Crustal structure and density models of central sector of Tocantins Province from deep seismic refraction experiment

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Abstract

This research is based on an execution of two lines of deep seismic refraction of 300 km of extension (L1-Porangatu and L2-Cavalcante), crossing over central sector of Tocantins Province from west to east by using, in each line, 120 digital seismographs and explosions with controlled time and explosive charges between 500 and 1,000 kg in each 50 km; GPS receivers were employed in order to control the time and geographical coordinates from recording and shot points. Obtained 2D models represent the final result of seismic velocity distribution from crust beneath L1 and L2 lines. The gravimetric model, obtained in this work in terms of seismic model, adequately adjusts with observed gravimetric data by using theoretical densities slightly modified, within limits allowed by the function employed to calculating the densities based on VP values achieved from this work.

Introduction

The studies were performed in the thematic project, first-time in Brazil, had the objective of using a combined geophysical and geological tools for a better understanding of geotectonic environment of a large orogenetic Neoproterozoic area, comprising the Tocantins Province (Figure 1).

Before the seismic refraction experiments of this project, some attempts were made to deep seismic refraction survey, using explosions in quarries and analogic recorders with the number below 20 (Giese & Shutter, 1975; Bassini, 1986; Mignona, 1987; Alarcon , 1989; Pedreschi, 1989) and a similar amount of seismographs, but digital (Pereira, 1995).

The deep seismic refraction conducted in Tocantins Province use over a hundred digital seismograph record working with both direct and reverse explosions, with hours of origin controlled by GPS, planned exclusively for these experiment.

Method

The seismic refraction method uses active or passive energy sources, geophones and recorders to capture and store the disturbances produced by these energy after pass through the layers of Earth interior. We used 7 explosions (active sources) with explosive charge of 500 to 1000 kg in each 50 km, and 120 recording stations for each seismic refraction line of 300 km.

Initially experiment data, which have been considered of good quality, allowed the elaboration of 1D models, using TTInvers program (Figure 2). Successive models were related to represent layers with similar characteristics in a preliminary model aiming of modeling in 2D (Figure 3) accomplished with MacRay program (Luetgert, 2004). Obtained 2D models represent the final result of seismic velocity distribution from crust beneath L1 and L2 lines.

To make the gravimetric modeling, initially, the densities theoretical values of gravimetric model are calculated using the function $\rho = a + b.Vp$, suggest by Christensen & Mooney (1995), which relates the P-wave velocity with density through a and b constants that are related for each crustal depth. Besides these constants, the standard deviation is provided to estimate the ρ error in terms of Vp.

Near the shot EX16, almost middle of L1, there is a strong negative gradient in the curve of gravity data that coincides with the interface between the Goiás Massif and fold-and-thrust belt and the deeper crust of the Tocantins Province. This negative gradient could not be modeled considering only the features of the crust, in this case it was necessary to adopt mantle density values to satisfy the observed anomalies along the lines L1-Porangatu and L2-Cavalcante.

These values of density used in the modeling are in agreement with that proposed by Soares et al. (2006a), which considers that the mantle beneath Archean/Paleoproterozoic cratons are less dense that the mantle of Neoproterozoic cratons because of the possibility of being less rich in FeO and cooler, according Artemieva and Mooney (2001), O'Reilly et al. (2001), Durrheim and Mooney (1994) and Hawkesworth et al. (1990).

For this reason the velocity of seismic waves can be higher in older cratons, as observed in seismic velocity models obtained in this work (Figures 20 and 21), where the Vp beneath Araguaia Belt, Goias Magmatic Arc and Goias Massif is 8.07 km/s and beneath fold-and-thrust belt and São Francisco craton is 8.26 km / s.

