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Are the large wave-length South American intraplate deformation and the incipient inversion of Brazilian continental basins manifestations of ongoing lithospheric/crustal folding?

Cláudio Lima, Claudio Amaral, Anderson Moraes e Alvaro Maia*

* PETROBRAS/CENPES

ABSTRACT

The South American plate (SAP) is now in horizontal compression and shortening. This is shown by stress data compilations, intraplate stress field numerical models and space-based geodetic results. Thrust regimes prevail in SE Brazilian margin, Central Brazil and Amazon region; strike slip regimes prevail in NE Brazilian margin (Assumpção, 1998). In most Brazilian basins, breakout orientations are usually consistent for the World Stress Map qualities A, B and C, allowing a good estimate of the regional maximum horizontal stress (SHmax), which is in general in good agreement with the available nearby focal mechanisms (Lima et al., 1997). Available stress magnitudes derived from hydrofracturing and leak-off testes have shown that strike-slip stress regimes prevail *within* the Potiguar and the Campos basin (Lima Neto, 1998 ; Lima Neto & Beneduzzi, 1998). Results from the French geodetic space-based system DORIS are consistent with the observed ongoing compression since all but one of the available base-lines are shortening. Base lines that cross the Andes towards the intraplate are shortening 13-20 mm/yr; intraplate shortening between Cachoeiro Paulista (SE Brazilian coastal ranges) and Kourou (French Guyana) is about 7 mm/yr (L. Soudarin, CNES, Toulouse, written communication). Geodetic results have also confirmed that the Andean belt is still moving eastwards, thrusting the Brazilian craton (Norabuena et al, 1998). The compression / shortening is probably due to the interactions amongst the SAP and its neighborhood (mostly its convergence with the Nazca and the Caribbean plates and its divergence from the African plate) and with the asthenosphere as well (Cobblentz &Richardson, 1996 ; Silver & Russo, 1996).

In western Europe, ongoing NW-trend compression is inducing regional tectonic deformation (Illies and Greiner, 1979 ; Illies et al., 1979). On the basis of in-situ stress determinations, focal mechanisms, geodetic measurements and Quaternary volcanic activities, these authors have demonstrated that since Pliocene times, the current stress field has controlled faulting, patterns of uplift and deposition through a 800 km-long belt of seismotectonic activity affecting the Rhine graben, the Reshenish shield, the lower Rhine embayment and the Zuideer depression. These phenomena have been named as *"incipient inversion"*, an intraplate deformation attributed to the Alpine tectonics (Ziegler, 1989).

Similarly, plate wide deformation related to the Andean tectonics has been put into evidence by integrated visualizations of available plate-scale information on tectonics, continental geology, topography / bathymetry, seismicity, stresses, active deformation, residual isostatic anomalies, fission track analyses, and seismically derived Moho depths and P and S wave velocity anomalies (Lima, 1999).

As stated by Gephart (1994), the Euler equator of the Tertiary convergence between South America and Nazca symmetrically bissects the Central Andes and the underlying slab. This equator is also roughly coincident with a chain of positive residual isostatic anomalies (Ussami et al, 1993) crossing all the midplate, from the Andean salient up to NE Brazil (Lima, 1999). That chain concentrates seismicity, is associated with the major plate divide and separates the plate in two different geotectonic, gravity and topographic domains: southeastwards, *Brasiliano* (450- 700 Ma) terrains, gravity lows and highlands predominate; northwestwards, *Tranzamazonico* (~2000 Ma) terrains, gravity highs and lowlands predominate. Implication is that strong mechanical links exist amongst the convergence of the South American and the Nazca plates, Andean deformation and intraplate deformation. Moreover, its implicit that the plate wide deformation is strongly dependent on older Precambrian major structures.

