Aeromagnetic Study of the Morro Redondo an Alkaline Complex in Rio de Janeiro

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Abstract

This work provides valuable information about the geological context, research methodology, and filtering techniques utilized in a geophysical study conducted in the state of Rio de Janeiro. Describes the geological setting of the study area, highlighting its location within the Mantiqueira Province and the presence of the Morro Redondo alkaline complex. It discusses the composition, mineral zoning, and origin of the complex and explains the materials and methods employed in the study. Magnetometry is introduced as a potential method for investigating geology based on Earth's magnetic field anomalies, making it possible the data processing was performed using Geosoft Oasis Montaj software, with features like ASA (Analytic Signal Amplitude) filter and the Tilt Derivative filter.

Introduction

Brazil has massive natural structures within its territorial constitution, and studying these bodies requires methodologies that encompass sciences such as Geochemistry and Petrography. Carvalho (1989) stated that environmental geochemistry is among the natural sciences that are particularly concerned with human quality of life and anthropocentric natural balance. Its field of action is the planet Earth, particularly its observable crust. While a petrologist, for example, uses chemical results to define the characteristic mineralogical suite of a specific geological process, the geochemist seeks to understand the properties of elements and ions, their behavior under thermodynamic and physiochemical conditions responsible for, let's say, an observed migration process (Carvalho, 1989). In analytical geochemistry, temporal and spatial variance analyses are performed, as in exploration geochemistry. In petrography, in addition to chemical analysis, the recognition and characterization of the main phases of minerals and accessories and their textural relationships are included, aiming to establish possible parageneses and sequences of crystallization, as well as to differentiate, through observed textures, magmatic and post-magmatic crystallization events (Vilalva, 2012).

The gravity method focuses on the study of small local disturbances in the Earth's gravitational field, generated by the distribution of masses in the subsurface, specifically the presence of rocks with different densities. Denser materials contribute more strongly to the gravitational field than less dense ones, considering the same volume and depth for both types of materials. If the materials have the same density, the greater contribution comes from those closest to the surface, or if they occupy the same volume, from those that have a larger volume (Gouvea and Lúcia, 1995).

Each rock becomes magnetized according to its magnetic susceptibility, which depends on the quantity and distribution of magnetic minerals present. The concentration of magnetic minerals produces local distortions in the Earth's magnetic field, which can be detected and provide information about the subsurface. Magnetometry is based on the study of local variations in the Earth's magnetic field, derived from the existence of rocks containing minerals with strong magnetic susceptibility, such as magnetite, ilmenite, and pyrrhotite (Gouvea and Lúcia, 1995).

According to Valença et al. (1983), Morro Redondo has a rounded shape and covers an area of 8 km^2, with abrupt contact with the pre-Cambrian gneissic basement. Field observations also highlight the presence of mineral zoning throughout the massif. The study will be conducted through airborne surveys, using the magnetic susceptibility of these rocks through the magnetic method. In general, most magnetic measurements are carried out using instruments on the ground or in aircraft.

Additionally, measurements can be taken in water-covered areas with the help of vessels. The magnetic method, along with the gravimetric method, is based on the Theory of Potential. Both methods are very similar in theory, but the main difference that makes the magnetic method more complex is the dipolar nature of the magnetic field, as opposed to the monopolar nature of the gravitational field. One advantage of the magnetometric method is its low survey cost, making it one of the most widely used methods in exploration (Gouvea and Silva, 1995).

In the specific case of massif Morro Redondo, one approach of study can be the use of magnetic data to characterize the size and depth of the massif. By interpreting the magnetic data, it is possible to map variations in the distribution of magnetic minerals and identify geological structures, such as faults and intrusions. This information can help understand the geological evolution of the region and the relationship between the massif and the surrounding structures.

Geological context

Regional Geology: The study area is located in the state of Rio de Janeiro, at the triple border of the municipalities of Barra Mansa, Resende, and Porto Real, at the geographic coordinates 22°29'28" S, 44°19'46" W. The state of Rio de Janeiro is geotectonically situated within the Mantiqueira Province (Almeida et al., 1981). This province represents a geotectonic entity characterized by a northeast orientation, established west of the São Francisco Craton at the end of the Neoproterozoic and the beginning of the Paleozoic. Along with the Brasília Belt, the Guaxupé Ridge, and the metasediments of the so-called Alto Rio Grande Belt, it forms the geotectonic framework of Southeastern Brazil (CPRM, 2001). According to Almeida (1981), Mantiqueira Province, located along the southern part of the Atlantic coast, affected chiefly by “the Brasiliano folding cycle”.

