



ISSN: 2447-3359

REVISTA DE GEOCIÊNCIAS DO NORDESTE

Northeast Geosciences Journal

v. 10, nº 1 (2024)

<https://doi.org/10.21680/2447-3359.2024v10n1ID34802>



Gravimetric inversion applied to the study of the basement relief of the Recôncavo-Tucano-Jatobá Rift System in Northeast Brazil

Inversão gravimétrica aplicada ao estudo do relevo do embasamento do sistema Rift Recôncavo-Tucano-Jatobá no Nordeste do Brasil

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Abstract: This article presents results from the implementation of an inverse modeling algorithm that considers the Bouguer anomaly signal to estimate and gain a better understanding of the boundary between the sedimentary package and the basement of the sub-basins within the Recôncavo-Tucano-Jatobá rift system. The algorithm for modeling the basement relief is considered a medium constituted by a set of discrete two-dimensional prisms with fixed density contrasts between sediment and basement and variable depth. Initially, it was applied to synthetic models, resulting in depth variation curves of the basement top that fit well with the true model. Subsequently, this methodology was applied to satellite gravity data obtained from the high-resolution Earth gravity field model called SGG-UGM-2. The results of this application were compared with the depth of the Moho interface estimated beneath the studied units and obtained through the Parker-Oldenburg methodology. The information produced here allowed the interpretation of the gravity anomaly over the depositional space of the studied basins and the geometry of their basement. Together with the knowledge of their stratigraphy, this interpretation may be analyzed to characterize the region's reservoirs. By interpreting the basement relief in conjunction with the Moho topography, this study portrays the geotectonic evolution of the aulacogen and its association with estimating the depocenters of the Recôncavo, Tucano, and Jatobá sub-basins.

Keywords: Rift System; Gravity Inversion; SGG-UGM-2 Model.

Resumo: Este artigo apresenta resultados da implementação de um algoritmo de modelagem inversa que considera o sinal da anomalia Bouguer, para estimativa e melhor entendimento do limite entre o pacote sedimentar e o embasamento das sub-bacias do sistema rife Recôncavo-Tucano-Jatobá. O algoritmo para a modelagem do relevo do embasamento, considerou um meio constituído por um conjunto de prismas bidimensionais discretos, com fixos contrastes de densidades entre sedimento e embasamento, e profundidades variáveis. Este, foi aplicado inicialmente a modelos sintéticos, resultando em curvas de variações da profundidade do topo do embasamento concordantes com o modelo verdadeiro. Em seguida, esta metodologia foi aplicada a dados gravimétricos de satélite obtidos a partir do modelo de campo gravitacional terrestre de alta resolução denominado SGG-UGM-2. Os resultados desta aplicação, foi comparado com a profundidade da interface Moho estimada abaixo das unidades estudadas e obtida através do uso da metodologia de Parker-Oldenburg. As informações aqui produzidas permitiram a interpretação da anomalia gravimétrica sobre o espaço deposicional das bacias estudadas e a geometria do seu embasamento. Juntamente com o conhecimento de sua estratigrafia, esta interpretação poderá ser analisada para caracterização dos reservatórios da região. Ao interpretar o relevo do embasamento em conjunto com a topografia Moho, este estudo retrata a evolução geotectônica do aulacógeno e sua associação com a estimativa dos depocentros das sub-bacias Recôncavo, Tucano e Jatobá.

Palavras-chave: Sistema Rift; Inversão de Gravidade; Modelo SGG-UGM-2.

Received: 11/12/2023; Accepted: 07/02/2024; Published: 25/02/2024.

1. Introduction

Rift-type sedimentary basins originate from tectonic processes known as rifting (SZATMARI et al., 1985; MILLANI et al., 1988). This phenomenon occurs when the continental crust undergoes stretching and separation, resulting in the creation of openings in the Earth's surface called rifts. Typically, rifting is accompanied by volcanic activity and earthquakes. As the crust stretches, it descends, forming an elongated central depression. Sediments gradually accumulate in this depression over time, giving rise to extensive layers of sedimentary rocks. In rift-type basins, a common characteristic is the presence of inland lakes or seas. Tectonic activity can cause adjacent rock blocks to sink, creating depressions that may be flooded by seawater or freshwater from rivers. These bodies of water create favorable conditions for sediment deposition, leading to the development of distinct sedimentary sequences in rift basins.

The Rift Valley in East Africa is a renowned example of a rift-type basin that spans across multiple countries, including Kenya, Tanzania, and Ethiopia. This region is distinguished by faults and is home to numerous lakes, including Lake Victoria and Lake Tanganyika (TIERCELIN, 1990). From a geological perspective, rift-type basins are important due to their potential for valuable natural resources such as oil, natural gas, and groundwater. Moreover, these basins offer valuable insights into the tectonic and geological evolution of a region. In Brazil, examples of basins generated from rifting are the Recôncavo, Tucano, and Jatoba basins, located in the northwest of the state of Bahia, Brazil. These basins belong to the Recôncavo-Tucano-Jatobá rift system, which originated during the Jurassic period when the supercontinent Gondwana separated (MAGNAVITA, 1992; MAGNAVITA et al., 2005). Considered sub-basins within this system, they possess a complex geological history marked by several phases of rifting and subsidence, resulting in distinct geological characteristics for each sub-basin. It is also worth noting that since the 1940s, these sub-basins have been subject to exploratory activities, establishing themselves as crucial contributors to onshore oil and natural gas production in Brazil. These regions have played a pivotal role in the Brazilian oil industry, and their exploration extends to groundwater production, showcasing significant potential for the development of renewable energies, including geothermal energy.

This work presents a non-linear inverse gravitational modeling algorithm specifically designed for estimating basement depth of rift-type sedimentary basins. This algorithm utilizes the Gauss-Newton method coupled with regularization by smoothness to enhance the stability of the inversion process. Synthetic data tests were conducted to evaluate the reliability of inversion estimates concerning the depth parameter of the modeled basement. Two synthetic models were analyzed, introducing noise in the gravimetric data synthetic, and applying different regularization techniques to check the efficacy of the inversion algorithm. Moreover, the developed algorithm was applied to gravimetric data collected by satellite, processed, and employed to delineate the structural characteristics of the Recôncavo, Tucano Central, and Jatobá Sub-basins' depocenters. To estimate the Moho discontinuity, this work used the Parker-Oldeburg method (PARKER, 1973; OLDENBURG, 1974), through the algorithm of Gómez-Ortiz and Argawal (2005) applied to the Bouguer anomaly gravimetric data.

