Crustal and tectonic features of northeast of São Paulo State and southwest of Minas Gerais State based on gravimetric studies in southeast Brazil

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Abstract

This paper presents the results of a geophysical study carried out at Northeast of São Paulo State and Southwest of Minas Gerais State (an area 80 km wide and 97,5 km long) in SE Brazil. The Bouguer anomaly map, geological and structural data allowed to identify three different gravity domains related to the structural pattern (crustal blocks limited by major discontinuities) in the area. These discontinuities were interpreted as geosuture zones lying under the Paraná Basin sediments and have their extends in the Pré-Cambrian Basement. The crustal discontinuities named Alterosa and Ribeirão Preto may be seen as A - type collision sutures with triple junction arrays. Two linear proeminent anomalies are recognized in the Bouguer anomaly map, the limit between the Brasília and São Paulo crustal blocks or paleoplates, the Alterosa suture is deduced in a NW-SE trend, and in a NE-SW trend is the Ribeirão Preto suture. The produced Bouguer anomaly map provides subsidies and information to new concepts and theories to the refinement of tectonic models

Introduction and objectives

A gravity survey in a regional extend allows to identify characteristics between the crustal masses and its relations. These concepts, associated with geological and structural informations and its lithological constituents provides an important background to produce a coherent structural and geological model. A semi-detail gravimetric and geological survey provides necessary informations to gravity modeling based theories. The main objective of this study was:

-Determine and delineate the strong gravimetric gradients related to the Alterosa and the Ribeirão Preto suture zones allowing a better understanding of its junction array and their extend in the entire area.

-Data reprocessment of previous undergraduate students gravimetric surveys 1994 and 1998 (UNESP – Universidade Estadual Paulista. At the time the sum of 108 gravimetric stations were acquired.

Geological Settings

The studied area (Figure 1) can be described by the basement rocks (Araxá and Canastra Groups) and the Paraná Basin sedimentary units. In the sedimentary basin domain the stratigraphic units are; Aquidauana Formation (Itararé Group), Pirambóia Formation, Botucatu Formation, Serra Geral Formation and the Cenozoic coverings (Figure 2).

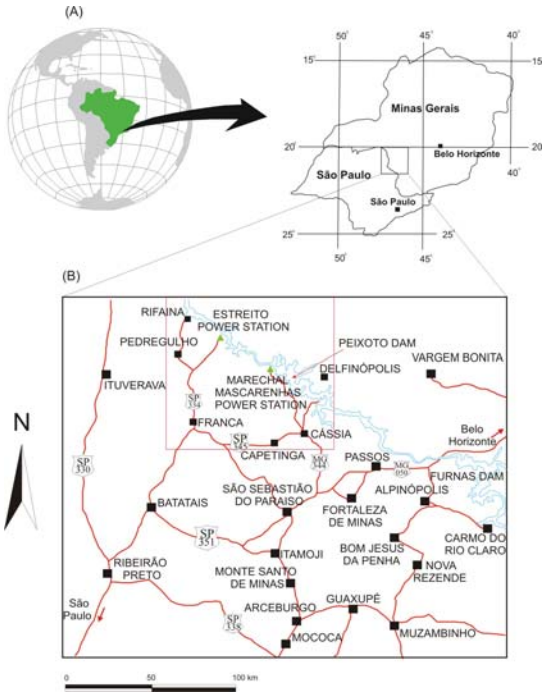

Figure 1 a) Location map showing the studied area in São Paulo and Minas Gerais states SE Brazil , b) Enlarged area with main roads and cities. The square shows the studied area limits.

