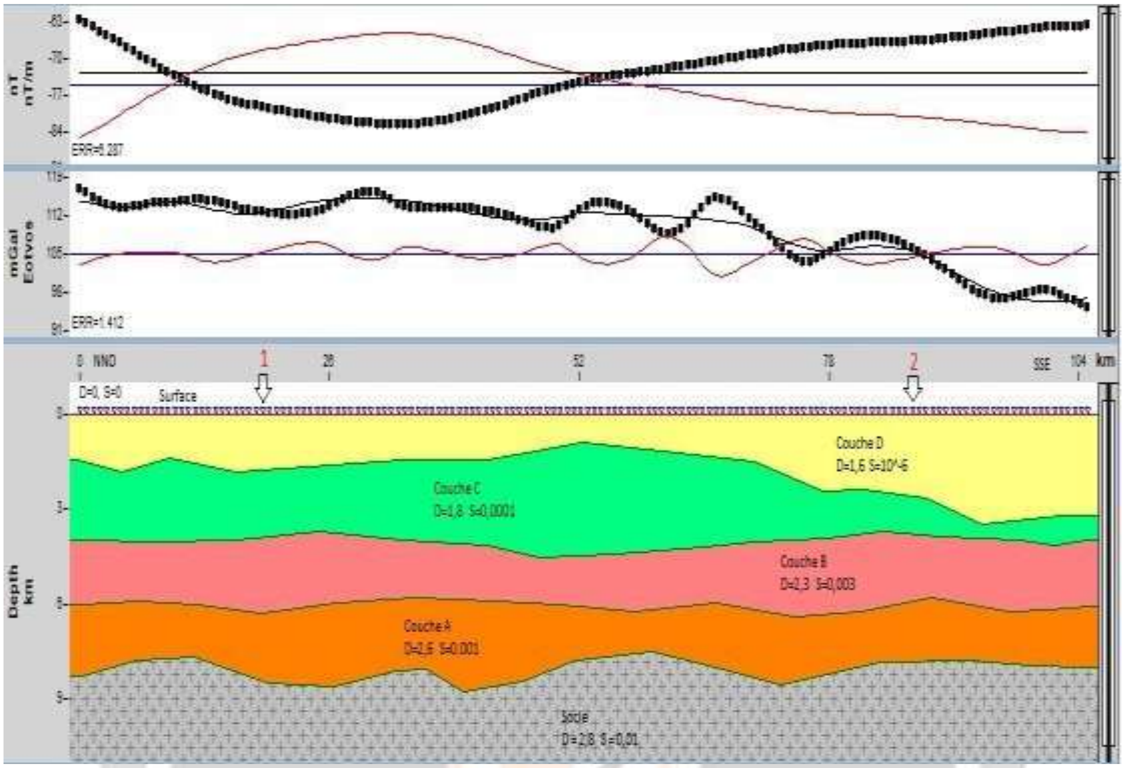

Fig-13: AA' profile

The shape of the two curves is visibly different throughout the profile. The magnetic anomaly curve has a decreasing trend until the point of abscissa X=35km at the beginning of the curve, then it

decreases at the point of abscissa X=40km, which marks the minimum magnetic value on this profile. The Bouguer anomaly curve remains stable between the interval X=0km to X=50km, and then decreases progressively until the end. For the magnetic anomaly, these values vary between -84nT and -63nT and for the gravity anomaly, they vary between -97mGal and 118mGal.

Consequently, the modelling obtained highlights a succession of six (05) stratigraphic formations that differ in terms of magnetic density and susceptibility. The error between the calculated and observed values is small, with 6.287% for the magnetic anomaly curve and 1.412% for the Bouguer anomaly. This observation allows us to deduce the good quality of the modelling and we can conclude that the model obtained is closer to reality.

- BB' profile (Fig-14)

This profile seems to have the same direction as the previous one and also from the point of view of the choice of profile which is almost parallel. It runs from North-North-West to South-South-East and is up to 108km long.

