2D Gravimetric Modelling of the central portion of Quadrilátero Ferrífero, Brazil

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Abstract

The Quadrilátero Ferrífero, located at the southern São Francisco craton, is one of the most important metallogenic districts in Brazil. Multiple deformational events affected this region and several studies, based mainly on structural field mapping argue about its tectonic evolution. Geophysical techniques applied to delineate subsurface can be useful for a better understanding of its tectonic framework. The present study consists of a gravimetric survey in the central portion of Quadrilátero Ferrífero, encompassing its three main geological units: the TTG basement, the Rio das Velhas greenstone belt, and the Minas Supergroup. The acquired data were processed in three gravimetric 2-D profiles and the modeling was based also on surface geological data and previous tectonic studies of the area. The geophysical-geological profiles modeled suggest that the Rio das Velhas basin, in the Nova Lima-Caeté tectonostratigraphic block, shows distinct composition and thickness in its eastern and western regions. The eastern portion would be composed of a thin base layer with a predominance of mafic/ultramafic metavolcanic rocks and a thick top layer with metasedimentary rocks. On the other hand, the western area would have a remarkable predominance of mafic/ultramafic metavolcanic rocks belonging to a thick basal layer. For the Minas Supergroup in the Serra da Piedade region, an inverted syncline is the model that best suited the gravimetric data. The inverted flank is exposed by the Serra da Piedade and the normal flank doesn't outcrop.

Introduction

The Quadrilátero Ferrífero (QF) comprises an area of approximately 7000Km2 in the southeast portion of the São Francisco craton, within the central and southern regions of Minas Gerais state (Almeida, 1967; Dorr II, 1969). It contains three main lithostratigraphic units: (i) an Archean granite-gneiss complex including the exposed Belo Horizonte, Caeté, Bonfim, Bação and Santa Bárbara domes (Teixeira et al., 2000); (ii) the Rio das Velhas greenstone belt (RVGB), an Archean volcano-sedimentary sequence divided into the Quebra Osso, Nova Lima and Maquiné groups (Dorr II, 1969; Zucchetti and Baltazar, 2000; Araújo et al., 2020); and (iii)

Neoarchean-Proterozoic metasedimentary sequences represented by the Minas Supergroup and the Sabará and Itacolomi groups (Dorr II, 1969).

The present study consists in the gravimetric 2D modeling of the Nova Lima – Caeté region. It is part of the project '2D and 3D modeling of the Rio das Velhas greenstone belt framework', inserted into the Quadrilátero Ferrífero Program of the Brazilian Geological Survey (SGB-CPRM). The first stage of this project aimed the 2D modeling of geophysical-geological profiles in various sectors of the Quadrilátero Ferrífero, with a focus on the Rio das Velhas greenstone belt. The modeling used terrestrial gravimetry data, obtained by the SGB-CPRM and by the national bank of gravimetric data (BNDG), and geological and geotectonic maps from the study area. The aim of this research is to contribute to the understanding of the tectonic framework of the QF. The integrated interpretation of geologic and geophysical data provides important insights into the behavior of the main geologic units in depth, following the approach already used successfully in other greenstone belts (Ranganai, 2012; Ramotoroko et al., 2016).

Method

The gravimetric data from SGB-CPRM were acquired with the CG5 Autograv Gravity Meter differential gravimeter (Scintrex) and a pair of differential GPS, model Hiper SR (Topcon). One GPS were used as base station and its distance from the mobile GPS did not exceed 40 Km. A total of 212 stations, with spacing between 250m and 2Km, were acquired along major highways and local roads in the Nova Lima-Caeté area, in three profiles that crosscut important geologic structures (Fig. 1). In addition, the data provided by the BNDG were used.

For GPS data processing, the softwares Magnet Tools, MAPGEO2010 and MAPGEO2015 were used. The gravimetric data processing, done in the Oasis Montaj (Geosoft) software, includes the following corrections: tidal, sensor height, drift, latitude, absolute gravity, normal gravity, Free Air, Bouguer and Terrain. After that stage, the Bouguer Anomaly, Regional Gravity and Residual Gravity Maps were elaborated.