Local Geology: The alkaline complex of Morro Redondo was first reported by Lamego (1936). According to Valença et al. (1983), it has a rounded shape and covers an area of 8 km², with abrupt contacts with the pre-Cambrian gneissic basement. Field observations also highlight the presence of mineral zoning throughout the massif. Based on field data, it is considered that the episode of emplacement of the phonolitic magma, which gave rise to the breccias, is later than the one that formed the various types of syenites.

According to Brotzu et al. (1989), the rocks of the alkaline massif essentially consist of medium to coarse-grained nepheline syenites, occurring in the eastern, southern, and northern sectors, and predominantly altered phonolitic and trachytic breccias in the central-western part. The rocks located in the central region of the body, which are the highest areas, are slightly enriched in nepheline, amphibole, clinopyroxene, and especially biotite, corresponding to the mafic minerals in the rocks that outcrop near the edge of the alkaline intrusion. Magnetite is the only opaque mineral contained in the rocks of Morro Redondo.

Regarding the genesis of the intrusion, according to Brotzu et al. (1989), petrographic, mineral chemistry, and geochemical observations indicate a co-genetic character of the various lithological types found, suggesting fractional crystallization of the observed phases and accumulation of crystals, preferentially of alkali feldspar, as the process responsible for their formation. The initial isotopic ratios of Sr point to the mantle nature of the parental magma of these rocks, probably generated in the subcontinental lithosphere. In parallel, Mota (2012), based on the integration of geochemical and isotopic data, proposes the possibility that the genesis of the alkaline intrusion corresponds to the model of fractional crystallization with the assimilation of country rocks. Additionally, it is noted that no pyroclastic rocks or feeder dikes were found, allowing for the association of current denudation at the level of the magma chamber.

The Nd and Sr isotopic results obtained for the rocks of Morro Redondo indicate that the origin of these rocks occurred in the sub-lithospheric mantle, resulting from the partial melting of a reservoir enriched with low 87Sr/86Sr and 143Nd/144Nd values.

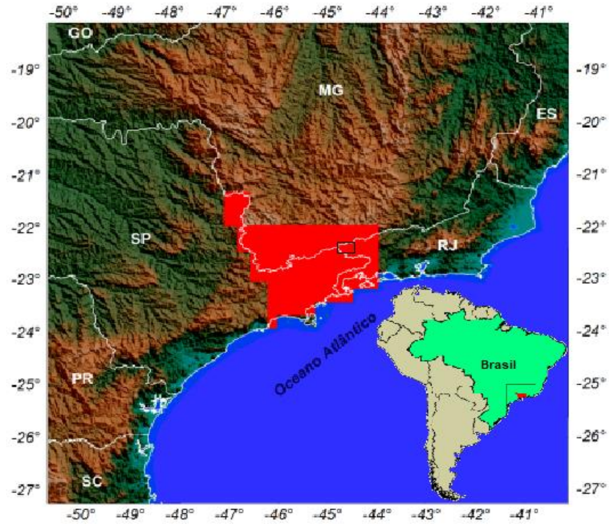

Figure 1: São José dos Campos – Resende is located in the southeastern region between the states of Minas Gerais, Rio de Janeiro, and São Paulo.

Method

Magnetometry is a potential method that measures small variations in the Earth's magnetic field. It enables the investigation of geology based on anomalies in the Earth's magnetic field, which result from the magnetic properties of subsurface rocks. Magnetic susceptibility is a fundamental parameter, where values for certain materials can be positive, negative, or constant, reflecting the intensity of magnetization relative to the field (Kearey et al., 2009; Sordi, 2005).

The magnetic method, along with the gravimetric method, is based on the Theory of Potential. Both methods are similar in theory, but the main difference that makes the magnetic method more complex is the dipolar nature of the magnetic field, unlike the monopolar nature of the gravitational field (Gouvea and Silva, 1995). Thus, magnetometry plays a crucial role in the conducted survey, the Aerogeophysical Project São José dos Campos - Resende, related to survey 1105, which is available on the website of the Geological Survey of Brazil (CPRM) in XYZ format. It was conducted between October 19, 2010, and October 11, 2013, in the southeastern region spanning the states of Minas Gerais, Rio de Janeiro, and São Paulo, covering an area of 47,321 km². The survey included 101,085 linear kilometers of high-resolution aeromagnetic and aero gamma-spectrometric profiles, with flight lines and control spaced at 0.5 km and 10.0 km, respectively, oriented in the N-S and E-W directions, and with reading intervals of 0.1 (10 Hz) to 0.01 (100 Hz) second.

