FIRST INTERNATIONAL GOCE SOLID EARTH WORKSHOP

16-17 October 2012
Faculty ITC, University of Twente
Enschede, The Netherlands

GOCE data demonstrate magmatic underplating beneath the Paraná basin

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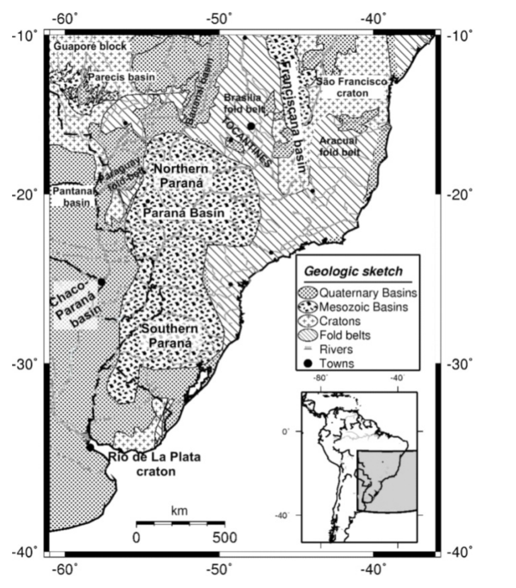

Fig.1 Geological sketch

GOAL

The goal is to explain the apparent discrepancy between crustal thickness and gravity observation by modeling the internal crustal density anomalies through the gravity field on Paraná basin (South America).

MOTIVATION

- The intracratonic basin belongs to a Large Igneous Province.
- Deep crust-mantle interface below the Paraná basin: 40-46 km (Assumpção et al., 2012; Lloyd et al., 2010; Feng et al., 2007).
- Thick crust and thick sediment thickness generally generate a strongly negative Bouguer anomaly:
- It is not found for the Paraná basin.

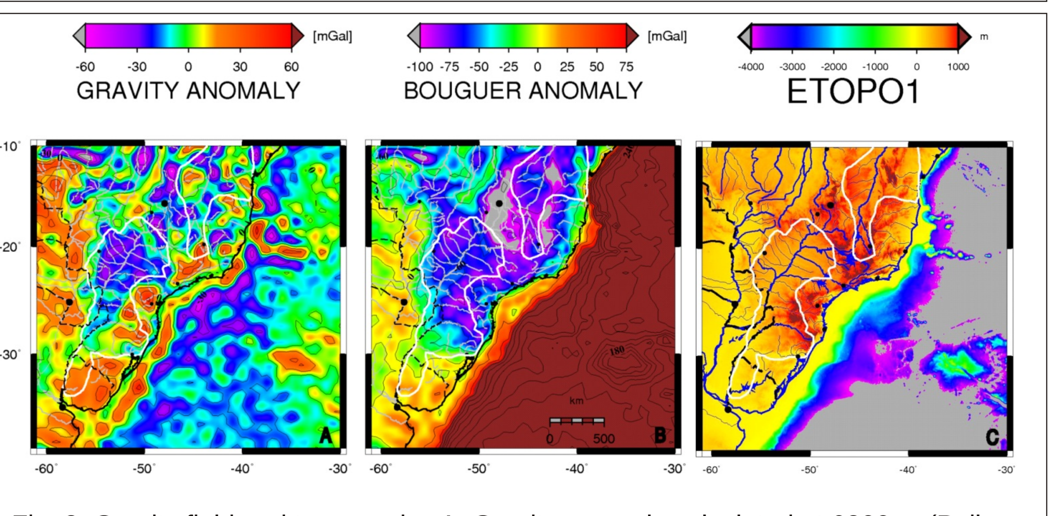

Fig. 2: Gravity field and topography. A: Gravity anomaly calculated at 6200 m (Pail et al., 2011); B: Bouguer Anomaly; C: Topography provided by ETOPO1 (Amante

METHODOLOGY

Our approach integrates:
1)The newest gravity data of the satellite mission GOCE (Gravity Ocean Circulation Explorer) provided by model of Pail et al. (2011);
2)The seismological and geophysical drilling information to determine the Paraná basin lithospheric structure.