2. Geological Setting

The Recôncavo-Tucano-Jatobá Basin rift system (Figure 1) represents a complex series of interconnected rift basins located near the coastline of the Northeast Region of Brazil, extending from the State of Bahia to the State of Pernambuco (Gordon et al., 2017). This system is composed of the Recôncavo, Tucano, and Jatobá Basins, formed during the separation of the supercontinent Gondwana in the Jurassic period, and which is related to an aborted rift of the continental separation between South America and Africa during the Mesozoic, which then generated the South Atlantic Ocean. The stretching and subsequent separation of the continental crust led to valleys and rift basins forming in the region, characterized by a combination of faults, subsidence, and sedimentation. The system is limited to the south by the Camamu Basin, to the west by the Itabuna-Salvador-Curaçá Block, Serrinha Block, Sergipana Belt, and the Pernambuco-Alagoas Massif, limited to the east by the Salvador-Esplanada Belt, Sergipano Belt, and Pernambuco-Alagoas Massif and to the North by the Pernambuco Shear Zone (SILVA, 2017).

The Recôncavo Basin is the largest and best-known component of this rift basin system, occupying an area of approximately 11,500 km², and has been located near the northeast coast of Bahia, being one of the main oil and gas producers in Brazil since the 1940. This basin is known for its extensive sedimentary filling, with a maximum thickness of around 6,900 m, in the Lower Camaçari region, which consists of sandstone, shales and limestone deposited over millions of years. Furthermore, based on SANTOS et al., (1990), the sedimentary thickness in the Recôncavo is more than 6,000 m wide, and Bessoni et al. (2015) state that this basin is an aborted intracontinental rift with architecture that reflects a semi-graben NE-SW orientation. The Tucano Basin is located north of the Recôncavo Basin. It is a relatively more minor

basin, with an approximate area of 30,500 km², and where its sedimentary deposit is composed of sandstones, shales, and conglomerates, which were formed during the rift and subsequent filling stages. Structural features with an NW-SE direction make it possible to subdivide it into Tucano Sul, Central, and Norte sub-basins. To the north, the Tucano Central Sub-basin separates from Tucano Norte by the Vaza-Barris Zone; to the south, the limit between the Tucano Sul Sub-basin and the Recôncavo Basin is given by the Alto de Aporá; to the east, the Inhambupe and Ajustina faults constitute, respectively, the boundaries between the Tucano Sul and Central Sub-basins (MAGNAVITA, 1992). The boundary of the Tucano Norte Sub-basin with the Jatobá Basin is given by the São Francisco Fault to the Northeast. At its depocenter, the estimated basement depths are greater than 6,000 m for the Tucano Sul Sub-basin and approximately 8,000 m for the Tucano Central Sub-basin (Lower Cícero Dantas). For the Tucano Norte Sub-basin, in Baixo Salgado do Melão, estimated depths are around 6,000 m (MAGNAVITA, 1992). The Jatobá Basin is the westernmost component of the rift system with an approximate area of 5,000 km², located near the border with the state of Pernambuco and with a NE-SW orientation. The faults of São Francisco to the west and Ibirimir to the north constitute its main structural limits. The sedimentary rocks of the Jatobá Basin include sandstones, shales and conglomerates, similar to the other basins of the system. Their contact is discordant or occurs through small faults to the south and north. The change in the direction of the rift opening from S-N in Tucano Norte to SW-NE in the Jatobá Basin may be the most explicit example of control exercised by basement structures in the past. This inflection is conditioned by the Pernambuco-Paraíba Shear Zone, whose reactivation during the Early Cretaceous gave rise to the Ibirimir Fault, the northern limit of the Jatobá Basin (SANTOS et al. 1990; MAGNAVITA, 1992). The estimated basement depth in Baixo de Ibirimir is around 4,000 m (MAGNAVITA, 1992).

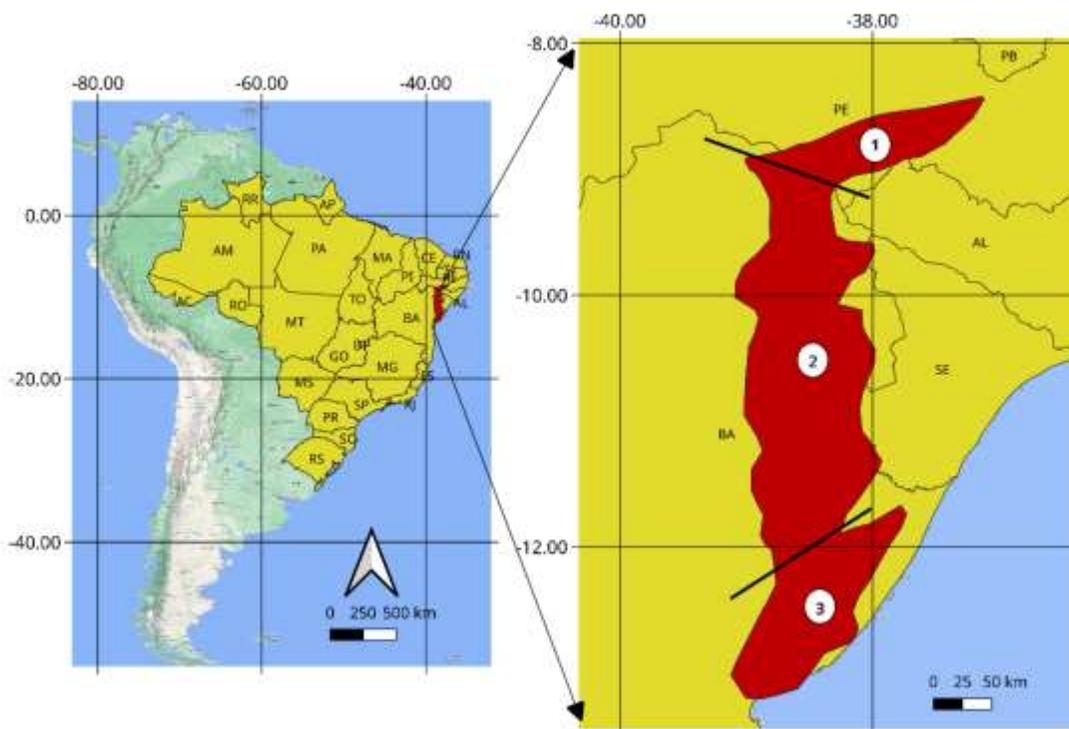


Figure 1 – Location of the study area: (1) Jatobá Basin, (2) Tucano Basin and (3) Recôncavo Basin.