The western edge of the Brazilian craton has been uplift along a line that mimics the structural lines of the chain (fig. 1). This surface uplift is due to a flexural bulge induced by vertical and horizontal loads associated with the dynamics of the chain (Shiraiwa & Ussami, 1993). In response to the uplift, denudation of a Tertiary and older sedimentary cover has been taken place, producing sedimentary scarps that retreat towards the Brazilian craton, exhuming the Precambrian shield, associated with large areas of Neogene sedimentation (the Pantanal basin). Eastwards to the Pantanal basin, seismological data available for the Parana basin indicate that the Moho is depressed under the centre of the basin and raised towards its erosional borders (fig. 1; Assumpção *et al*., 1997). These observations suggested a continental-scale lithospheric deformation comprising, at least, an antiform at the Pantanal and a synform at the Parana basin. Seismicity, associated with positive residual isostatic anomalies, is concentrated about inflection points between the synform and the antiform, that is, along the erosional borders of the Parana basin. The tendency to buckle is controlled by the previous lithospheric/crustal structure. The advection of mantle materials towards the forming antiforms, associated with denudation is supposed to promote adiabatic decompression, facilitating fusion, and hence, the Upper Cretaceous and Tertiary alkali-magmatism. This tendency is stronger during peaks of the Andean orogeneses.

Therefore, the Parana basin is actually a remnant of a basin which is in *incipient inversion*. In spite of the fact that the deep lithospheric structure below other Brazilian continental basins remains unknown, similar phenomena relating topography, isostatic anomalies, seismicity and denudation have been observed for all these basins. They are

actually *remnants of basins* in *incipient inversion*: their borders are associated with positive isostatic anomalies and frequently with seismicity and are being uplifted and eroded; on the other hand, their axes, along with major rivers flow (*i.e*. the Amazon and the Parana) are subsiding, being sites of sedimentation. An apparent paradox is then systematically produced, the (erosional) borders of the basins being local highs with respect to the adjacent basement (Lima, 1999).

In order to explain this scenario, and mainly this paradox, we propose that in response to the compression, the lithosphere as a whole (or only the crust if thermal gradients are high enough) tends to be folded. The forming antiforms are responsible for uplift along the erosional basin borders, whereas the forming synforms are sites of continental sedimentation, at basin centers. Analogue and numerical models support this interpretation (Lima, 1999).

Here we presented modeling results of an schematic 3000 km-long lithospheric sections, using elasto-plastic rheologies. The section incorporates an initial senoidal Moho topography (with a wavelength of about 2000 km) and, on the other hand, a layered profile of lithospheric strengths. This profile takes into account a strong 15 – 20 km-thick upper crust (including 5 km of sediments), overlying a 20 km-thick very week lower crust, underlain by a 115 km-thick strong upper mantle. The layered lithosphere overlies a 100 km-thick very weak astenosphere (supposed to be attached to the lithosphere (VanDecar et al., 1995 ; Russo & Silver, 1994). Such a profile is supposed to roughly represent a lithosphere submitted to intermediate temperatures (Davy & Cobbold, 1991). We have fixed one end of the section and incrementally applied displacements to the other, up to accumulate a shortening of about 0.25 – 0.30%. This scenario is intended to simulate the action of Andean horizontal loads against the Brazilian craton (western edge of the section) pinned on a fixed and very strong oceanic lithosphere (eastern edge of the section). An average intraplate strain rate of about 6.97 $x10^{-17}$ s^{-1} had been estimated from the shortening measured along the Cachoeria Paulista-Kourou base-line of the DORIS space-based geodetic system (Lima, 1999). Assuming this average intraplate strain can be linearly extrapolated, it would have been accumulated over about 1-2 Ma.

Under the imposed boundary conditions, the deformed models show similarities to nature, imitating the the systematic anticorrelation between topography and structure observed in basins in incipient inversion across South America (fig. 2):

1. Topographic depressions are formed over the original lithospheric antiforms.
2. High elevations are produced over the original lithospheric synforms, mainly on the limbs of the structure.
3. The deformed models underwent uplift as a whole.