SEISMOLOGICAL MODELS

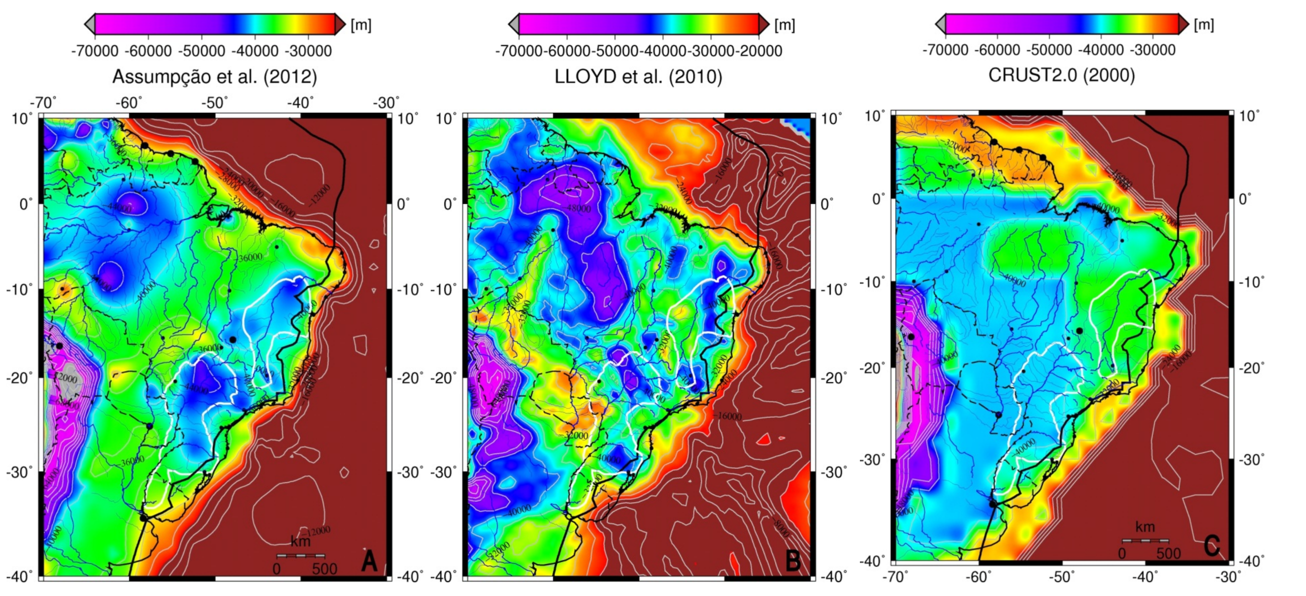

Fig. 3: Seismological models: A: Laske et al. (2000); B: Lloyd et al. (2010); C: Assumpção et al. (2012).

In recent years different authors have carried out seismologic investigations that have produced a Moho crustal thickness model for the South American plate. The latest model is the crustal thickness according to Assumpção et al. (2012), that includes data from active source experiments (deep seismic reflection surveys) and receiver functions, whereas offshore the seismologic information is combined with the crustal thicknesses derived from the Bouguer gravity values according to the works of Mohriak et al. (2000) and Zalán et al. (2011).