The Paraná Basin expansion and growth have begun in the Paleozoic time over a Pre-Cambrian cratonic basement being in this manner classified as a intracratonic basin (Davino *et al.,*1982). The Paraná Basin limits, extends from the Paramirim craton and its coverings advance toward west covering the suture zone. In the NE region the most representative structural lineaments are NW and NE coincident with the lineaments found in the Paramirim craton. The NW trend is the oldest (Archean) and the NW trend (younger) have been reactivated during the Mesozoic. These structual trends are strongly representative and recognized in gravimetric

anomalies related to the A - type crustal thickening model. The NW-SE trend configures a triple junction array of a low angle thrusting crustal block in a manner that a granulitic rocks belt of the São Paulo block

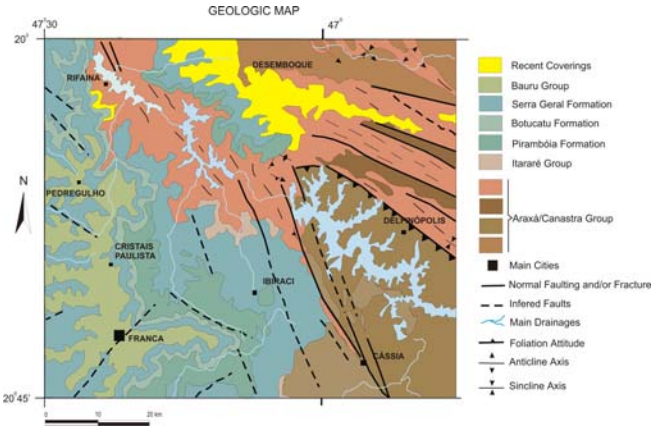

Figure 2 Geologic Map of the studied area, main cities, lithologies and structural features (Modified from Radam Brasil project, 1982; Simões, 1995 and Claro, 1999).

confirms these configuration constituing the Alterosa suture zone.

The NE trend is related to less stronger gravimetric anomalies gradients (Haralyi *et al.,* 1985) without safe evidence of a crustal thickening discontinuity (Ribeirão Preto suture) from Hasui & Haralyi (1982), that is underlying under the Paleozoic and Mesozoic sediments of the Paraná Basin.

The southwestern region of Minas Gerais has its delineated geotectonic pattern in terms of two great crustals blocks, the southern (São Paulo Block) and the northern (Brasilia Block) with greenstone belts terrains separated by a suture zone near Alterosa (MG), well observed in gravimetric studies (Haralyi & Hasui 1982, Haralyi et al., 1985).

The geology of São Paulo Block is represented by high grade metamorphic rocks (granulitic rocks belt) in the colisional zone, typical of deeper parts of the crust warped by the masses colision. The most important lithologies in the area are grouped as Varginha Complex and its related rocks are acid to basic granulitic, granitic, biotite and anfibolite gnaisses, in lesser expression are quartzites, calc-silicated gnaisses, marls and kinzitic gnaisses.

The Brasilia Block represents the overthrusted block with rocks mainly composed by granitic gnaisses complexes, greenstone belt sequences and meta-vulcanic-sedimentary coverings. The Barbacena Complex represents the basement with migmatitic gnaisses and granodiorites showing diferent structures with meta-basic and metasedimentary rocks between them representing the greenstone belt terrains. The rocks of the Araxá Group and its constituents are represented by the metasedimentary coverings of the Brasília Block composed mainly by schists, quartzites and gnaisses metamorphosed in a greenschist to anfibolite facies (Almeida, 1997).

Methods and Procedings

A bibliographic investigation from earlier studies in the area with subsequent treatment and processing of the preexisting survey data on the area was initially made (Hasui et al.,1989 and undergraduate students years 1994/1998). An altimetric/barometric survey was performed to obtain the free-air and Bouguer corrections and correct altitude of each gravity station.

For this task the named first-order level references of Instituto Brasileiro de Geografia e Estatística (IBGE) had been used for (a) the implantation of the gravimetric stations and (b) as base stations for a simultaneous barometric altimetric and gravimetric survey (Figure 3).