Results

Results show crust under central section of Tocantins Province with thickness varying from 36 to 43 km, and whose parameters are correlated to main geological structures existents in surface. VP as well as VP/VS ratio mean values vary about 6.5 km/s and 1.74, respectively, with the exception of fold-and-thrust belt, whose values are 6.3 km/s and 1.73. Those values reach 6.8 km/s and

1.74 beneath São Francisco cráton (Table 1). There are indicia of double subduction occurred in the eastern portion of Tocantins Province with São Francisco Cráton subducting to west (in ~ 760 Ma), as well as in the western portion, with Amazon Cráton subducting to east (in ~ 620 Ma). The gravimetric model, obtained in this work in terms of seismic model, adequately adjusts with observed gravimetric data by using theoretical densities slightly modified, within limits allowed by the function employed to calculating the densities based on VP values achieved from this work. Adopted mantle densities to modeling took in consideration Paleoproterozoic age, beneath São Francisco Cráton, less dense (3.31 g/cm^3), and with higher VP (8.26 km/s), as well as Neoproterozoic one, beneath Tocantins Province, denser (3.34 g/cm^3), and with lower VP (8.07 km/s)

Conclusions

In this model, there are indicia of double subduction occurred in eastern portion of Tocantins Province with Sao Francisco craton subducting to west (about 760 My), as well as in western portion, with Amazon craton subducting to east (about 620 My). This situation is in according to Soares et al. (2006b), that suggest around 500 My when the cratons Amazon, San Francisco and Paranapanema clash, ending in the form Tocantins Province

as a double subduction in the Tocantins Province. In the eastern portion, with the San Francisco craton subductingo to west, which would have occurred around 760 My and, in the west portion, Amazon craton subducting to the east, which probably began around 620 Ma This was completed in according to Soares et al. (2006b), around 500 Ma when the crátons Amazon, San Francisco and Paranapanema collided, ending in the form Tocantins Province.

The gravimetric model, obtained in this work based on this work seismic model, adequately adjusts with observed gravimetric data by using theoretical densities slightly modified, within the limits allowed by the function employed to calculating the densities based on modeled Vp values. Adopted mantle densities to modeling took in consideration Paleoproterozoic age, beneath São Francisco craton, less dense (3.31 g/cm^3), and with higher Vp (8.26 km/s), as well as Neoproterozoic one, beneath Tocantins Province, denser (3.34 g/cm^3), and with lower Vp (8.07 km/s). See Figure 5.

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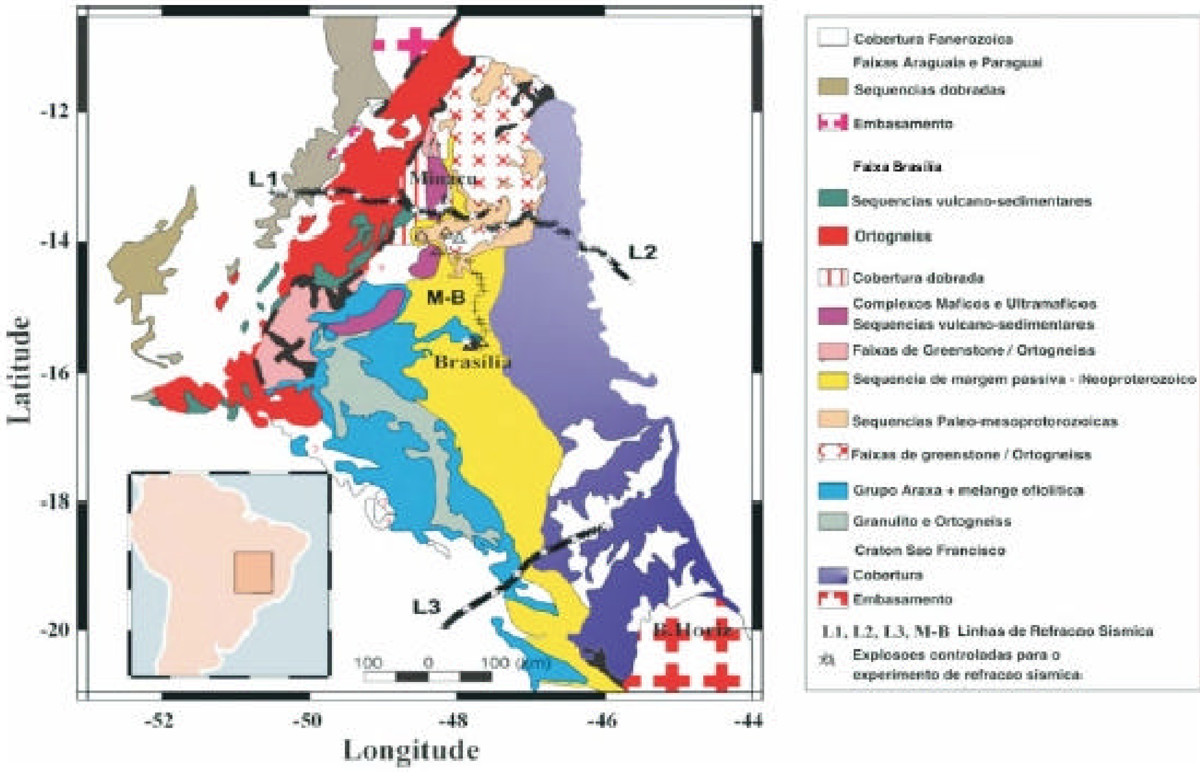