GEOPHYSICAL CONSTRAINTS

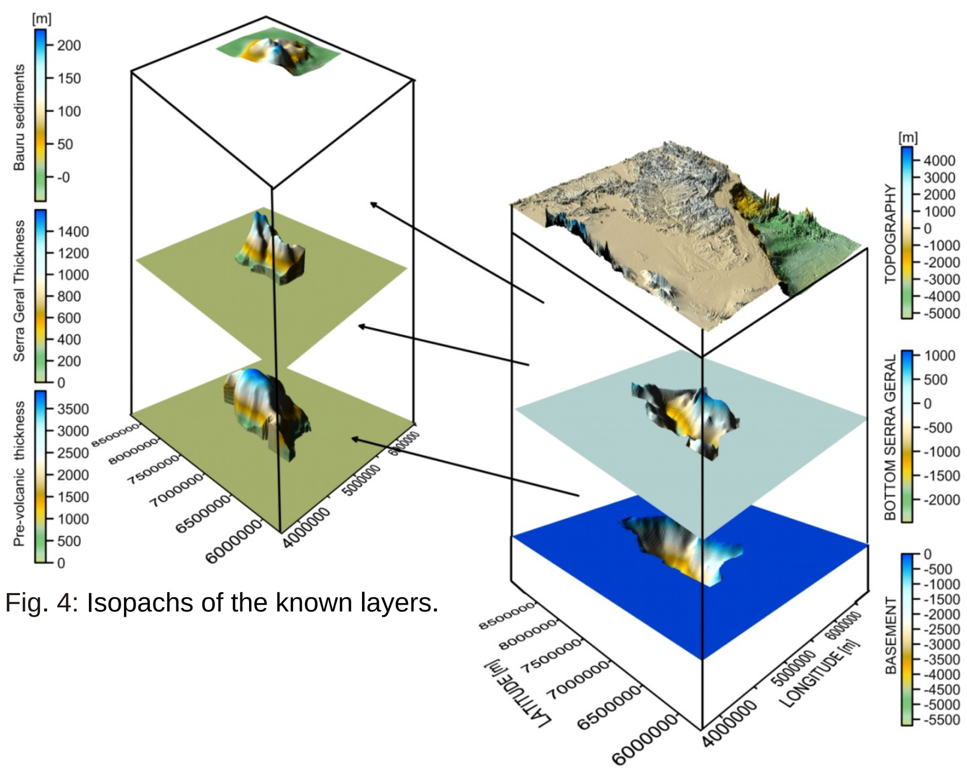

Fig. 4: Isopachs of the known layers.

Isopachs of known sediment acquired from drilling and seismic investigations Zalán et al. (1986, 1987); Melfi et al. (1987).

FORWARD MODEL

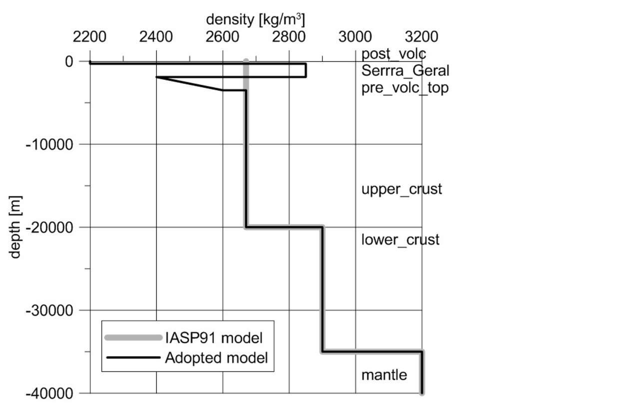

Fig. 5: Forward model.

We define a reference crustal model, with an upper crust 20 km thick, and a lower crust reaching the normal crustal thickness of 35 km, with standard densities of 2670 e 2900 kg/m^3, respectively. The mantle has the density of 3200 kg/m^3. The reference model corresponds to a standard crustal model (IASP91, Kennet 1991; Kennet and Engdahl, 1990). The reference model and the densities of our model are graphed in **Fig. 5**.

GRAVITY INVERSION

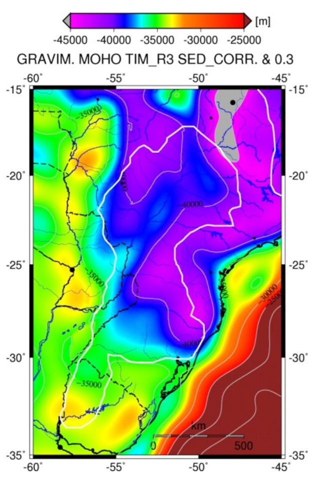

Fig. 6: Inverse modeling.

Gravity inversion (Braitenberg et al., 2007) does not explain great crustal thickness under Paraná.