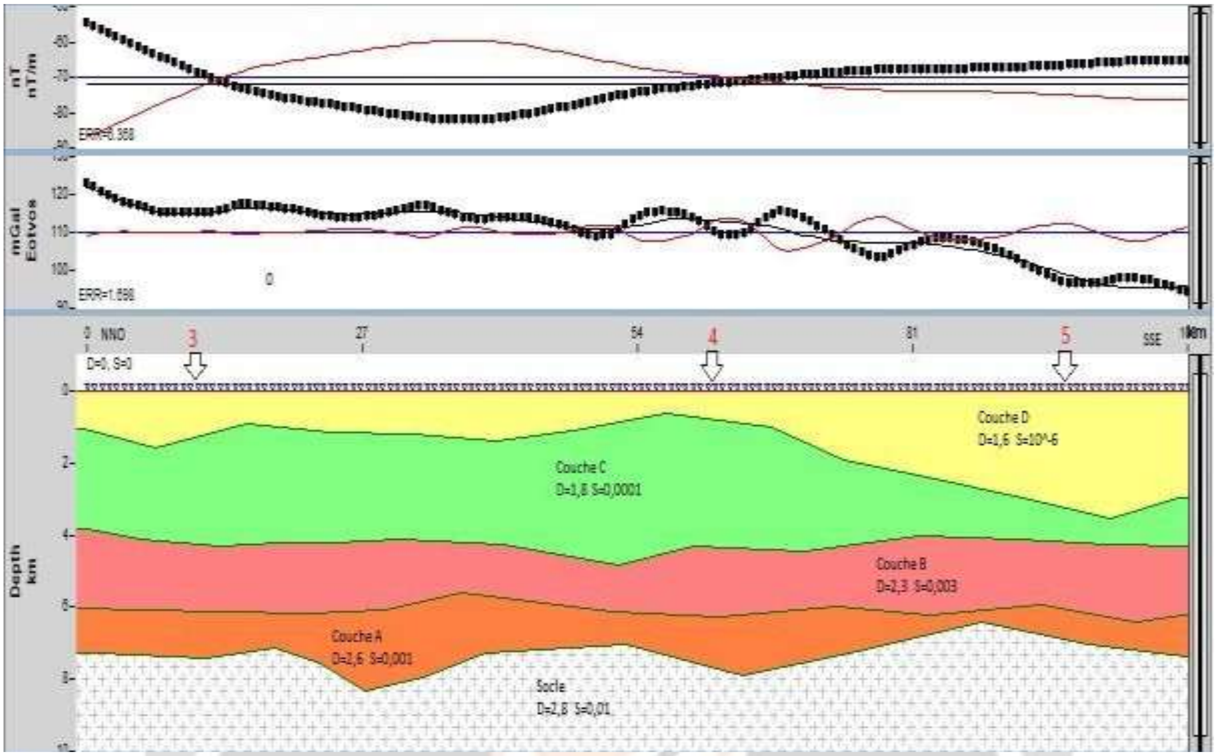

Fig-14: BB' profile

The shape of the two curves is always different. The magnetic anomaly curve decreases from the left to the point of abscissa X= 40 km and then increases slightly until the end of the profile. It varies between -80nT and -55nT. On the other hand, the Bouguer anomaly value is always positive, varying between 90mGal and 125mGal, and decreasing gradually throughout the profile. The modelling still shows the formation of six layers with different magnetic densities and susceptibilities. The error between the calculated and observed values is small, with a value of 6.368% for the magnetic anomaly and 1.698% for the Bouguer anomaly, which concludes that the modelling is reliable. So all the physical parameters, the colouration and the geological nature of each layer in this profile are identical to those in the previous profile (AA').

- DD' profile (Fig-15)

This profile is located in the central part of the study area and is concentrated over a distance of 89km in a NNE to SSW direction.

The value of the magnetic anomaly varies between -80nT and -60nT. From a global point of view, its trend decreases from the beginning to the X=20 km abscissa and becomes constant towards a progressive increase until the end of the profile. The value of the magnetic anomaly is negative. The Bouguer anomaly value in this profile remains more or less constant with its general trend either increasing or decreasing. The value of the anomaly is between 98mGal and 118mGal, which is always positive.