The results from the Residual Bouguer Anomaly were utilized for the 2D gravimetric modeling of three geophysical-geological profiles. Due to the winding roads, the stations were projected in straight profiles. The direct modeling was performed using the software GMSYS-2D, a toolkit within the Geosoft Oasis montaj platform, which calculates the predicted anomaly following Talwani and Heirtzler (1964) and Talwani et al. (1959). The layers, with a defined density, are drawn and adjusted to better suit the observed data. The values used were based on the average density of rocks present in each layer. Data

from drill core samples from the Nova Lima-Caeté region, afforded by the company Anglo Gold Ashanti, provided additional information that helped in the modeling process and to define densities.

Results

The Nova Lima-Caeté area comprises three gravity profiles, designated Caeté, Nova Lima and Caeté-Gongo Soco (Fig. 1). The profiles crosscut three important geologic units: (i) the granitic-gnaissic basement represented by the Belo Horizonte and Caeté Complex and the General Carneiro granitoid; (ii) the RVGB metavolcanosedimentary sequence; and (iii) metasedimenary rocks from the Minas Supergroup and Sabará Group.

For the modeling, a simplification of the geology was made, grouping units containing rocks with similar densities. The Nova Lima Group was divided into three layers containing predominantly: mafic/ultramafic metavolcanic rocks; mafic metavolcanic rocks, chemical and clastic metasedimentary rocks; clastic metasedimentary rocks. The Minas Supergroup was also divided in three units: the banded iron formation (BIF) layer from the Cauê Formation and metasedimentary rocks below and above it.

* Caeté profile: It is approximately 21 Km long, with WNW-ESE direction, and 114 gravimetric stations, acquired along the BR-262 highway, in the vicinities of Sabará and Caeté cities (Fig. 1).

The data for this profile (Fig. 2AI) shows the biggest Bouguer anomaly over the Minas Supergroup, with intensity of approximately +6 mGal. Both Belo Horizonte and Caeté Complex are characterized by low Bouguer signature, while the General Carneiro granitoid present intermediate values. The RVGB is mainly marked by a low Bouguer signature although where the mafic-ultramafic metavolcanic rocks outcrop there is a Bouguer anomaly of approximately +2 mGal.

* Nova Lima profile: It is located near Belo Horizonte and Nova Lima cities, with about 30 Km in length and WNW-ESE direction. The 46 stations were collected along the MG-030 road (Fig. 1). ,

The Belo Horizonte Complex outcrops at the beginning of this profile (Fig. 2BI) and it is characterized by a low Bouguer signature. The Bouguer anomaly gradually increases over the Minas Supergroup and reaches the higher values over the RVGB (+ 15 mGal).

* Caeté-Gongo Soco profile: This 26 Km long profile, with WSW-ENE direction, has 52 stations acquired along the AMG-150 road, from Nova Lima to Raposos, and a secondary road from Raposos to Barão de Cocais (Fig. 1).