GRAVITY ANOMALY

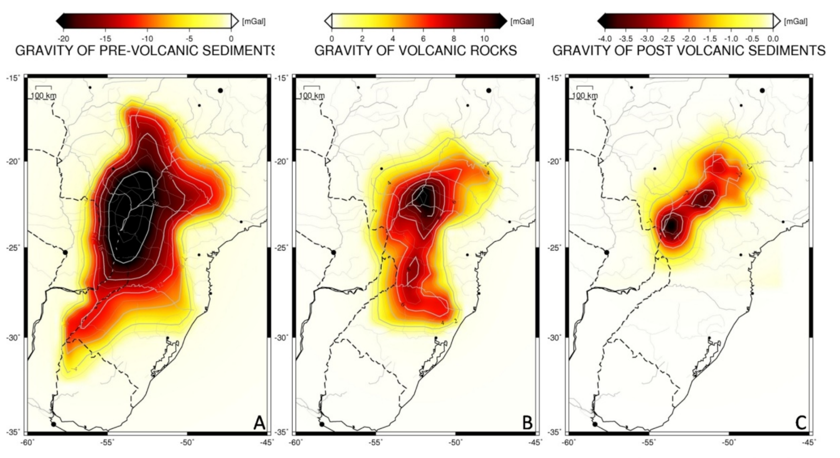

Fig. 7: Gravity effect of the sediments of the Paraná basin calculated at 6200 m. A) Pre-volcanic sediments. B) Basalt of Serra Geral Formation. C) Post-volcanic Bauru Group.

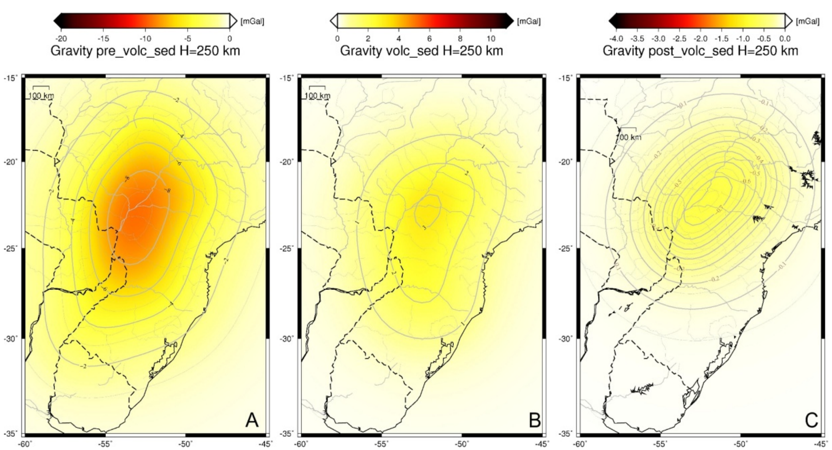

Fig. 8: Gravity effect of the sediments of the Paraná basin calculated at 250 km. A) Pre-volcanic sediments. B) Basalt of Serra Geral Formation. C) Post-volcanic Bauru Group.

The gravity effect of the three layers was calculated by discretizing the known geometries of the units into layers of varying density. Each layer is 100 m thin, to approximate variation of density with depth (Braitenberg et al., 2007; Uieda et al., 2011). The composite gravity contribution of the sediments reveals that the positive mass of the Serra Geral Formation is smaller than the mass deficit imposed by the lighter sediments. In terms of mass balance, this implies that with respect to the standard crustal column, the sediments of the Paraná basin add up to a mass deficit, notwithstanding the presence of the basalt layer. The gravity field at GOCE height cannot appreciate the small structures as sediment layers. It follows that the best resolution is using topographic height, as **Fig. 7-10** shows quite well.

SECOND VERTICAL DERIVATIVE (Tzz)

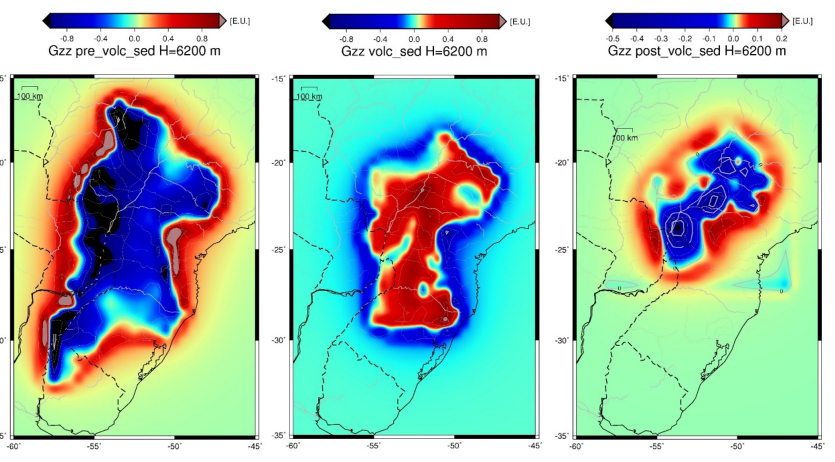

Fig. 9: Second vertical derivative effect of the sediments of the Paraná basin calculated at 6200 m. A) Pre-volcanic sediments. B) Basalt of Serra Geral Formation. C) Post-volcanic Bauru Group.