Figure 1 –. Geological map of Tocantins Province showing the seismic refraction lines in central sector. (Perosi, 2006)

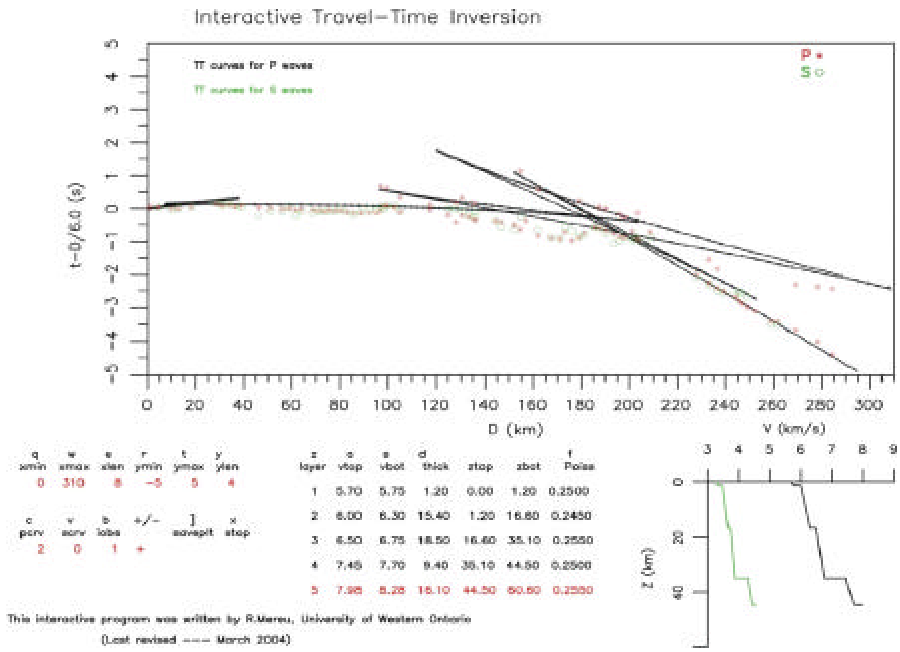

Figure 2 – Example of 1D model obtained with TTInvers. (Perosi, 2006)