For the altimetric/barometric survey six American Paulin System altimeters had been used, three of them registering the temperature and barometric variations each 10 minutes at the base station (Delfinópolis and Franca) and other three (named “travelers”) with the gravimetric survey, registering the temperature and barometric variations at every measured point (Figure 3).

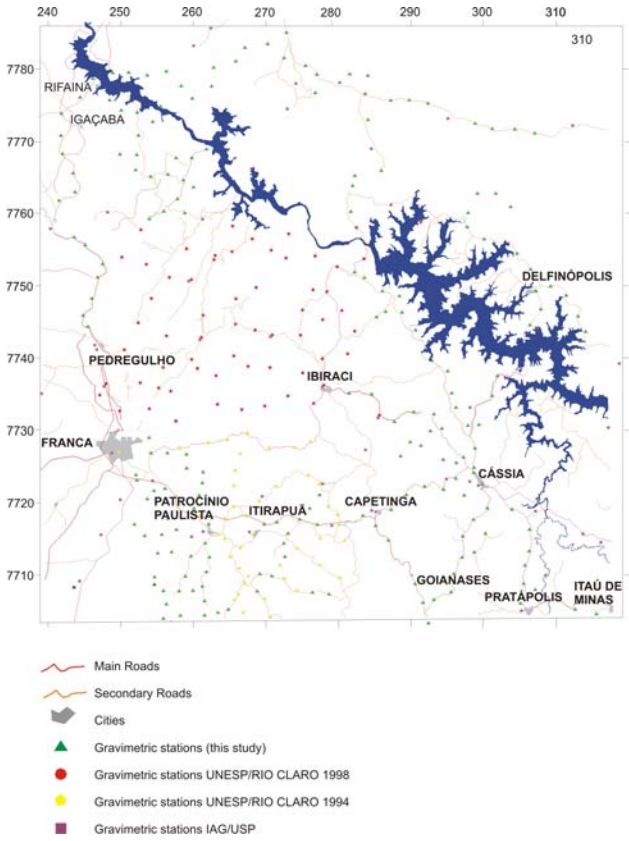

Figure 3 Gravimetric stations used in the Bouguer anomaly map and the main acess roads.

Temperature measurement had been taken simultaneously with the altimeter readings for correction of this variable. With the “traveler” altimeters was important to keep a maximum range of 30 km from the base station base so that the best aproximated level value (altitude) is obtained. The altimetric/barometric calculations follow the procedure considered by Hodgson

(1989), using a programmed Microsoft Excel 2000 spread sheet.

In this study 400 new gravimetric stations was obtained. A total sum of 614 stations (added the pre-existing 214 gravimetric stations) with the support of a La Coste & Romberg gravimeter model *G* 987 with 0.01 mGal precision. The gravity stations and the UTM coordinates acquisition were performed with a portable 10 meters precision (Garmin) GPS.

The gravimetric survey was executed along the main access roads and highways and the stations were separated 2 km away from each other. The reference base stations used for Bouguer anomaly reduction data were a) stations of the São Paulo Gravimetric Net, determined by Instituto Astronômico e Geofísico IAG/USP (University of São Paulo) and b) Gravimetric Stations determined by Instituto Brasileiro de Geografia e Estatística (IBGE), being therefore located in Franca (São Paulo) and Delfinópolis (Minas Gerais State). The Brazilian Basic Net and also de São Paulo Basic Net are referenced by the 1971 IGSN71 (International Gravity Standardization Net).

The acquired gravimetric stations and the Bouguer anomaly values have been determined using the software OASIS/MONTAJ commercialized by Geosoft inc. In the Bouguer and free-air correction and reduction were adopted the mean value of 2.67 g/cm^2 for the crustal density.

Bouguer anomaly map characteristics

The Bouguer Anomaly map (Figure 4) is a product derived from a 80 X 83 (X and Y direction respectively) gridding points and the interpolation method for gridding and isovalues is the minimum curvature adequate for potential geophysical methods such as gravimetry.