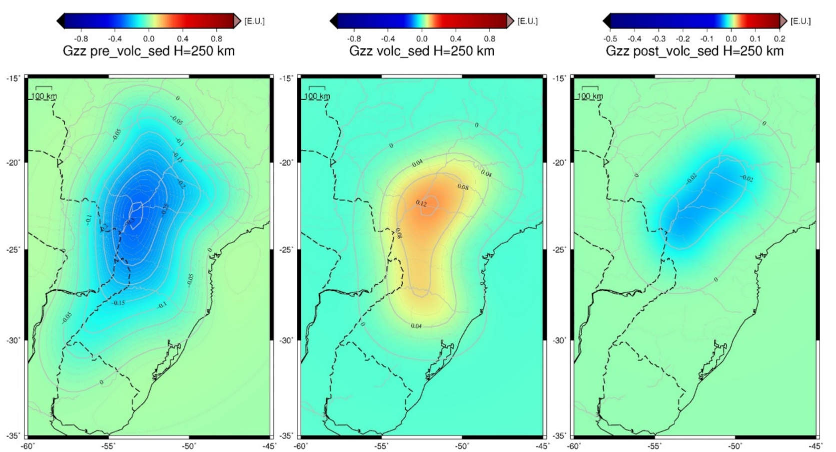

Fig. 10: Vertical second derivative effect of the sediments of the Paraná basin calculated at 250 km. A) Pre-volcanic sediments. B) Basalt of Serra Geral Formation. C) Post-volcanic Bauru Group.

2D PROFILES

If the seismologic Moho is deeper than the gravity and isostatic Moho, it means that there is a densification in the crust, that has not been accounted for in our model. If the seismologic Moho is shallower than the gravity and isostatic Moho, it means that there is a density reduction in the crust.