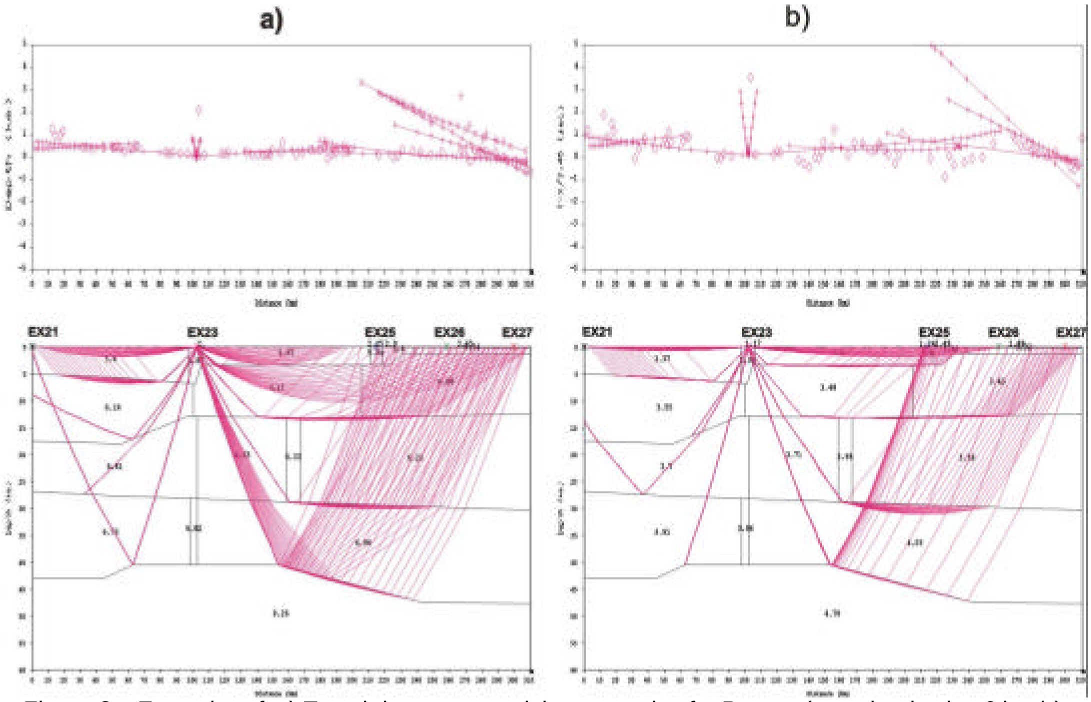

Figure 3 – Examples of: a) Travel-time curve and the ray tracing for P wave (speed reduction 6 km /s)
b) travel-time curve and the ray tracing for S wave (speed reduction 3.46 km / s) (Perosi, 2006)

Table 1 – Average P-wave, S-wave velocities and Vp/Vs ratio. (Perosi, 2006)

Faixa Araguaia				
Camada	Espessura (km)	Vp (km/s)	Vs (km/s)	V_P/V_S
1	0,08	2,00	1,17	1,86
2	2,04	5,75	3,44	1,67
3	10,27	6,17	3,53	1,75
4	7,3	6,6	3,78	1,75
5	15,7	6,9	3,96	1,74
6	8,3	7,13	4,08	1,75
	Média	6,66	3,82	1,74

Faixa Araguaia sem camada mais profunda				
Camada	Espessura (km)	Vp (km/s)	Vs (km/s)	V_P/V_S
1	0,08	2	1,17	1,86
2	2,04	5,75	3,44	1,67
3	10,27	6,17	3,53	1,75
4	7,3	6,6	3,78	1,74
5	15,7	6,9	3,96	1,75
	Média	6,55	3,76	1,74

Arco Magmático de Goiás				
Camada	Espessura (km)	Vp (km/s)	Vs (km/s)	V_P/V_S
1	0,09	3,32	1,24	1,84
2	3,67	6,01	3,43	1,75
3	10,3	6,19	3,54	1,75
4	7,20	6,47	3,71	1,75
5	15,7	6,85	3,94	1,74
	Média	6,50	3,73	1,74

Maciço de Goiás				
Camada	Espessura (km)	Vp (km/s)	Vs (km/s)	V_P/V_S
1	0,09	3,32	1,34	1,84
2	3,67	5,89	3,37	1,75
3	10,30	6,19	3,54	1,75
4	8,20	6,47	3,71	1,75
5	17,80	6,85	3,94	1,74
	Média	6,51	3,73	1,74

Faixa de dobras e empurrões				
Camada	Espessura (km)	Vp (km/s)	Vs (km/s)	V_P/V_S
1	0,04	2,00	1,17	1,71
2	5,70	5,80	3,37	1,72
3	12,60	6,18	3,55	1,74
4	9,30	6,41	3,70	1,73
5	12,30	6,73	3,91	1,72
	Média	6,34	3,67	1,73

Faixa de dobras e empurrões próximo ao Cráton SãoFrancisco				
Camada	Espessura (km)	Vp (km/s)	Vs (km/s)	V_P/V_S
1	0,04	2,00	1,17	1,71
2	5,70	5,87	3,40	1,73
3	12,60	6,11	3,48	1,76
4	9,30	6,43	3,71	1,73
5	15,00	6,96	4,03	1,73
	Média	6,69	3,71	1,74

Cráton São Francisco				
Camada	Espessura (km)	Vp (km/s)	Vs (km/s)	V_P/V_S
1	0,06	3,65	1,99	1,86
2	1,30	5,74	3,32	1,73
3	11,00	6,08	3,43	1,77
4	17,90	6,23	3,59	1,73
5	17,30	6,96	4,03	1,73
	Média	6,77	3,70	1,74