Source: The current authors (2023)

3. Inversion Process

In this research, the sedimentary basin composed of sediments and basement was represented by a set of two-dimensional prisms, each displaying a specific density contrast between the sediment layer and the basement (Figure 2). Each prism has a variable length, representing the different depths of the basement top.

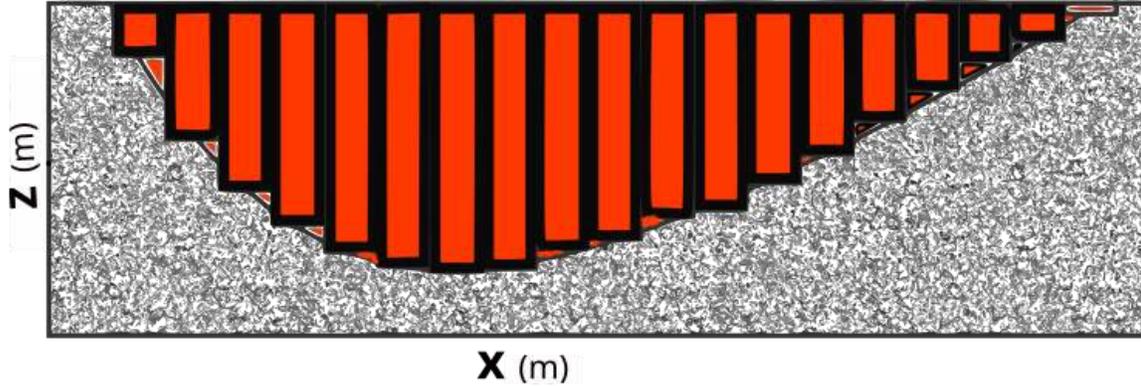


Figure 2 – Illustration of the prism model used to model a sedimentary basin. Prisms having a fixed density contrast between the sediment and the basement and with variable depth.

Source: Adapted from Uieda (2020).

Let be a vector with N data set of gravitational anomalies produced by a sedimentary basin. The basin is composed of a density contrast between sediment and basement ($\Delta\rho$) defined, as a variation of basement depth. One can approximate the interpretation model through a set M of prisms juxtaposed with the 2D dimension. The prisms are placed so that their type is aligned with the ground surface and all prisms are the same width (Figure 2).

Considering the defined density contrasts and the depth variation of the prisms, the predicted gravitational anomaly to map the basement is a non-linear function of the parameters z_j , $j = 1, \dots, M$. Let g_i be the set of observations of the N Bouguer Anomalies produced by the basement relief and the density contrast $\Delta\rho$ between the sediment and the basement of the sedimentary basin. He assumed that possible regional effects were removed and was generated the residual Bouguer anomaly or simply Bouguer anomaly. The thickness of the prisms between the sedimentary layers and the basement are the parameters to be estimated and are related to gravity g_i through non-linear relationships,

$$g_i = \sum_{j=1}^M F(p_i, r_i), \quad (1)$$

$$p = [z]^T, \quad (2)$$

where $F(p_i, r_i)$ is a non-linear function that produces gravimetric anomaly of a prism at position r_i , thickness z_i , and density contrast $\Delta\rho$ between the sediment and the basement (SILVA, OLIVEIRA and BARBOSA, 2010).

We use the regularized Gauss-Newton method for the nonlinear inverse problem with an estimate of z_i . Let $g^o = \{g_1^o, g_2^o, \dots, g_M^o\}^T$ be the vector of the observed gravitational data and g , whose i th element of the vertical component of gravitational predicted by Equation 1. To estimate the parameters to be inverted, producing predicted data as close as possible to the observed data, we use the following objective function to be minimized,

$$\tau(p) = \Phi(p) + \mu\Psi(p), \quad (3)$$

where, μ is the weight assigned to the regularization function $\Psi(p)$ and $\Phi(p)$ is the misfit function given by

$$\Phi(p) = \frac{1}{N} \|g^o - g\|_2^2, \quad (4)$$

where $\|g^0 - g\|_2^2$ represents the Euclidean norm squared between observed and calculated data.

A type of restriction is implemented so that the inverse problem is well posed and has a stable solution. Constraints are introduced via smoothness regularization (also known as first-order Tikhonov). The smoothness regularization is introduced to the depth z_j (Ψ), as implemented in the works of (BARBOSA et al., 1997; BARBOSA et al., 1999; SILVA, OLIVEIRA and BARBOSA, 2010 and BASTOS & OLIVEIRA, 2019). Mathematically, the smoothness regularizations for z_j , equality with a priori information for z_j is given by,

$$\Psi(z) = \|S z\|, \quad (5)$$

where S is a $2(N - 1) \times M$ matrix given by,

$$S = \begin{bmatrix} R & 0 & 0 \\ 0 & R & 0 \end{bmatrix}_{2(N-j) \times M}, \quad (6)$$

$$[R]_{ij}, \begin{cases} 1, & j = i \\ -1, & j = i + 1 \\ 0, & \text{Otherwise.} \end{cases} \quad (7)$$

Minimizing functional $\tau(p)$ given, in Equation 3, concerning p is a nonlinear problem that will be solved iteratively. The standard procedure for performing this search iteratively starts with a particular initial approximation p_0 and calculates a correction Δp . This correction is then applied to the initial approximation giving rise to a new vector p_1 . This new vector is an initial approximation for calculating a second vector p_2 , and so on. The process ends when a vector \tilde{p} is found that minimizes the function in question. The Gauss-Newton method calculates the correction Δp starting with the Taylor series expansion up to the second order of the function to be minimized. Therefore, the calculation of the correction is performed by solving the system of equations,

$$H \Delta p = G, \quad (8)$$

$$H = J^T J + \mu \Psi(z), \quad (9)$$

$$G = J^T [g^0 - g] - \mu \Psi, \quad (10)$$

where J is the jacobian matrix of g_i (Equation 1). The solution of the system of equations described in Equation 8 is obtained through the Singular Value Decomposition (SVD) method. The method consists of decomposing the matrix H , in such a way that,

$$H = U \Sigma V, \quad (11)$$

where U is a unitary matrix ($U^* U = U U^* = I$), where U^* is the conjugate transpose and I the identity matrix. The matrix Σ is composed of diagonals with singular values of H (SHLENS, 2003).