The data processing for this study was carried out using Geosoft Oasis Montaj software, version 8.4. Oasis Montaj is a software used for processing, interpretation, and visualization of geophysical data. Developed by Geosoft, a global company that provides services to clients in various fields, such as mineral exploration.

The use of filters via Oasis Montaj is applied to the data after pre-processing to remove trends. It aims to eliminate unwanted noisy effects for the recognition and highlighting of relevant features. The data processing follows the following sequence: (1) Importing the data obtained from CPRM, (2) Coordinate system correction to the UTM of the region, (3) Gridding of maps and subsequently applying the filters. Some of these filters were used in the research work to process the raw data provided on the CPRM website.

ASA Filter (Analytic Signal Amplitude): According to Barkley (1996), the analytic signal amplitude consists of a combination of horizontal and vertical gradients of a magnetic anomaly. The ASA filter is used to calculate the amplitude of the analytic signal in magnetic data.

Tilt Derivative Filter: This filter is used to enhance details that can be obscured by higher amplitude anomalies. It is a linear combination of the horizontal and vertical field derivatives, normalized by the analytic signal amplitude (Miller and Singh, 1994).

Spector and Grant (1970) were the first to introduce the identification of magnetic layers based on the inclination of the power spectrum using a total magnetic field grid. In other words, equivalent source depths exhibit distinct responses. Therefore, by analyzing the logarithmic graph of the spectrum, it is possible to conclude that each line (slope) corresponds to a layer composed of a set of sources with similar depths. Consequently, quick depth estimates can be determined by analyzing the radial power spectrum of the anomaly. The calculations for the sources generate a logarithm of the power spectrum, which consists of a linear gradient whose magnitude depends on the depth of the source (Barkley, 1996).

Conventional Euler deconvolution is widely used for interpreting profile, grid, and un gridded potential field data. The Tensor Euler deconvolution applies additional constraints to the Euler solution using all gravity vectors and the full gravity gradient tensor. These algorithms use a series of different-sized moving windows to yield many solutions that can be employed to estimate the source location from the entire survey area (Cao et al., 2023). Traditional discrimination techniques use markers with different shapes, colors, or/and sizes to indicate depth and SI values for Euler solutions for locating anomalous sources (Zhang et al., 2000; Allsop et al., 1991; Reid, 1995). However, these methods can hardly analyze complex Euler solution datasets. Furthermore, traditional discrimination techniques cannot evaluate the overall quality of the solutions or determine how dense/compact the clusters are (FitzGerald et al., 2004; Ugalde and Morris, 2010), such as dense distributions (for example, the centroids of geological bodies) and sparse distributions, for example, the gaps among geological bodies, of Euler solutions.

Results

In this study, our objective is to discuss and analyze the alkaline massif known as Morro Redondo using filters. We aim to provide an estimate of its depth and qualitatively identify the structural highlights of the region surrounding the alkaline massif.

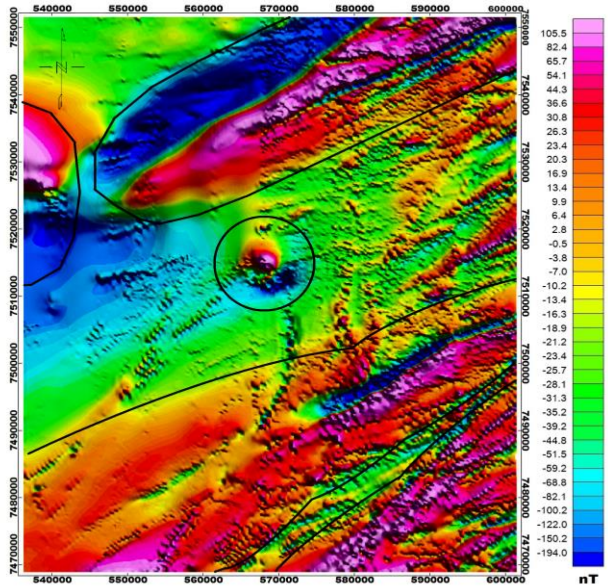

Figure 2: AMF (Anomalous magnetic field). Total study area.