The mafic/ultramafic metavolcanic rocks from the Nova Lima Group that outcrop in the beginning of this profile (Fig. 2CI) are related with a Bouguer amplitude signature of approximately + 12 mGal. The Bouguer anomaly gradually decreases towards the metasedimentary and mafic/ultramafic metavolcanic rocks from the Nova Lima that outcrops in the middle of the profile (between +12 mGal and -5 mGal). Finally, the Caeté Complex present a low Bouguer signature.
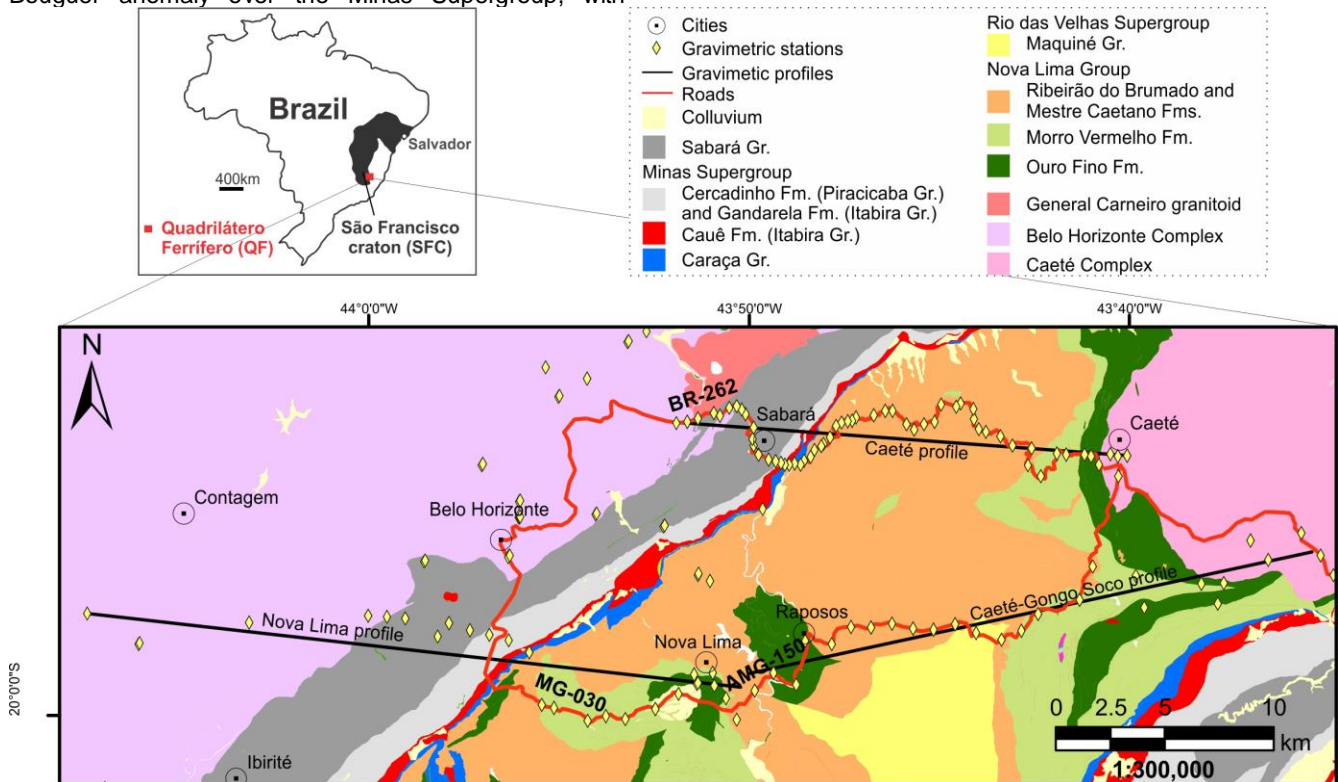

Fig. 1 – Location of the three gravimetric profiles in a simplified geological map, modified from Silva et al. (2020).

AI — Caeté gravimetric profile

WNW / ESE

Bouguer Anomalie (mGal)

— Calculated
● Observed

AII — Caeté geophysical-geological profile

WNW / ESE

2810 Kg/m³ — 2720 Kg/m³ — 2785 Kg/m³
3130 Kg/m³ — 2820 Kg/m³ — 2770 Kg/m³
2780 Kg/m³ — 2900 Kg/m³ — 2950 Kg/m³
2725 Kg/m³

Depth (km) / Distance (Km)

Vertical exaggeration: 1x
Scale 1:250.000

WNW UTM E: 618750 UTM N:7801710
ESE UTM E:639510 UTM N:7800193

Geophysical-geological units modeled

Diverse metasedimentary rocks (2810 Kg/m³)
Dolomites and quartzites from Minas Sg. (2800-2820 Kg/m³)
BIF (3130 Kg/m³)
Quartzites, metaconglomerates and metapelites from Minas Sg. (2720 Kg/m³)
Metasedimentary rocks from Nova Lima Gr. (2770 Kg/m³)
Mafic metavolcanic and metasedimentary rocks from Nova Lima Gr. (2900 Kg/m³)
Mafic-ultramafic metavolcanic rocks from NovaLima Gr. (2930 Kg/m³)
Granitoid (2800 Kg/m³)
Orthogneiss1 (2725-2730 Kg/m³)
Orthogneiss2 (2720-2785 Kg/m³)

Geologic units

Sabará Group
Cercadinho Fm. (Piracicaba Gr.) and Gandarela Fm. (Itabira Gr.)
Cauê Fm. (Itabira Gr.)
Batatal and Moeda Fms. (Caraça Gr.)
Ribeirão do Brumado and Mestre Caetano Fms.
Morro Vermelho Fm.
Ouro Fino Fm.
General Carneiro granitoid
Belo Horizonte Complex
Caeté Complex