The inversion process adopted so far aims to find the optimal basement depth parameter for a sedimentary basin. To complement the geophysical-geological studies of the region, an inversion method is also implemented to find the depth of the interface between the Lithosphere and Asthenosphere (Moho). The method of inverting gravimetric data in order to estimate the Moho depth is based on the Parker-Oldenburg (OLDENBURG, 1974) algorithm. The program describes the gravimetric data anomaly density interface of the iterative Parker-Oldenburg method. The methodology is based on the relationship between the Fourier Transform of the anomalous gravimetric data and the sum of the Fourier Transform of the density interface topography. The algorithm is described in more detail in GÓMEZ-ORTIZ et al. (2005). Van der Meijde et al. (2013) applied the Parker-Oldenburg inversion methodology to South America and compared it with other proposed models. The comparison of the models showed that the gravimetric inversion presents a good correlation with the punctual observations.

4. Results and Discussions

To evaluate the implemented methodology in alignment with the established research objectives, was examined the outcomes derived from inverting synthetic gravimetric data, subsequently extending the analysis to real data.

4.1. Synthetic Data

In the synthetic tests, we generated two sets of theoretical Bouguer anomalies using two different sedimentary basin models. These basins simulate 2D grabens consisting of fault systems, where the density contrast between sediment and basement is represented by $\Delta\rho$. We added Gaussian pseudo-random noise to this data with a mean of zero and a standard deviation of 0.3 mGal. These synthetic models were built with a density contrast of $\Delta\rho = -300 \text{ kg/m}^3$.

Figure 3 depicts the comparison between observed and calculated data, the actual and estimated basement relief, and the sedimentary package thickness for synthetic basin model 1. Figure 3a illustrates the comparison between the theoretical (points) and estimated (red line) Bouguer anomaly, showcasing the outcome of the inversion process. This adjustment resulted in an RMS value of approximately 0.30. In Figure 3b, the real (green line) and estimated (blue line) basement relief for model 1 are showcased. The estimated relief (Figure 3b), obtained using the true values of $\Delta\rho = -300 \text{ kg/cm}^3$, closely resembles the actual relief, validating the effectiveness of the method within this context.

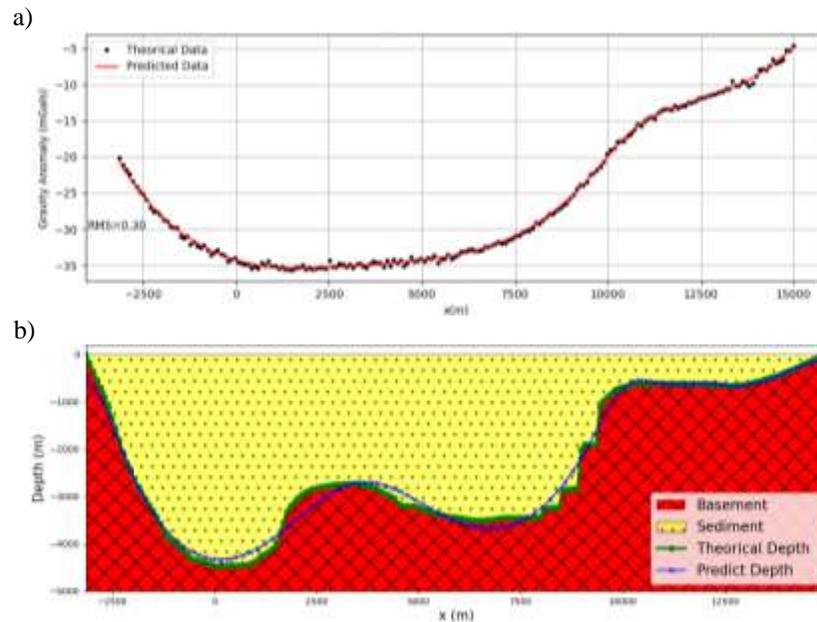


Figure 3 – Synthetic results for Model 1: (a) Theoretical and estimated Bouguer anomaly, and (b) Actual and estimated generated relief.

Source: The current authors (2023)

In Figure 4, the comparison between observed and computed gravimetric data for synthetic model 2 is depicted alongside the variation in basement relief (depth variation of the base of the basin - sedimentary package thickness) for this model. Figure 4a illustrates the comparison between actual and computed data resulting from the inversion process, yielding an RMS value of approximately 0.29. This estimation resulted in the estimated (depicted by the blue line) that is compared with real (depicted by the red line) relief, as shown in Figure 4b. The estimated relief (Figure 4b), calculated using $\Delta\rho = -300 \text{ kg/cm}^3$, closely resembled the actual relief, thereby validating the method's efficacy within this context.

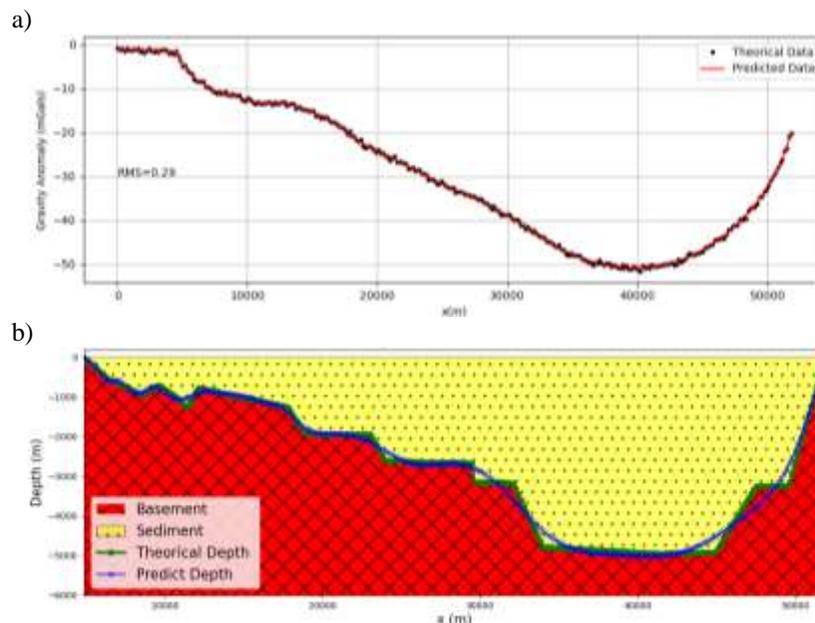


Figure 4 – Synthetic results for Model 2: (a) Theoretical and estimated Bouguer anomaly, and (b) Actual and estimated generated relief.