The Anomalous Magnetic Field (AMF) has a dipolar character, where its physical measurement field is the calculated magnetic field in terms of intensity or its components (x, y, z), with the unit of measurement being nanoTesla (Sordi, 2007). This dipolar character has a high and a low magnetic aspect. In Figure 2 we highlight an area known as the Ribeira Orogen or Ribeira Belt. There are several important points to note, such as:

Morro Redondo circled in the center of the image, has an elliptical-rounded geometry with its major axis oriented in the north-south direction. It exhibits mineral zoning throughout its body.

In the semi-circle on the left side of the image, we can see the municipality of Itatiaia (RJ), which is worth mentioning because it shares the same dipole as the alkaline massif. It is formed by a composite structure elongated in the northwest direction, consisting of rocks with varying degrees of silica saturation. There is also the presence of alkaline intrusions in the form of dikes, which tend to orient themselves between the northeast and east-west directions. These dikes are more common near the globular intrusions that are geographically associated with normal faults, often filled with silicified breccias (Heilbron, 2017).

In the northern part of the image, we can highlight a region with an inverse dipole compared to Morro Redondo. This structure emerged through a rifting process accompanied by magmatism, leading to the opening of a rift system in the Southeast, resulting in the formation of the Resende, Volta Redonda, Itaboraí, and

Guanabara Graben basins in the state of Rio de Janeiro (Riccomini et al., 2004).

The area between the two circled fields is known as Embu. This name is used to designate a metasedimentary or metavolcanosedimentary association that outcrops in a limited area in the western portion of the Rio de Janeiro state, in the region of the middle Paraíba do Sul Valley between Resende and Itatiaia (RJ), southwest of the Resende Sedimentary Basin.

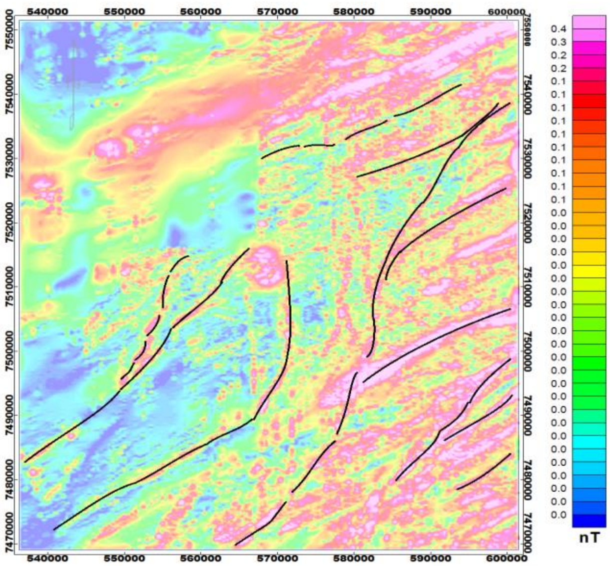

Figure 3: ASA Filter (Analytic Signal Amplitude)

ASA - The main advantage of using ASA is the ability to delineate and simplify the geometry of the anomaly. According to Reeves (2005), the amplitude map of the analytic signal results in monopolar anomalies located directly above their sources (bodies), and it is independent of the magnetization vector direction. Through this filter, we can observe a structural geology with a NE-SW orientation, with many of them being sigmoidal in shape.

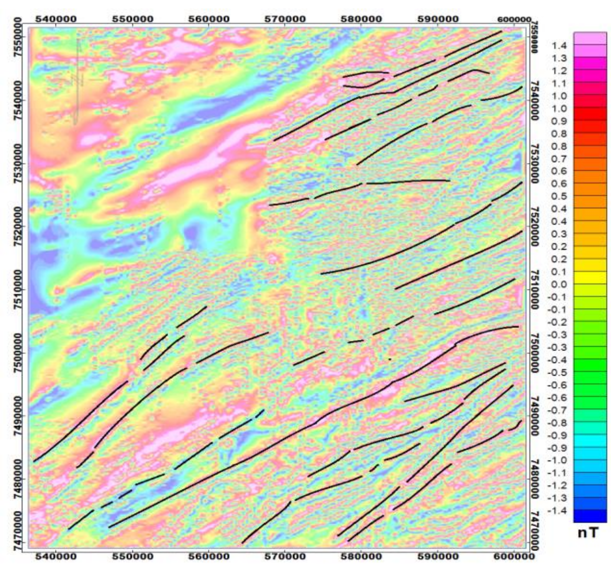

Figure 4: Tilt Filter (Tilt Derivative)

The Tilt filter provides us with a better understanding of the structural aspects of the area, revealing certain characteristics of the Ribeira belt, such as zones of intense deformation or high-temperature ductile shear zones that may be reactivated at lower temperatures. These features are predominantly oriented in the NE-SW direction (Almeida, 2000).