BI — Nova Lima gravimetric profile

WNW / ESE

Bouguer Anomalie (mGal)

— Calculated
● Observed

BII — Nova Lima geophysical-geological profile

WNW / ESE

2770 Kg/m³
2810 Kg/m³
2800 Kg/m³ — 2900 Kg/m³ — 2930 Kg/m³
2730 Kg/m³ — 3130 Kg/m³ — 2720 Kg/m³

Depth (km) / Distance (Km)

Vertical exaggeration: 1x
Scale 1:250.000

WNW UTM E: 591.774 UTM N: 7.792.959
ESE UTM E: 621.744 UTM N: 7.789.573

CI — Caeté-Gongo Soco gravimetric profile

WSW / ENE

Bouguer Anomalie (mGal)

— Calculated
● Observed

CII — Caeté-Gongo Soco geophysical-geological profile

WSW / ENE

2930 Kg/m³ — 2770 Kg/m³ — 2900 Kg/m³ — 2720 Kg/m³
2730 Kg/m³

Depth (km) / Distance (Km)

Vertical exaggeration: 1x
Scale 1:250.000

WSW UTM E: 622.256 UTM N: 7.790.209
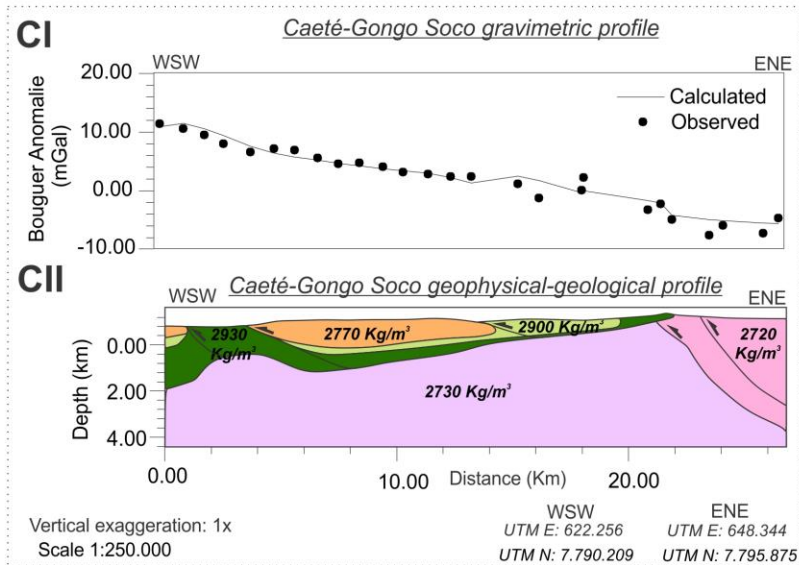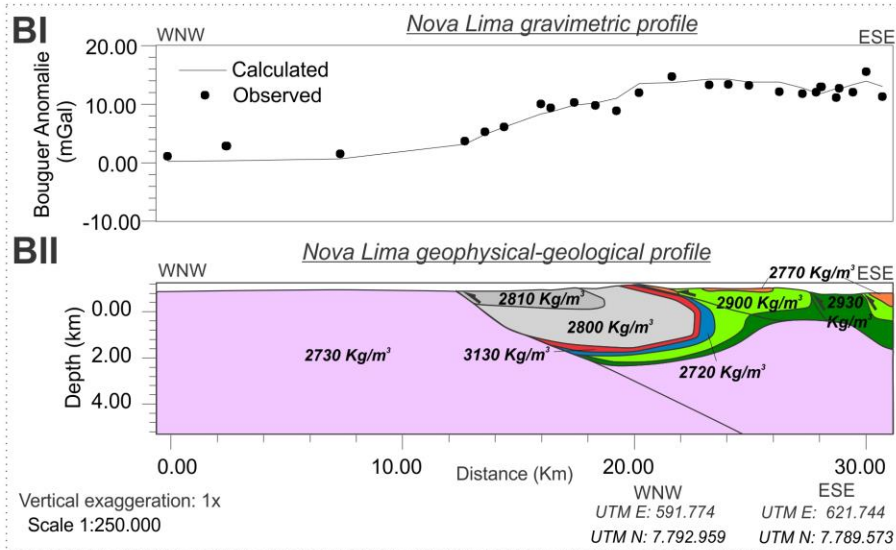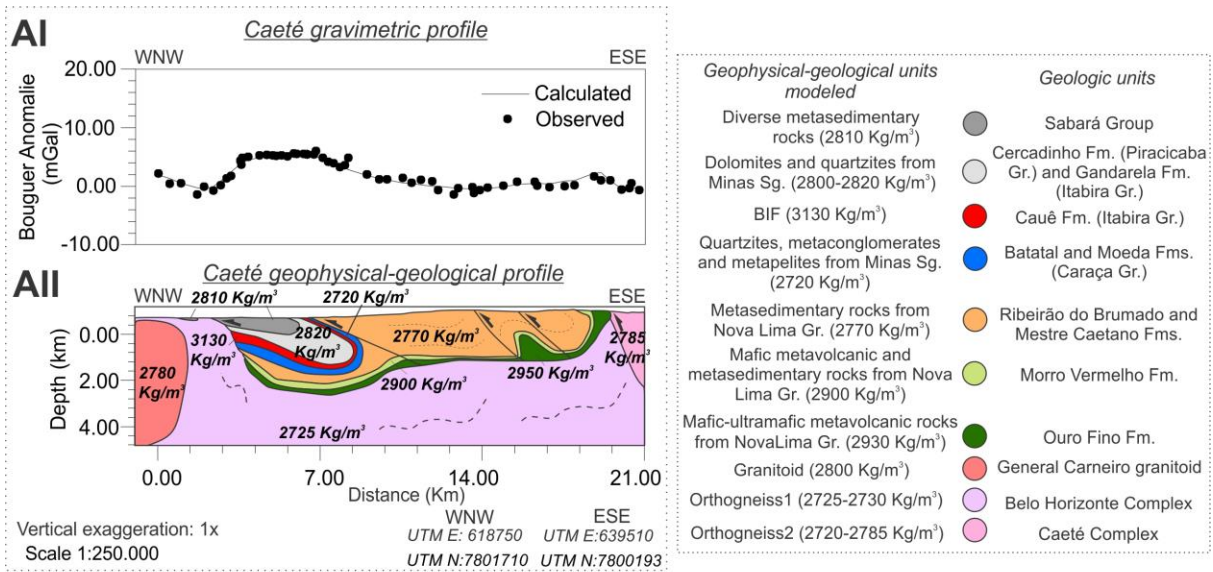ENE UTM E: 648.344 UTM N: 7.795.875