Source: The current authors (2023)

The results presented for the synthetic data reaffirm and validate the Gauss-Newton inversion technique through prism modeling. Evaluating the root mean square error (RMS) metric between the observed and calculated data it is possible to legitimize the methodology and progress to an analysis of real data.

4.2. Real Data

For real applications we employed gravimetric satellite data obtained from the high-resolution Earth gravity field model called SGG-UGM-2. Additionally, gravity data derived from the 2008 Earth Gravitational Model (EGM2008) were utilized, which is based on the theory of ellipsoidal harmonic analysis and transformation coefficients (EHA-CT) (LIANG et al., 2020). These dataset were delimited according to the area of this study and are available via the International Center for Global Earth Models (ICGEM) website (DREWES et al., 2016; INCE et al., 2019), with a grid spacing of 0.01° .

The Bouguer anomaly gravimetric data were processed with regional/residual separation before of be entering the data into the inversion. For this, the regional/residual separation was used with the polynomial of degree three. Figure 5 displays a map showcasing residual Bouguer anomalies data processed using the satellite data. For the development of this research, study profiles were generated to analyze the internal structure of the Basins studied and this map presents a collection of four study profiles: AA', BB', CC', and MtMt'. These profiles intersect the Jatobá, Central Tucano, and Recôncavo Basins, providing gravimetric values crucial for mapping their depocenters. Specifically, the MtMt' profile was intentionally designed to facilitate a comparative analysis between its interpretation in this research and the findings outlined in the study by Corrêa-Gomes et al. (2022).

A rift is the result of the stretching process of a crust (in this case, continental), where a depression (basin) filled with sediments is generated. Given its mechanical nature, its main control is structural, and its sedimentation is largely controlled by tectonics. As the routing process continues, the subsidence of the upper layers of the continental crust together with faulting and graben formation. This subsidence generates a response from the lower crust asthenosphere limit in accordance with the isostatic compensation of the region, causing it to undergo attenuation, that is, there is an elevation of this limit. With this stretching, there is a thinning of the lithosphere, directly affecting the gravimetric response of the Basin. It is possible to analyze through the map in Figure 5 the gravimetric response of the region, highlighting the negative responses. Therefore, it becomes evident that areas of low gravity are correlated with the geotectonic compartment

associated with the Mesozoic Basins of the Recôncavo-Tucano-Jatobá (RTJ). The RTJ Rift system is part of the discontinued rift system (MILANE, 1985), connected to the formation of the Atlantic Ocean.

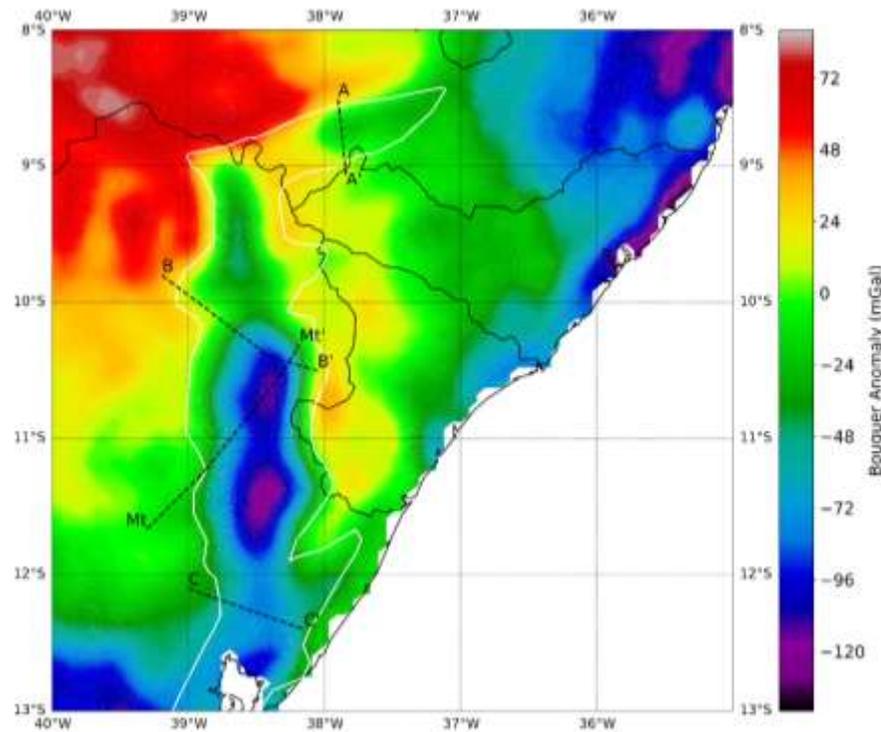


Figure 5 – Profiles location and Bouguer anomaly residual data retrieved from the global gravimetric model SGG-UGM-2 of the study area.

Source: The current authors (2023)

It is possible to acquire a more comprehensive understanding of the internal structure of the basins comprising the RTJ system by correlating their gravitational anomalies with the attenuation of the Mohorovičić discontinuity's (Moho) topographic features. For this purpose, we utilized the inversion technique established by Oldenburg (1974) on satellite gravimetric data from the RTJ system (Figure 5).

The map depicted in Figure 6 illustrates the results derived from this application, which led to the estimation of Moho depth with an RMS of 10.35. This estimation of Moho depth reveals a clear correlation between deeper Moho depths and the locations of sedimentary basins within the RTJ system. This correlation likely stems from the subsidence process attributed to crustal stretching in this region and the subsequent formation of these basins, along with associated isostatic compensation phenomena. Notably, Figure 6 highlights two distinct regions – the Central and South Tucano Basin – where depths exceed 40 km. When comparing these regions to the equivalent areas in Figure 5, there are also two gravitational lows with approximate values of -96 and -120 mGal, respectively. These highlighted areas indicate the largest depocenters within this system.