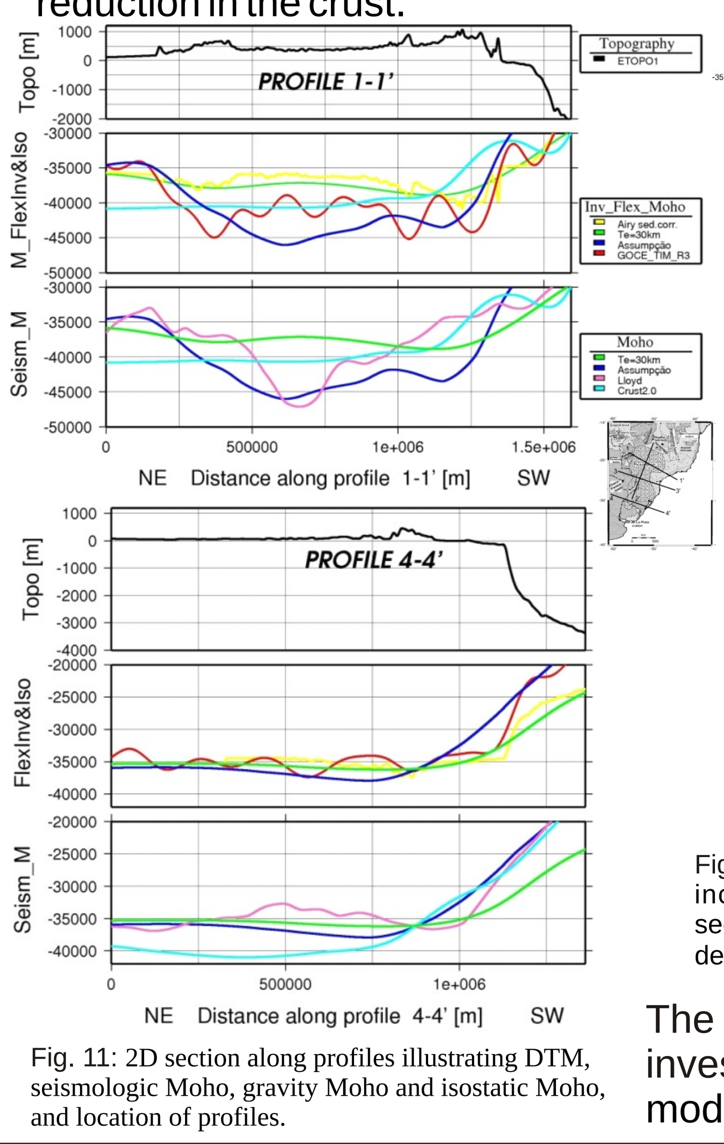

Fig. 11: 2D section along profiles illustrating DTM, seismologic Moho, gravity Moho and isostatic Moho, and location of profiles.

BOUGUER RESIDUAL ANOMALY

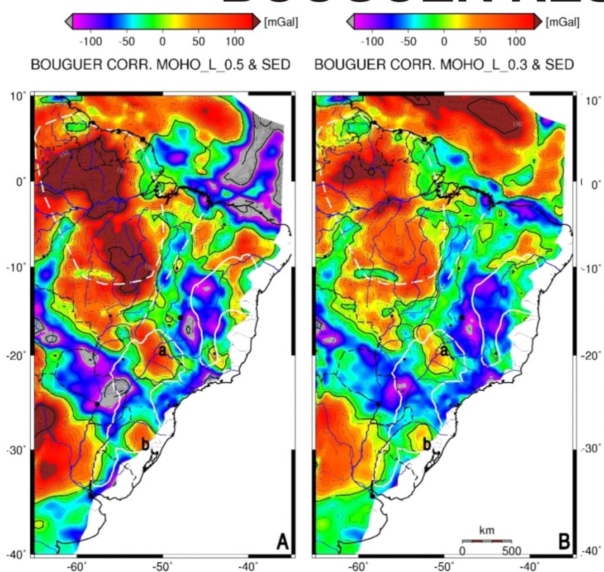

Fig. 12: Gravity residual of the crustal model including crustal thickness variation and sediments, with Moho model Lloyd et al. (2010), density contrast: A) -500 kg/m^3; B) -300 kg/m^3.

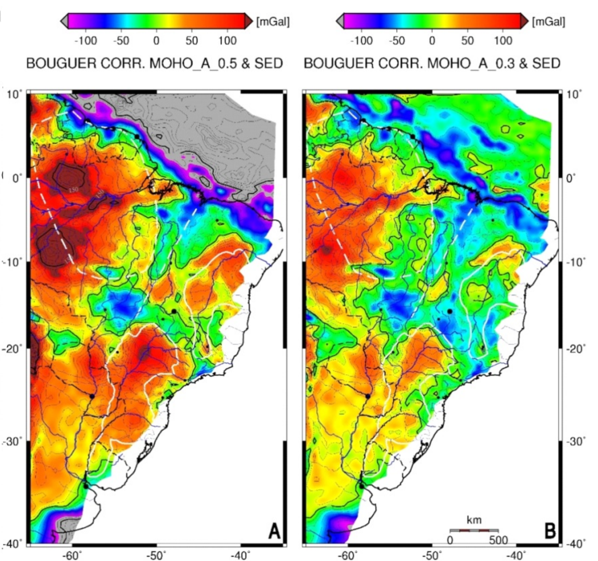

Fig. 13: Gravity residual of the crustal model including crustal thickness variation and sediments, with Moho model Assumpção et al. (2012), density contrast: A) -500 kg/m^3; B) -300 kg/m^3.