Fig. 2 – The gravimetric modelling for the (A) Caeté, (B) Nova Lima and (C) Caeté-Gongo Soco profiles, respectively. Ai, Bi and Ci show the gravimetric data and the calculated curve based on the geophysical-geological profiles modeled in Aii, Bii and Cii. The legend shows the geophysical-geological units modeled and their correspondent geologic units, as well as the densities used.

Discussion

The 2D modeling of these profiles, using the gravimetric and geological data available for the area resulted in the elaboration of deep geophysical-geological profiles (around 6 km) that are presented in the Fig. 2. The densities used in each geological unit are also available in these figures. The three geophysical-geological profiles that were modeled in this work present great adherence with the gravimetric data.

According to the suggested model, the Nova Lima Group has distinct characteristics, in terms of composition and thickness, in different regions of the Nova Lima-Caeté block. In the northwest portion, represented by the Caeté profile (Fig. 2AII), the layer composed mainly by metasedimentary rocks is much thicker than the layers where mafic/ultramafic metavolcanic rocks are predominant, and the thickess of the package reaches almost 4km. In the central area, better illustrated by the Caeté-Gongo Soco profile (Fig. 2CII), there is a more balanced proportion between metasedimentary and metavolcanic rocks, due to a decrease in the thickness of the layer rich in metasedimentary rocks. In this area, the thickness of the whole package reaches a maximum of 2,5 km and decreases gradually towards the east. Finally, on the western side of the block, there is a predominance of the basal units of the Nova Lima Group, composed mainly by mafic/ultramafic metavolcanic rocks, reaching up to 2,5 Km, as suggested by the Nova Lima profile (Fig. 2BII).