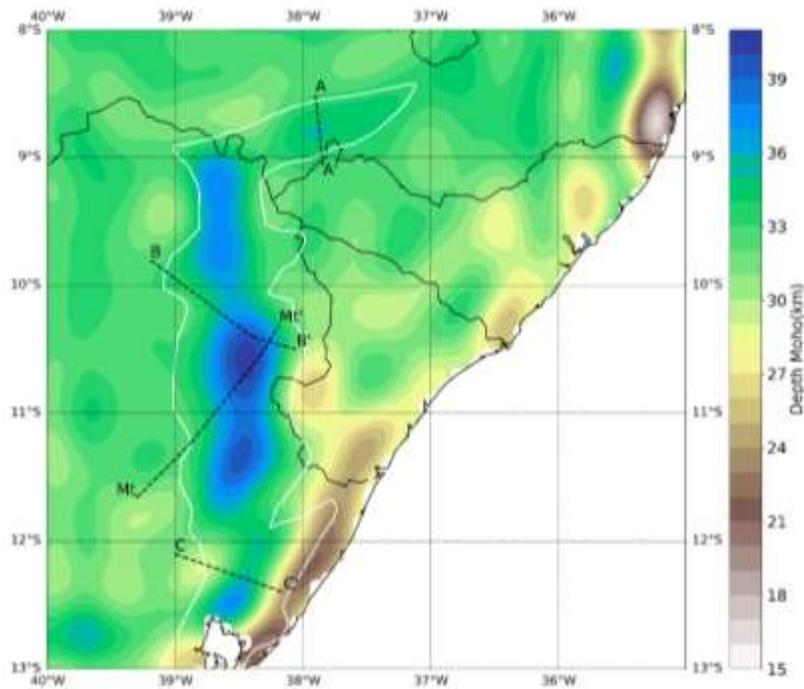


Figure 6 – Profiles location and Moho depth map for study area using Parker-Oldeburg algorithm.
Source: The current authors (2023)

The AA' profile intersects the Jatobá Basin, and the inversion results from the gravimetric data along this profile are depicted in Figure 7. The Figure 7a illustrates the gravimetric anomaly data inversion of the AA' profile, showcasing a comparison between the observed points and the calculated curve (indicated by the red line), resulting in an RMS adjustment value of 0.045, with regularization parameter $\mu = 10^{-4}$. All curve adjustments in this research were executed using the smoothly regularized inversion algorithm developed and employing a density contrast of $\Delta\rho = -300 \text{ kg/cm}^3$ between the sediment and basement layers.

As a consequence of this inversion, Figure 7b presents the depth variation of the top of the Jatobá Basin's basement along this profile, estimating a maximum depth of approximately 3 km. In this region, gravitational anomalies reach values on the order of -35 mGal. In general, based on the evolution of sedimentary deposition within the basins of the RTJ system, the lower-density sediments that accumulated caused a reduction in the gravitational response within their central areas, which experienced subsidence due to rifting. Consequently, the lower regions underwent intense sedimentation sequences.

Estimated Moho topography data were extracted along Profile AA', enabling us to infer a maximum depth of approximately 35 km (Figure 7c).

The BB' profile traverses the Tucano Central Basin. The inversion results obtained from the gravimetric data along this profile are depicted in Figure 8. This adjustment yields an RMS value of 2.11 and $\mu = 10^{-5}$ (Figure 8a). The estimated depth of the basement along the BB' profile indicates a depocenter depth of approximately 12 km (Figure 8b) for a gravimetric anomaly of approximate -100 mGal. The depth value is consistent with the work of Santos et al. (2010). Figure 8c showcases the inversion results for the Moho depth along the BB' profile, indicating a depth of approximately 39 km. Notably, both the basement and Moho inversions exhibit increased depths within the same interval (between 6 and 8 km of distance). This alignment in depths may potentially be influenced by the sedimentary thickness within the basin.

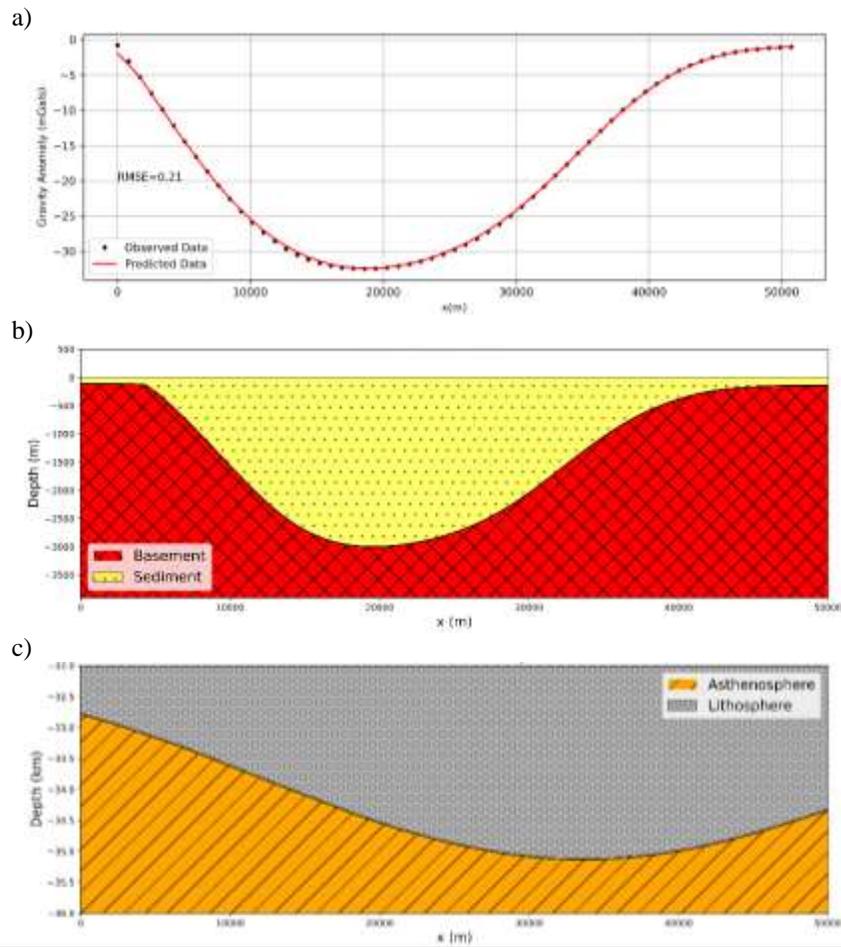
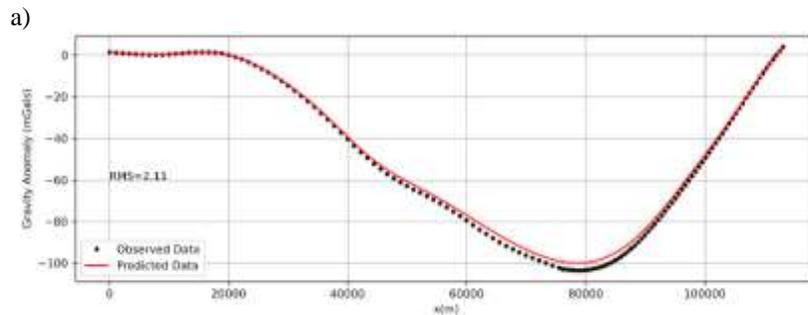