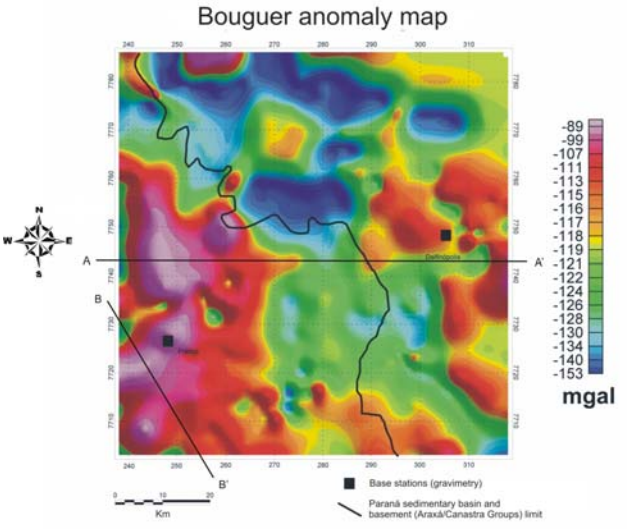

Figure 4 Gravimetric Bouguer anomaly map showing: gravimetric base stations (Franca and Delfinópolis), observed gravimetric profiles (A – A', B – B') and basin/basement limit. The contourn interval is 2 mGal.

The generated map, its interpretation and also the arrangement of the anomaly Bouguer values in the studied area alows to predict and elaborate the following crustal models. Using geologic profiles from earlier studies (Claro, 1999), geologic map with its surface lithologies, structural arrangement and faulting characteristics and observing the gravimetric anomalies two main gravimetric profiles were determined.

Crustal modeling and the sutures

Two main crustal models were elaborated to attend the basic objectives of this study. The models fix the most important boundaries (suture zones) Alterosa and Ribeirão Preto and the Bouguer anomaly signatures along two main profiles in the area. The crustal modeling have been delineated along the two profiles, A - A' and B - B' (Figure 4) and have the objective to quantify and understand the undersurface masses related to the crustal portions and to test the São Paulo and Brasília blocks collision tectonic model deduced and conceived from surface lithostructural/geological data and information.

a) Models description

The A - A' profile (Figure 5) with a E-W direction, pass through the two main stronger gravimetric gradients related to the Alterosa suture zone. Lower strong horizontal gradients in a triple junction array (perpendicular to Alterosa sutura lineament) are represented by the NW-SE direction B - B' profile (Figure 6).

This profile pass through isogalic curves with lower horizontal gradients (less than 10 mgal/km and is still a characteristic block collision zone feature. This profile is related to the Ribeirão Preto suture zone with few surface evidences (Hasui *et al.,* 1989).

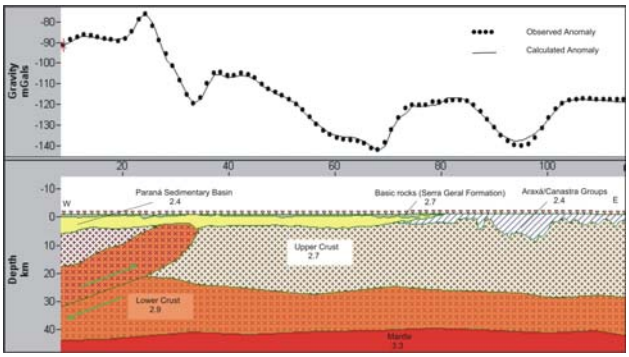

Figure 5 Profile A – A' (see Figure 4) showing Bouguer anomalies, calculated anomalies and interpreted crustal models. Density contrasts are shown in g/cm^3.