The model also suggests the presence of tight folds that locally can increase the apparent thickness of the basal layers (Fig. 2AII). These tight to isoclinal folds are a common feature in the GBRV due to the multiple events deformation the area was exposed (Zucchetti and Baltazar, 2000; Baltazar and Zucchetti, 2007; Baltazar and Lobato, 2020). They can also be related to the restricted exposure of mafic/intermediate metavolcanic rocks in the Cuiabá and Lamego mines, which are surrounded by an thick package of metasedimentary rocks.

The Caeté and Nova Lima profiles crosscut the Serra da Piedade in different points and the gravimetric signature over the Minas Supergroup is quite different between them (Figs. 2AI and 2BI), affected by the adjacent rocks of the Rio das Velhas Supergroup. In the Caeté profile, a big Bouguer anomaly amplitude occurs over the Minas Supergroup (Figs. 2AI and 2AII), that is in contact with predominantly metasedimentary rocks from the RVGB. In the Nova Lima profile, on the other hand, the Minas Supergroup is in contact with thick and dense mafic/ultramafic layers from the RVGB. As consequence, the higher Bouguer anomaly intensity in this profile is over the Rio das Velhas Supergroup (Figs. 2BI and 2BII).

Serra da Piedade is the extreme NE of the Serra do Curral. Its geologic architecture is not a consensus.

Pomerene (1964) interpreted the Serra do Curral as an overturned southeastern limb of a truncated syncline and the normal flank of this structure outcrops in its northeast extremitie, named Piedade Synclinal by Alves (1961). Alkmim and Marshak (1998) understood this structure as an anticlinal with its adjacent synclinal. Endo et al (2005, 2019) suggest that the Serra do Curral represent the inverted flank of an allochthonous recumbent fold (Curral Nappe) with a north tectonic transport. The Rio das Velhas Supergroup would represent the core of this fold.

In the present work, three different configurations were modeled for the Serra da Piedade structure, aiming to test the diverse proposal present in the literature: (i) a homocline representing the inverted flank of a northwest-verging anticline with the RVGB in its core (Fig. 3A); (ii) the inverted flank of a synforme which normal flank is no longer preserved (Fig. 3B); (iii) a complete synforme structure, but with the normal flank not exposed (Fig. 3C).

The model (iii) is the only one that fits well with the measured data (Fig. 3C). The strong Bouguer anomaly presented in the Caeté profile coincides with the region where the BIF of the Cauê Formation outcrops and extends to NW until the Sabará Group. For the model to have good adherence to this anomaly it is necessary the preservation in subsurface of the normal flank of the syncline. Additionally, the model suggests that, in the region of the Caeté profile, the dense BIF layer of the Cauê Formation in the normal flank would be at approximately 600m depth and would be thicker (~400m) than in the inverted flank. In contrast, in the Nova Lima profile, the model suggests that the Cauê layer is not very thick (~100m) throughout the structure and it is more than 2km deep on its normal flank.

Only with gravimetric data it is not possible to define whether the RVGB occur at the base of the Minas Supergroup. The presence or absence of this layer below the Serra da Piedade syncline does not significantly impact the gravimetric calculated curve, due to the great depth and small thickness. However, the proposed model kept an interpretative RVGB layer below the Minas Supergroup because a small sequence of this greenstone belt is mapped north of this range. Thus, the total depth of the Serra da Piedade syncline, encompassing these two units, was modeled up to 3300m.