Figure 7 – Real data in the AA' profile - Jatobá Basin: (a) comparison between observed and calculated gravimetric data, (b) estimation of basement depth along this profile, and (c) estimation of Moho depth.
 Source: The current authors (2023)



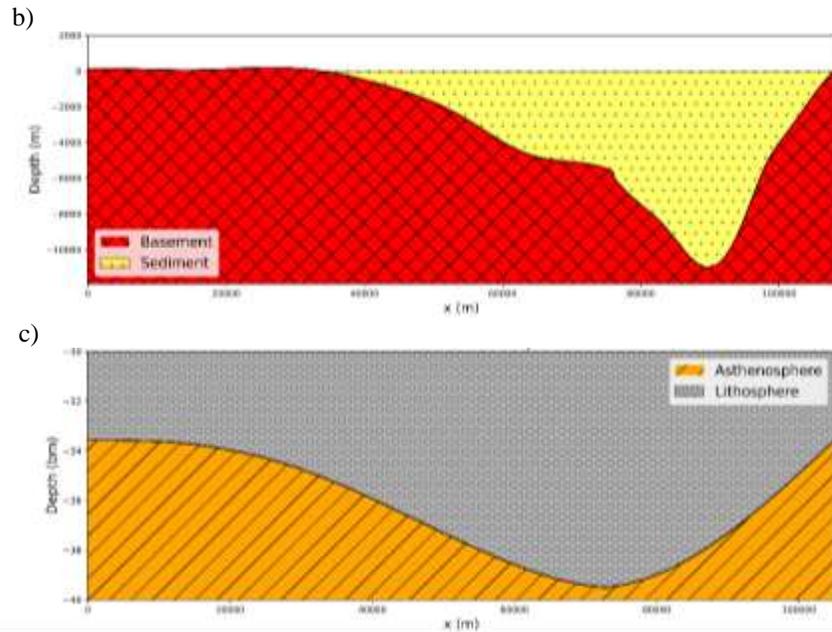
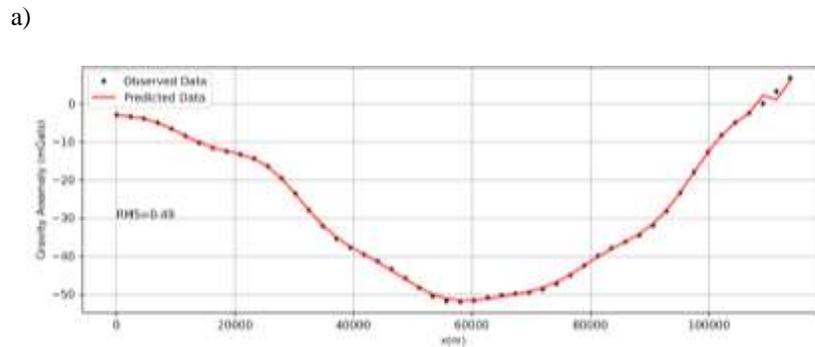


Figure 8 – Real data in the BB' profile – Tucano Central Basin: (a) comparison between observed and calculated gravimetric data, (b) estimation of basement depth along this profile, and (c) estimation of Moho depth.

Source: The current authors (2023)

The CC' profile extends across the Recôncavo Basin. The inversion adjustments obtained from the gravimetric data along this profile are presented in Figure 9a, resulting in an RMS value of 0.49 and $\mu = 10^{-5}$. Figure 9b illustrates the basement inversion of this basin, suggesting a maximum estimated depth of around 4.5 km for a gravimetric anomaly of approximate -55 mGal. Additionally, the Moho depth inversion, depicted in Figure 9c, indicates a maximum depth of approximately 36 km. Importantly, a noticeable correlation exists between the increased depths of the basement and the Moho interface, possibly attributed to subsidence.



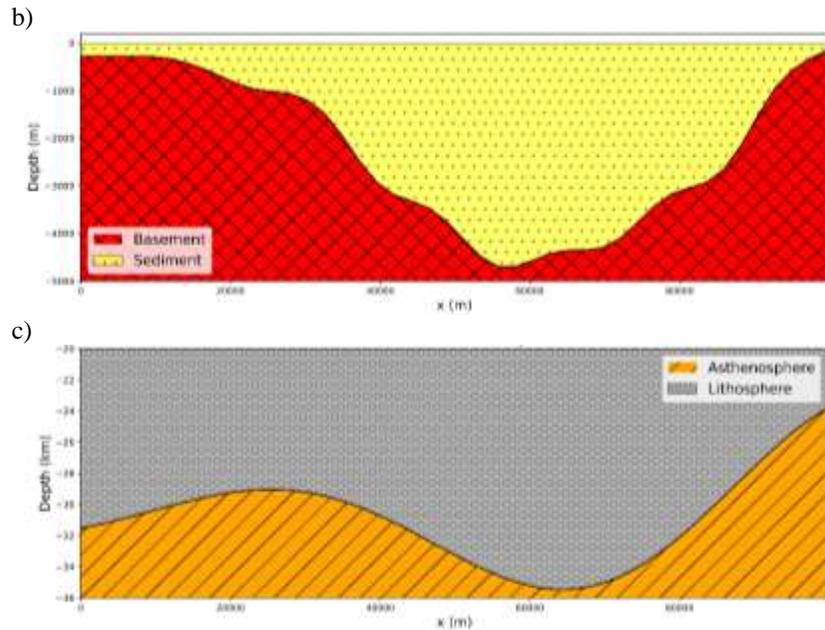
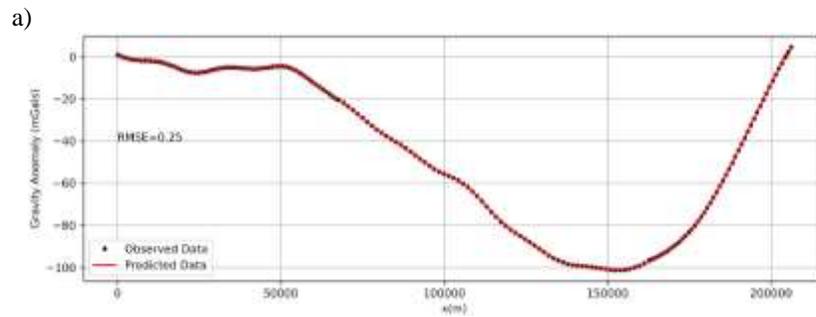


Figure 9 – Real data in the CC' profile – Recôncavo Basin: (a) comparison between observed and calculated gravimetric data, (b) estimation of basement depth along this profile, and (c) estimation of Moho depth. Source: The current authors (2023)

Similar to the BB' profile, the MtMt' profile traverses the Tucano Central Basin, originating further south and intersecting with the BB' profile. This profile maintains the same planned direction as the one interpreted by Corrêa-Gomes et al. (2022). The adjustment between the observed and calculated curves (Figure 10a) resulted in an RMS of 0.25 and $\mu = 10^{-5}$. The interpretation regarding the depth of the basement is depicted in Figure 10b. The maximum depth reached approximately 9.5 km for a gravimetric anomaly of approximate -101 mGal, values of depth consistent with the work of Corrêa-Gomes et al. (2022). Figure 10c illustrates the resulting Moho depth along this profile, approximately 41 km, coinciding with the peak values of sediment thickness observed along this profile.