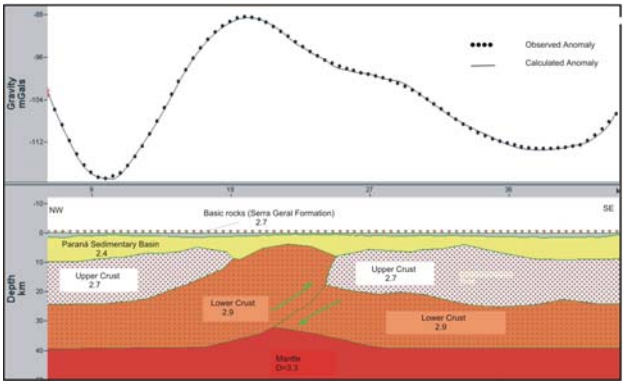

Figure 6 Profile B – B' (see Figure 4) showing Bouguer anomalies, calculated anomalies and interpreted crustal models. Density contrasts are shown in g/cm^3.

Models characteristics/attributes

A Bouguer anomaly map, a pre-determined geologic profile integrated in a GM –SYS software (NGA Inc.) was used integrated with the Oasis Montaj platform. The main lithologies and its rocks densities present in the area were specified from earlier studies as Hasui *et al.* (1989) and Malagutti Filho *et al.* (1996). The profiles were delineated to better attend the most significand anomaly signatures representing the geosuture zones and its respective boundaries.

Concluding remarks and final conclusions

In the studied area, lesser negative Bouguer anomaly values (or a gravimetric high) are evident in the west/southwest portion from the Bouguer anomaly map, reaching -80 mgal and becoming more negative toward northeast. In the map western portion (Figure 4) this gravimetric high and its values are concentrated in a zone with north/south direction alongated showing a high density area both in surface/subsurface and in deeper levels (lower and upper crust). This evidences follow the suture zones geotectonic model, described in earlier studies referenced before. Should be considered the abundance wide-range and thick basic rocks from the Serra Geral Formation present in this area.
With the isovalues Bouguer anomaly map, three main provinces or domains are obtained in this study (Figure 7).

(1) Gravimetric high with Bouguer anomaly values ranging from -80 to -120 mgal in the SW portion alongated in a NS direction zone.
(2) Gravimetric low with Bouguer anomaly values ranging from -120 to -150 mgal in the map central portion. Such domain are alongated in a NW/SE direction and coincident with the basin/basement limit.
(3) A NE/E and SE intermediary domain with values ranging from -110 to -118 mgal. In this area is present the basement and the Serra da Canastra are located represented lithologicaly by the Araxá and Canastra Groups.

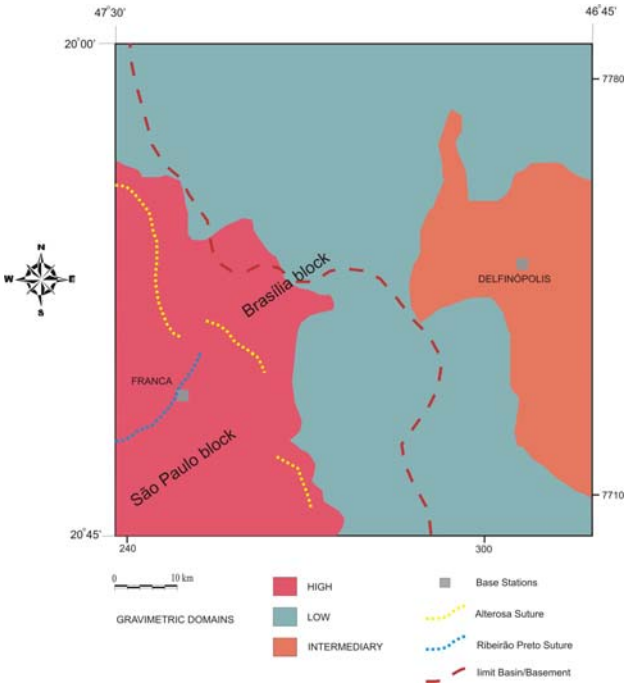

Figure 7 Main recognized gravimetric domains in this study, crustal blocks and its interpreted and delineated Alterosa and Ribeirão Preto descontinuities (sutures zones determined by Haralyi & Hasui, 1982).