We are now testing other boundary conditions. Meanwhile, preliminary results support the idea that ongoing large wavelength lithospheric folding can play an important role in the intraplate deformation, including the observed patterns of uplift/denudation and subsidence/sedimentation, and so help to explain why basement are topographic lows while borders of continental basins are topographic highs, where marine Paleozoic or Aptian sediments are sometimes more than 1000 m-height. Moreover, they also provides insights concerning some of the processes underlying the strong correlation observed between immense flooded lowlands and gravity positive anomalies in the intraplate of South America (fig. 2).

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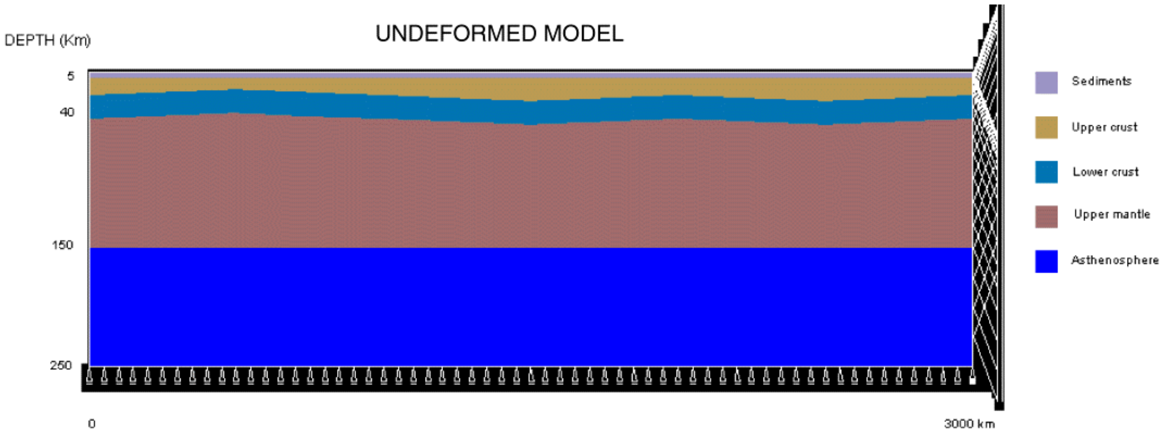
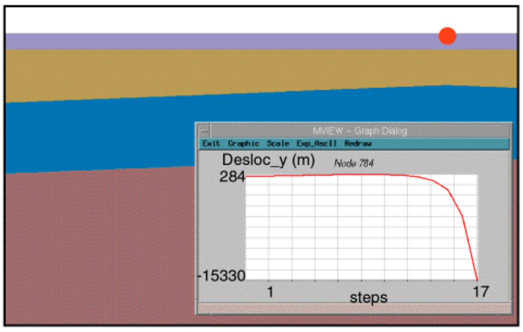
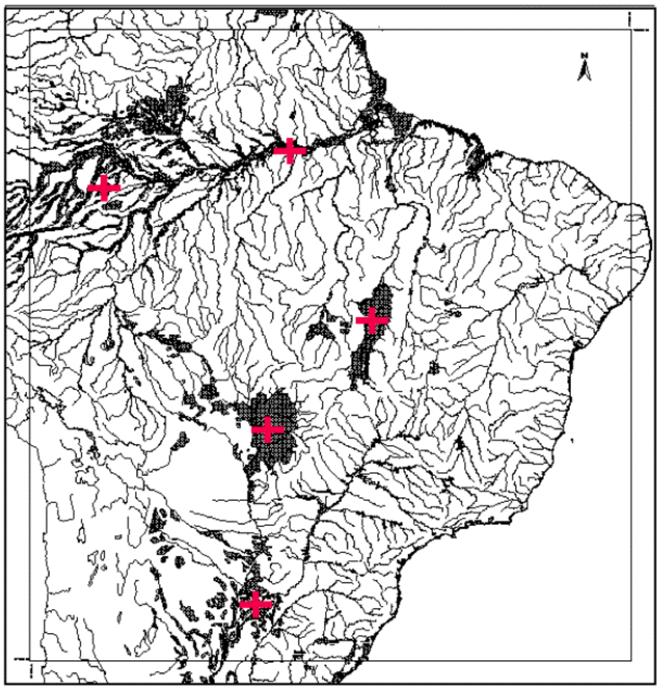