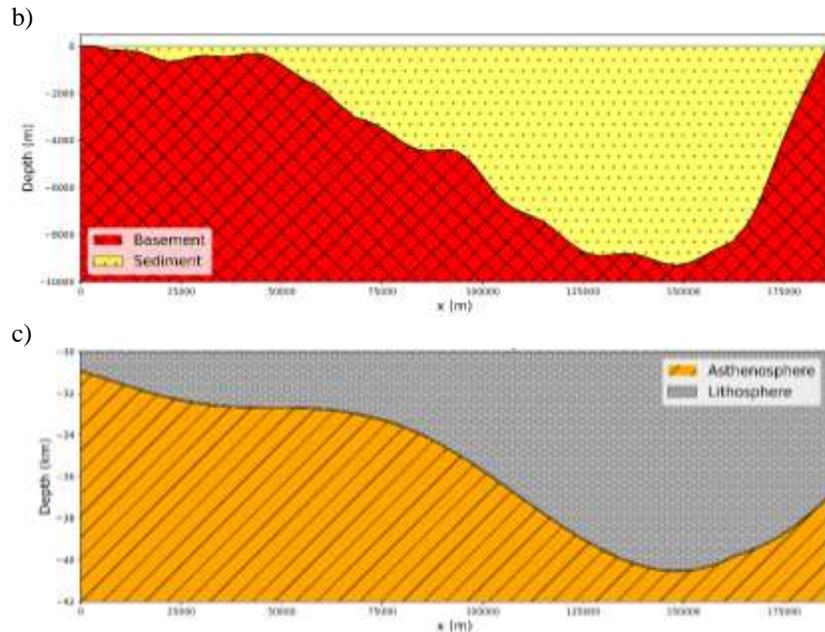


Figure 10 – Real data in the MtMt' profile – Tucano Central Basin: (a) comparison between observed and calculated gravimetric data, (b) estimation of basement depth along this profile, and (c) estimation of Moho depth.

Source: The current authors (2023)

Table 1 displays a summary of the estimated maximum depth values obtained through the inversion methodologies employed for the estimate basin relief and the Moho.

Table 1 – Table displaying a summary of the inversion results.

BASIN	DEPOCENTE DEPHT	MOHO DEPHT
Jatobá	≈ 3.0 km	≈ 35 km
Tucano Central (BB' Profile)	≈ 12.0 km	≈ 39 km
Recôncavo	≈ 4.5 km	≈ 36 km
Tucano Central (MtMt' Profile)	≈ 9.5 km	≈ 41 km

Source: The current authors (2023)

By correlating the gravimetric anomaly of the profiles with the topography of the basin's basement and the Moho, it is possible to identify a rapid increase in the gravimetric response at its edges, resulting from the pronounced upward displacement of the basin's basement. This led to the emergence of faults that delineate them.

As the basins exhibit a delayed attenuation of the Moho topography, meaning it does not coincide with the basins' locations, the negative anomalies stem from varying densities of the rocks within their stratigraphy. Additionally, the increase in gravimetric response correlates with the attenuation of the lithosphere, attributed to an upward shift in its lower limit. A rapid transition in the increase in gravimetric anomalies toward the offshore area is also evident, confirming crustal attenuation in response to active tectonism within the region.

4. Final Considerations

This research aimed at delineating the relief of the basement of the Mesozoic Basins within the Recôncavo – Tucano – Jatobá Rift system. Our interpretative model employed a series of juxtaposed prisms, assuming a fixed and known density contrast of -300 kg/m^3 . The inversion algorithm utilized the Gauss-Newton methodology with smoothed regularization in conjunction with the Singular Value Decomposition technique to estimate the basement relief of the Rift System basins.

Initially, we validated the methodology by testing it with synthetic data that simulated two real situations of Rift-type Sedimentary Basins. This resulted in close fits between theoretical and calculated gravimetric anomaly curves, accurate estimates of the basement geometry and depth. Consequently, this method reliably estimated the relief of the basement within the studied basin models, assuming their relief is smooth. It was demonstrated that the implemented method effectively works with basins exhibiting smooth relief, owing to the stabilizing information utilized.

The gravimetric anomalies derived from satellite data were used for application in real data, while also assuming a known density contrast of -300 kg/m^3 . Even without the inclusion of a priori information, the inverse algorithm developed and applied to the Bouguer Residual Anomaly of the Jatobá, Tucano Central, and Recôncavo Basins yielded good estimates of the basement relief and the depth of its depocenters. These estimates demonstrate values similar to those found in other studies. This information was correlated with estimates of the maximum depth of the Moho topography (Table 1), aiding in understanding the role of the basement rifting process in basin formation and contributing to the comprehension of the geodynamic evolution of this system.

Therefore, the results obtained in this research allowed the interpretation of the gravimetric anomaly used as a function of the depositional space of the basins studied and the geometry of their basement, which may help in the recognition of internal structures resulting from rifting, such as faults and blocks uplifted in the basement, which together with knowledge of its stratigraphy, it can be analyzed based on the characteristics of hydrocarbon reservoirs in the studied basins. Furthermore, the interpretation of the basement relief in conjunction with the Moho topography allowed this study to highlight some important aspects of this system, portraying the geotectonic evolution of the aulacogen through specific gravimetric signatures and their association with the estimation of basin depocenters.

Acknowledgment

Thanks to the National Institute of Science and Technology - Petroleum Geophysics (INCT-GP) for providing the research grant that supported the development of this study, and to the Federal University of Bahia (UFBA) for supplying the necessary infrastructure to conduct this research.

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