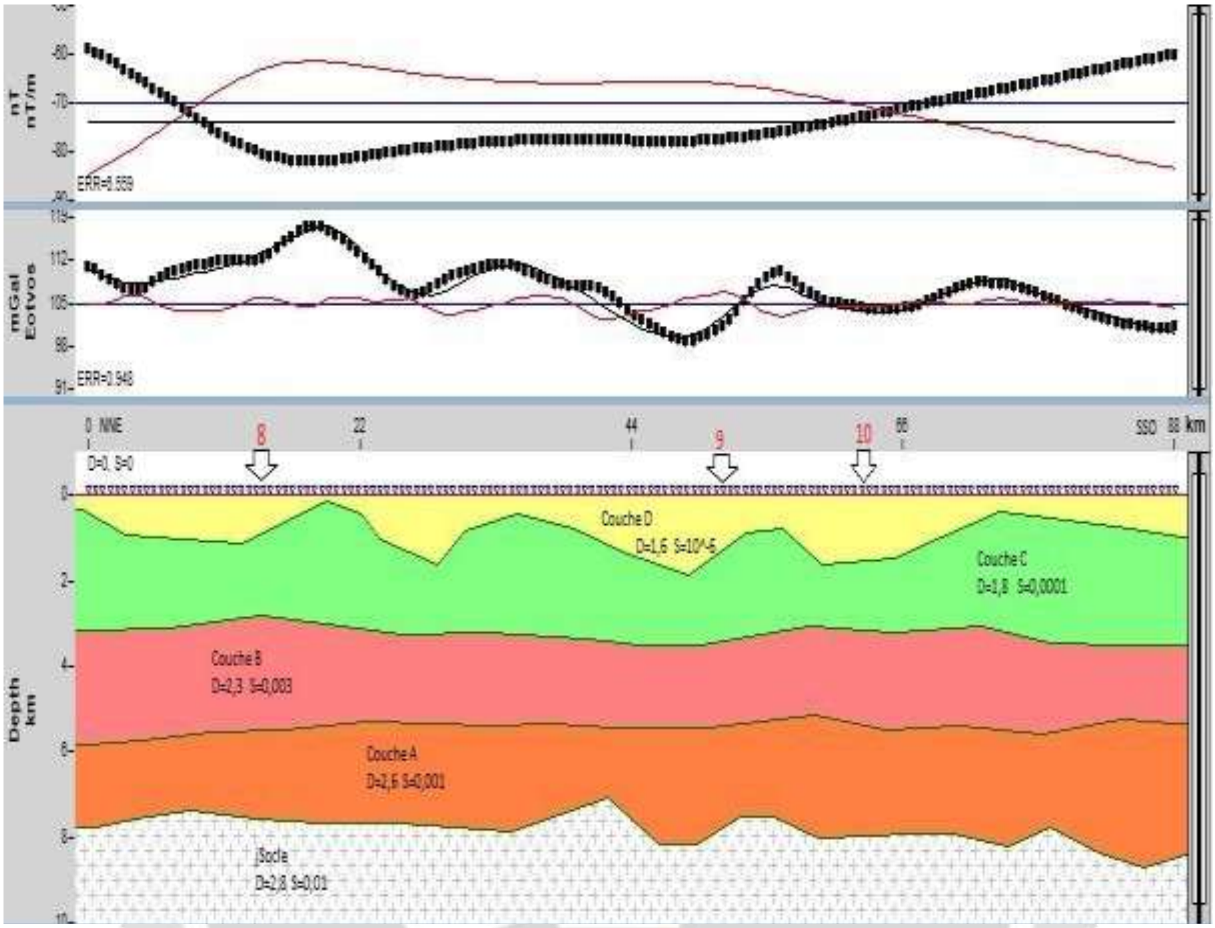

Fig- 15: DD' profile'

As with the previous profiles, the modelling highlights five formations. The error between the calculated and observed values is very small, 6.559% on the magnetic anomaly curve and 0.948% on the Bouguer anomaly curve. This interpretation brings the model even closer to reality.

5. DISCUSSION

The processing of the gravity and magnetic data in this work was carried out with a comparative study of the anomaly maps of the area and the choice of profiles. An in-plane model of the geological structure was simulated. This is done in order to derive a suitable interpretation, taking into account the hydrographic network, the geophysics and the geological nature of the Morondava basin, more specifically our interest in the Mahabo district.

In our profile, the porous rocks (presence of empty space and access to water) present low density and a magnetic susceptibility that tends towards zero. This highlights the presence of water: the origin of a reservoir rock known as an aquifer. The bottom of the profile is the bedrock with high densities, generally 2.8 g/cm3, and a high magnetic susceptibility, so it is difficult to identify aquifer sources in this layer. However, the D layer, which is represented by a layer of clay or sandy soil, is likely to be a source of water-bearing reservoir rock. We must refer to the anomaly curve of our profile because the geological structures may have intrusions or transformations. The weaker the gravimetric anomaly curve, the lighter the rocks. The lower the magnetic anomaly curve, the more water the rocks contain. The other layers, such as the A, B and C layers, may contain groundwater, but it all depends on the nature of each layer and the anomaly observed in our profile.

Layer A has a density of 2.6 g/cm3 and a magnetic susceptibility of 10-3 emu. It could be composed of detrital sandstone, thin limestone, thin shale (shaly clay and shaly marl). It is less likely and difficult to determine the presence of aquifer sources in this zone. Layer B is almost the same as layer A, with an average density of 2.3

g/cm3 and magnetic susceptibility of 0.003 emu. It may be composed of a layer of salt, marl, carbonate rock with interlayered limestone and sandstone. A small probability of the presence of aquifers can therefore be estimated from the sandstone composition.

6. CONCLUSION

This study provided an overview of the main geophysical methods used in the search for geothermal resources. Gravity and magnetic anomaly maps provide a close-up view of the structure of the subsoil. The combination of these two different methods provides an appropriate model of the geological structure of the Mahabo district.

Interpretation and modelling of the magnetic and gravimetric profiles showed the possibility of the existence of geothermal sources by studying the geological structures of the area and the characteristics of the porosity and permeability of the aquifer rocks. The results of our study show models of structures close to the area of interest with minimal errors. It is obvious to focus on the magnetic densities and susceptibilities of each layer in correlation with the map and the anomaly curve. This confirms the interest of hot springs in the Morondava sedimentary basin in the south-western part of the island.

Thanks to the model obtained and the correlation with the geology of the Morondava sedimentary basin, the presence of faults determines the location structures and the presence of groundwater. The more porous the rocks, the more empty space there is. So we need to know the porosity and permeability of the rocks. These voids are then filled by water, which means that surface water can flow into the groundwater from these rocks. So we have aquifer rock. The latter is easy to transfer heat from our hot source (geothermal reservoir) either by conduction or radiation, and the geothermal gradient (3°C/km) must be taken into account. We can say that the geothermal sources are made by correlation with the determination of the aquifer rocks or more porous rocks.

7. REFERENCES:

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