Lithosphere Material Properties

	C(MPa)	ϕ	ν	E(MPa)
Sediment	20	27	0,33	20000
Upper Crust	60	32	0,33	60000
Lower Crust	20	15	0,49	1000
Upper Mantle	60	27	0,33	60000
Asthenosphere	20	0	0,49	1000

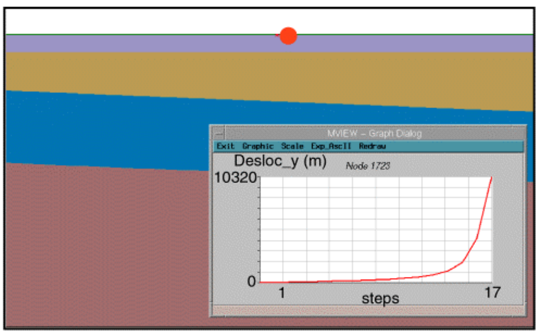
(a) Anticline History





(b) Drainage (flooded areas in black) and some major isostatic anomalies (red crosses; Ussami et al, 1993) in intraplate South America.

(c) Limb History



(d) Syncline History

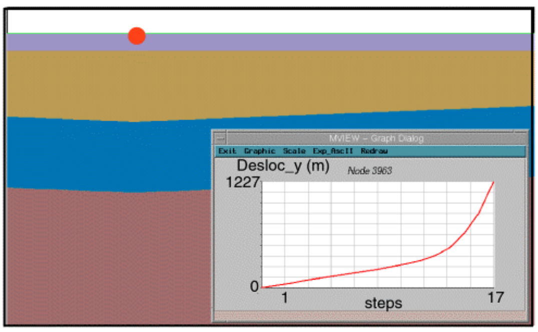


Figure 1. Topography, denudation, seismicity and incipient inversion of continental basins. (Image processing by Cristina M. Bentz, CENPES/DIVEX)

3-D visualization of a digital model (resolution 30 seconds of arc) produced by the USGS and the Earth Resources Observation Systems (EROS). Circles (in white and red) are epicenters (data base furnished by M. Assumpção). Continental seismicity is concentrated where the sedimentary cover has been denudated, adjacent to the raised borders of remnants of basins. These areas are systematically associated with positive isostatic anomalies. The Southeastern Brazilian margin is associated with an important seismicity and Cenozoic tectonic deformation. See how the western border of Brazilian craton (CB) is raised along a line that imitates the Central Andes (AC). The Pantanal basin (QPN) is a breached lithospheric antiform whereas the Parana basin is a lithospheric synform. The axis of this antiform is parallel to plan defined by Gephart (1994) concerning the symmetry of the Andean topographic and of subducting slab and the convergence between Nazca and South America. The abbreviations are: AT, transcontinental alignment of epicenters; PAR, PRC, PRN, PO, SFO, remnants of the continental basins of Parana, Parecis, Parnaiba, Potiguar and São Francisco.