Conclusions

The gravimetry is a very useful method to investigate the geometry and depth of the geological structures (Ranganai, 2012; Ramotoroko et al., 2016). The 2D modeling, product of this stage of the project, provided a better understanding of the subsurface configuration of the central portion of the Quadrilátero Ferrífero, an important metallogenic province.
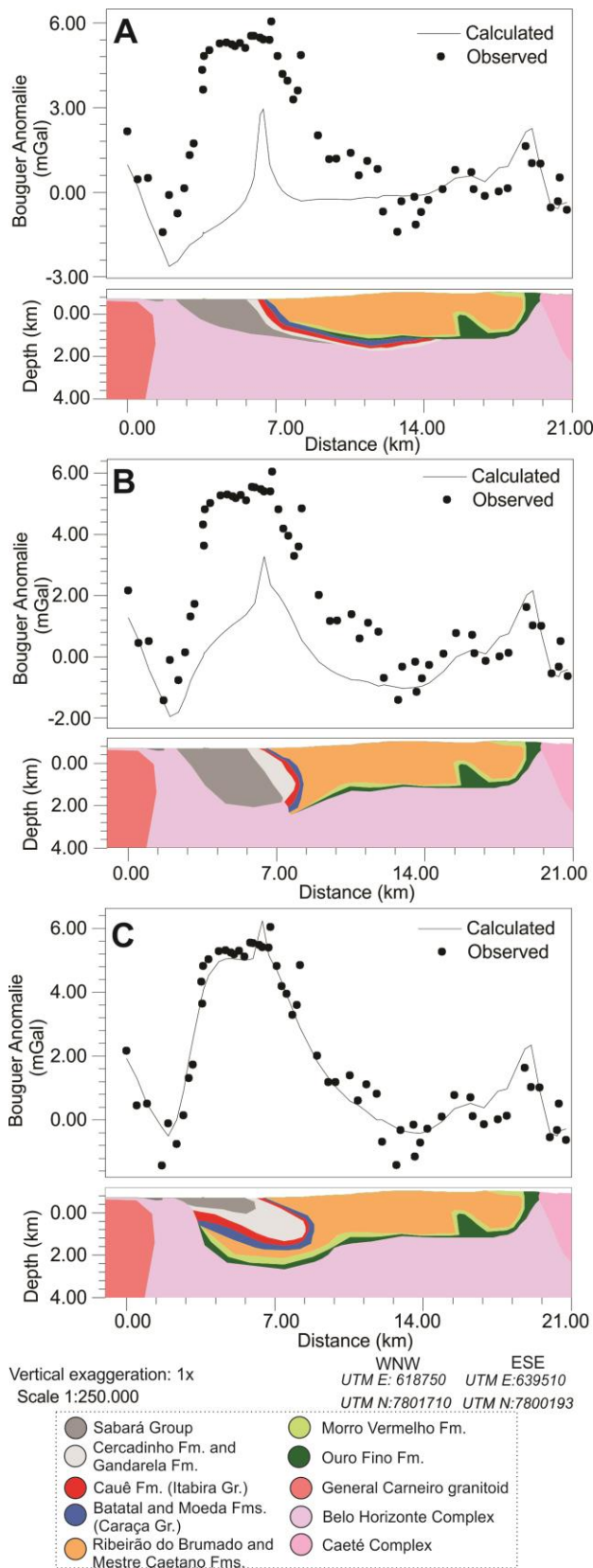
Vertical exaggeration: 1x
Scale 1:250.000

WNW   ESE
UTM E: 618750   UTM E:639510
UTM N:7801710 UTM N:7800193

- ⬤ Sabará Group
- ⬤ Cercadinho Fm. and Gandarela Fm.
- ⬤ Cauê Fm. (Itabira Gr.)
- ⬤ Batatal and Moeda Fms. (Caraça Gr.)
- ⬤ Ribeirão do Brumado and Mestre Caetano Fms.
- ⬤ Morro Vermelho Fm.
- ⬤ Ouro Fino Fm.
- ⬤ General Carneiro granitoid
- ⬤ Belo Horizonte Complex
- ⬤ Caeté Complex

Fig. 3 – Different configurations modeled for the Minas Supergroup in the Serra da Piedade: (A) a homocline representing the inverted flank of a northwest-verging

anticline with the RVGB in its core; (B) the inverted flank of a synforme which normal flank is no longer preserved; (iii) a complete synforme structure, but with the normal flank not exposed.

The Caeté, Nova Lima and Caeté-Gongo Soco profiles give valuable information about the depth of the Minas and Rio das Velhas basins. The gravimetric data suggest that the eastern area of the Rio das Velhas Supergroup, close to Caeté city has a predominance of metasedimentary rocks and a thin base composed predominantly by mafic/ultramafic metavolcanic rocks. In the western region, next to Nova Lima, there would be a predominance of a thick mafic/ultramafic package. Regarding the Minas Supergroup, the only configuration that fits well with the measured data is an inverted syncline. The Serra da Piedade exposes the inverted flank while the normal flank doesn't outcrop. However, the model suggests the presence of a thick layer of BIF at approximately 600m depth related to the normal flank.

Acknowledgments

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