In the southwestern portion of this area, the Bouguer anomaly values named as gravimetric high are strongly marked reaching a 10 mgal/km horizontal gradients , with a triple junction array of colisional crustal blocks. An observed Bouguer anomaly values east – west profile shows a gravimetric high (-80 and -120 mgal) and following toward east a gravimetric low with a second high or plateau containing gravimetric values of -110 and -140 mgal representing a characteristic A-type colision zones model as proposed in earlier studies (Thomas, 1977; Haralyi & Hasui, 1982; Haralyi *et al*., 1985; Thomas *et al*., 1988).
High gradients in the east and southeast portions are related, as show in the crustal model, to the supracrustal units (Araxá and Canastra Groups) presented in the studied area. The depicted model has a good adjustment with the geological features of the region both lithological and structural. The granulitic rocks occurence represents the exhumed lowwer cust (Almeida, 1997).
The strongly marked gradients in the southwest portion (suture zone) are present mostly in São Paulo block also named as the obducted block with it's limit in the NW/SE direction Alterosa Descontinuity. In the same domain with a perpendicular direction is the Ribeirão Preto Descontinuity evidence as mentioned in studies (Morales, 1993) and NE/SW trend faulting. This descontinuity is also recognized in aerial photos and observed drainage array. The suture zones concept based in a crustal model is basicly a low angle block overthrusting following the known Himalaian model were the deeper portion rocks of

the crust were uplifted in this collisional model and then eroded later.
The Ribeirão Preto suture zone, as previously explained, is a descontinuity with few evidences and a recent study product. To attend better the observed Bouguer anomaly values and the direct modeling generated calculated curve an alternative model has been built. This models correspond to the surface geological characteristics and the gravimetric high observed in the Bouguer anomaly map (Figure 8).

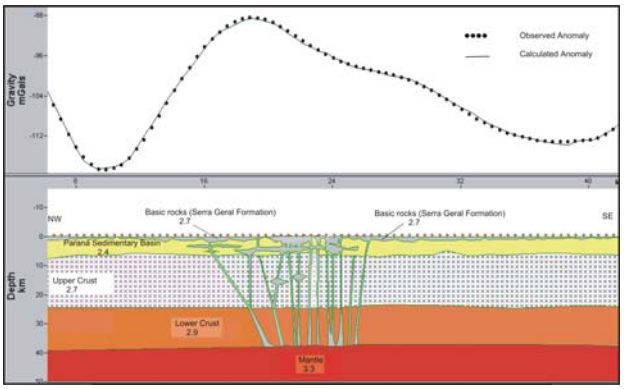

Figure 8 Alternative profile B – B' (see FIGURE 5) showing Bouguer anomalies, calculated anomalies and interpreted crustal models. Density contrasts are shown in g/cm^3.

This model supports that a basic rock dikes bundle from the mantle are the possible Serra Geral Formation feeding chanel with its high-density rocks widely present in this region. This model attends the observed Bouguer anomaly curve and the surface geology. A non-evidence of another geophysical studies in this area as sismic, bore-holes or eletric methods allows the conception of such crustal model.
The original junction array in the area from continental masses colision have been affected by tectonic processes (Cassia fault for example) changing, however, the original suture array. The Alterosa and the Ribeirão Preto descontinuity and its regional extend are extend and elongated beyond the studied area limits and have a complex array and jointing larger than the observed area.
Lithostructural studies as much as gravimetric associated with a sketched sectioning allows a better view and understanding from the units and its distribuition in the area. In such areas where the geologic and geophysical knowledge and mapping are at a general and regional recognizing level, a more detailed gravimetric data acquisition associated with a structural features study is certainly a valuable tool.

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