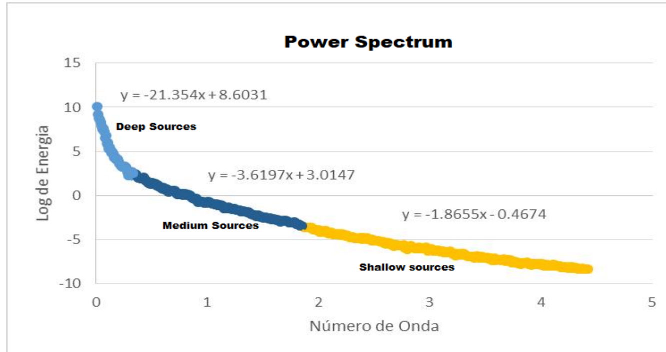

Figure 5: Power Spectrum Data

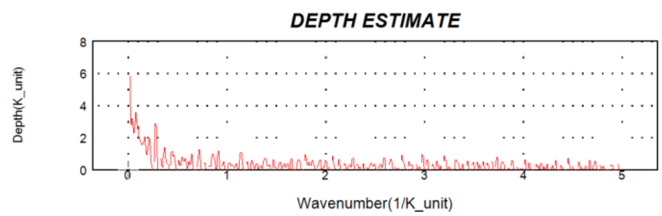

Figure 6: Depth Estimate Data

AMF depth estimation was performed using the Radial Mean Power Spectrum method (Spector and Grant, 1970), which allows the separation of sources into regional and residual components by interpreting the change in the slope of fitted straight lines in the power spectrum. As a result, we obtained a separation into three parts: depths up to 1700 m for deeper sources, 288 m for intermediate or medium, and depth sources up to 148 m for shallower sources.

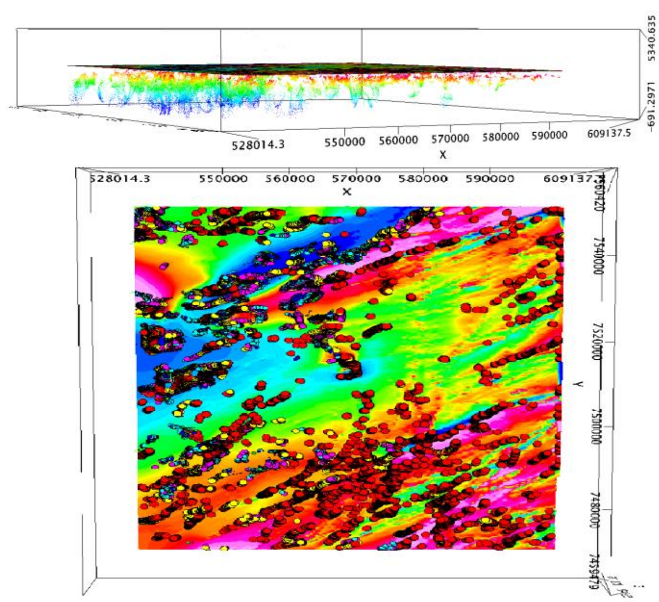

Figure 7: Euler deconvolution applied from the AMF.

The image demonstrates the Euler deconvolution of the magnetic data indicating the Euler solutions for depths. It employs a series of moving windows of varying sizes to obtain multiple solutions that can be engaged to estimate the source location throughout the survey area.

Conclusions

This study aimed to analyze the Morro Redondo alkaline massif and its geology, as well as to gain a general understanding of its surrounding geology and basic formation structures, including depth estimation. We obtained results from data collected through Magnetometry techniques based on the Earth's magnetic field, gaining insights into its structural geology through processing with geophysical filters ASA and TILT, and determining depth estimates and anomaly locations through Power Spectrum and Euler Deconvolution. The studies indicate that the alkaline massif exhibits lateral continuity of the depth source and that the geological structures in the region have a NE-SW orientation, with many of them displaying a sigmoidal shape. The maximum estimated depths are approximately 1700m. These findings closely align with the geological maps of the area.

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