INVERSION OF BOUGUER RESIDUAL

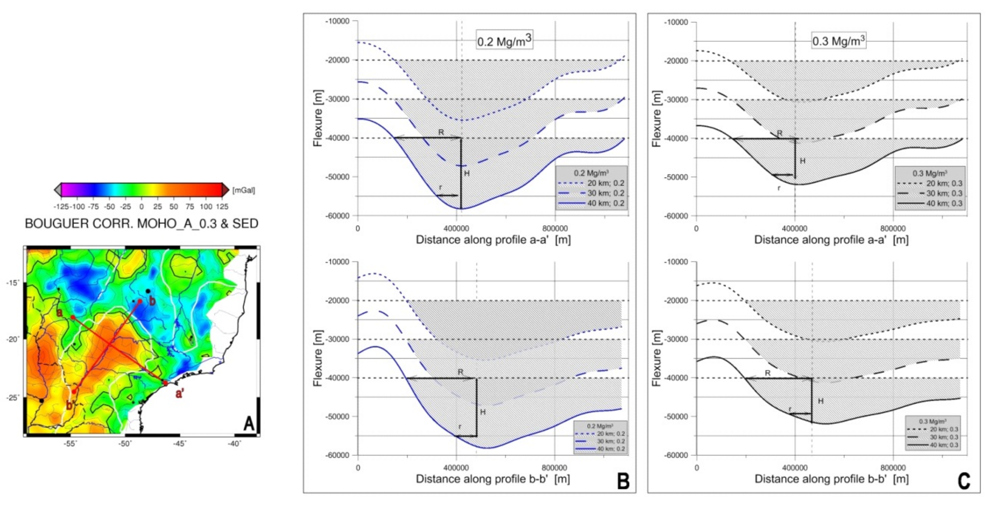

Fig. 14: Geometry of the high-density body in lower crust along the two profiles a-a' and b-b' from gravity inversion at different reference depths (20, 30,40 km) A) Location of profiles; B) Inversion with density contrast 200 kg/m^3. C) Inversion with density contrast 300 kg/m^3.

The constraints are used to define geometries and densities, and reduce the gravity values for these known structures. Assuming that these investigations define the correct geometry, a gravity residual points to density anomalies not contained in the previously published crustal model, and located either in the crust or mantle, according to the involved wavelengths of the residual gravity signal.

DISCUSSIONS AND CONCLUSION

- Already earlier works concerned with the gravity field and the isostatic equilibrium had encountered some evidence of extra-mass to explain the gravity field in the Paraná basin (Molina et al., 1987; Vidotti et al., 1998).
- However at the time, no Moho depth estimates were available. The present work is more robust in the sense that seismological data is now available.
- The seismologic investigations have several problems in the eastern South American continent due to the unsymmetric distribution of earthquakes, which are mostly from the Pacific side of the continent, the Atlantic side being near to aseismic.
- Ivrea Verbano area, a crustal section which was below a large volcanic source is exposed, revealing a large magmatic complex extending in the lower crust with amphibole gabbro and gabbro that form an underplated body that was incorporated into the metamorphic crust (Quick et al., 2009).
- The considerations on the velocity anomalies would suggest the hidden mass to be located in the mid-lower crust, rather than in the upper crust.
- Assuming a fixed density contrast we estimate the thickness of the underplated body by inverting the gravity residual.
- The model assumes the reference depth of the body to be located at 20, 30 or 40 km, and the inversion determines the geometry of the body, given the density contrast.
- The reference depth defines the top of the body.
- We find the total thickness of the body to be over 10 km (**Fig. 14**).
- The deeper the body is assumed to be, the bigger its mass must be to explain the gravity residual.
- If the density of the underplated material is greater, then the thickness of the body is proportionally smaller, as can be seen in **Fig. 14B**, where a density contrast of 300 kg/m^3 was used to illustrate the effect of a varying density.
- A density contrast between 100 kg/m^3 and 200 kg/m^3 is to be expected when considering the density of gabbro (see **Fig. 12**) and the density of the normal lower crust (2900 kg/m^3).

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OUTLOOK

- Study deep lithosphere: upper mantle.
- Analyze conjugate part of Brazilian LIP on African counterpart (Paraná-Etendeka province).

This work is a part of my PhD thesis:
Mariani P., 2012: "Caratterizzazione della struttura litosferica del bacino intracratonico del Paraná (Sud America) mediante modellazione di dati gravimetrici da satelliti di nuova generazione (GRACE e GOCE)". Università degli Studi di Trieste.
Moreover it represents a paper submitted to JOURNAL OF SOUTH AMERICAN EARTH SCIENCE: Mariani, Braitenberg, Ussami, 2012. "Explaining the thick crust in Paraná basin with satellite GOCE-gravity observations.

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