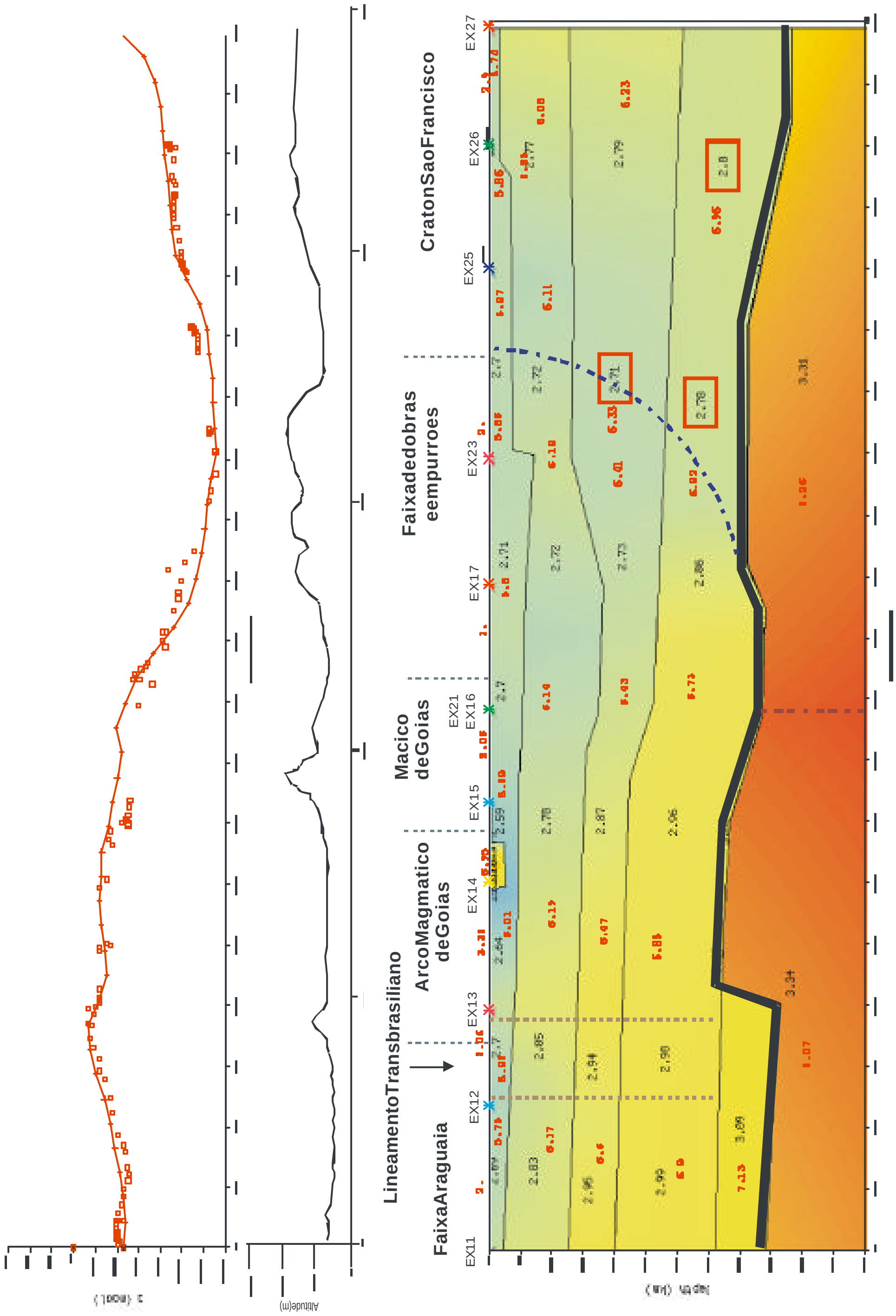

Figure 5 - The structural model for Tocantins Province obtained by MACRAY, from top to bottom, gravimetric modeling, elevation curve and the structural model. Numbers in red are the values of P-wave velocities and in black, values of the densities. Dotted lines probable failures or discontinuities. Red rectangles indicate anomalous values of density obtained in modeling. (Perosi, 2006).