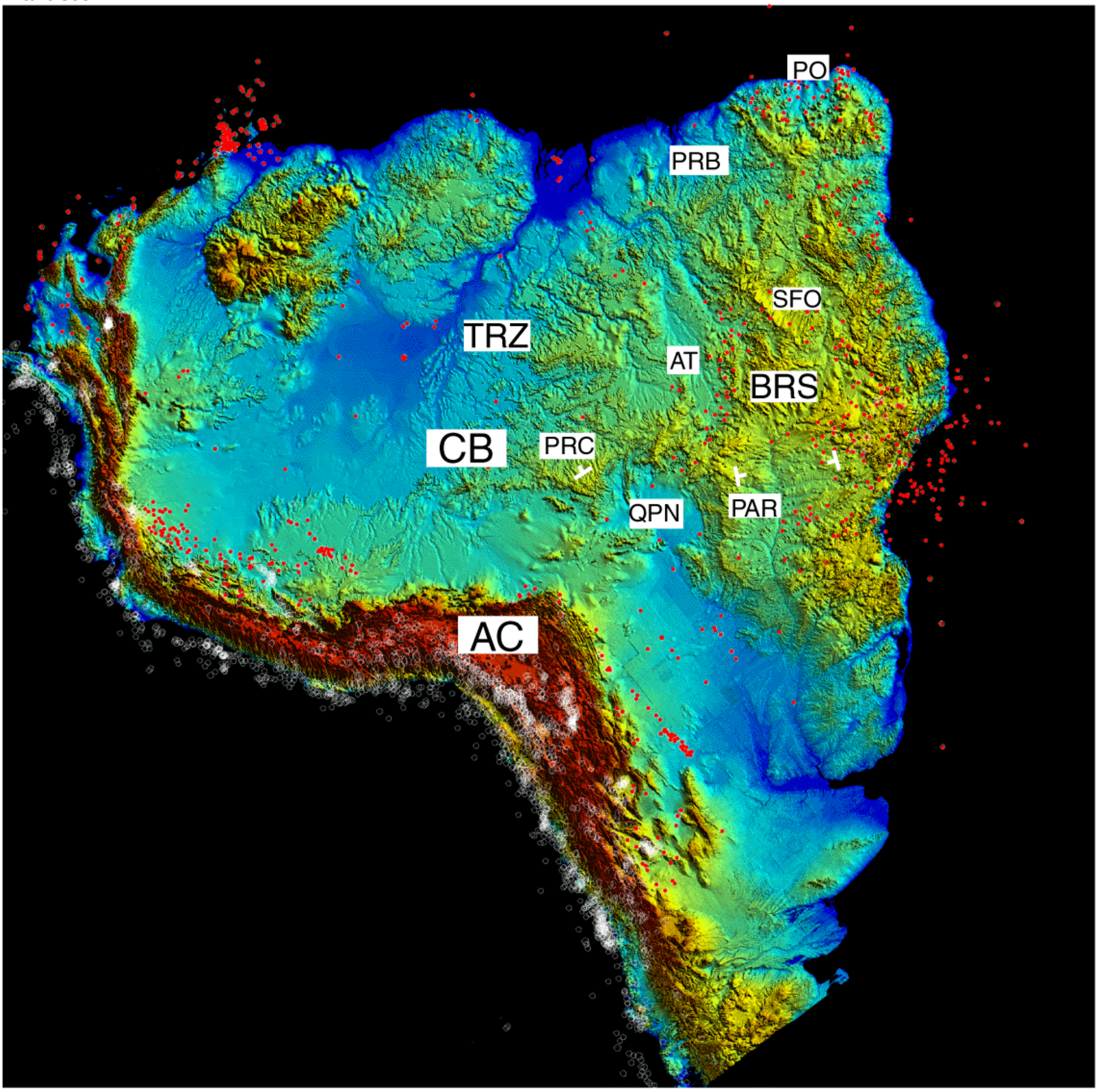


Figure 2. Results of the numerical modeling.

(a) Displacement history of a material point over the anticline hinge line. A small uplift at the first steps is followed by huge subsidence. (b) Intraplate flooded areas are correlated with major positive isostatic anomalies, an observation that is qualitatively consistent with the displacement history of the lithospheric anticline. (c) Displacement history of a material point over the limb between the anticline and the syncline. Here we observed the most important uplift, which is qualitatively consistent with the raised erosional borders of Brazilian continental basins. (d) Displacement history of a material point over the syncline. Less uplift is observed.