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The intraplate Porto dos Gaúchos seismic zone in the Amazon craton — Brazil

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ABSTRACT

The largest earthquake observed in the stable continental interior of the South American plate occurred in Serra do Tombador, Mato Grosso state — Brazil, on January 31, 1955 with a magnitude of 6.2 m_b. Since then no other earthquake has been located near the 1955 epicentre. However, in Porto dos Gaúchos, 100 km northeast of Serra do Tombador, a recurrent seismicity has been observed since 1959. Both Serra do Tombador and Porto dos Gaúchos are located in the Phanerozoic Parecis basin. Two magnitude 5 earthquakes occurred in Porto dos Gaúchos, in 1998 and 2005, with intensities up to VI and V, respectively. These two main shocks were followed by aftershock sequences lasting more than three years each. Local seismic stations have been deployed by the Seismological Observatory of the University of Brasilia since 1998 to study the "Porto dos Gaúchos" seismic zone (PGSZ). A local seismic refraction survey was carried out with two explosions to help define the seismic velocity model. Both the 1998 and 2005 earthquake sequences occurred in the same WSW–ENE oriented fault zone with right-lateral strike-slip mechanisms. The epicentral zone is in the Parecis basin, near its northern border where there are buried grabens, generally trending WNW–ESE, such as the deep Mesoproterozoic Caiabis graben which lies partly beneath the Parecis basin. However, the epicentral distribution indicates that the 1998 and 2005 sequences are related to a N60°E fault which probably crosses the entire Caiabis graben. The 1955 earthquake, despite the uncertainty in its epicentre, does not seem to be directly related to any buried graben either. The seismicity in the Porto dos Gaúchos seismic zone, therefore, is not directly related to rifted crust. The probable direction of the maximum horizontal stress near Porto dos Gaúchos is roughly E–W, consistent with other focal mechanisms further south in the Pantanal basin and Paraguay, but seems to be different from the NW–SE direction observed further north in the Amazon basin. The recurrent seismicity observed in Porto dos Gaúchos, and the large 1955 earthquake nearby, make this area of the Parecis basin one of the most important seismic zones of Brazil.

1. Introduction

Brazilian seismicity is lower than in other mid-plate regions such as Eastern North America, India, and Australia, where magnitudes larger than 7 have been observed, such as in the New Madrid area, USA, (Johnston, 1989; Johnston and Kanter, 1990; Johnston, 1996a,b; Gangopadhyay and Talwani, 2003; Schulte and Mooney, 2005). Mid-plate earthquakes in Brazil have not exceeded magnitude 6.2 m_b but intensities up to VI or VII are not uncommon and make seismic risk evaluation an important issue in projects of critical facilities such as nuclear installations. Models to explain intraplate earthquakes were proposed, for example, by Sbar and Sykes (1973), Sykes (1978), Talwani (1989), Talwani and Rajendran (1991) and Kenner and Segal (2000). Intraplate earthquakes appear to result from ruptures in weakness zones or from stress concentration. The proposed models try to correlate intraplate earthquakes with geological features that could indicate zones of crustal weakness such as extended crust in aborted rifts or continental margins (Johnston, 1989; Johnston et al., 1994), or with structural inhomogeneities, which could concentrate stresses in the upper crust (e. g., Sykes, 1978; Talwani, 1989, 1999; Talwani and Rajendran, 1991; Kenner and Segal, 2000; Assumpção et al., 2004).

Schulte and Mooney (2005) compiled an intraplate earthquake catalogue (magnitude ≥4.5) for stable continental regions (SCRs), and compared the data with a global catalogue of rifts (Sengör and Natal'in, 2001). 27% of the earthquakes fell in interior rifts/taphrogens, 25% were in rifted continental margins, and 36% occurred in non-rifted crust (the remaining 12% were uncertain). These numbers are similar to those presented in previous studies (Johnston and Kanter, 1990; Johnston et al., 1994), who found that 56% of all SCR earthquakes are associated with extended crust (interior rift and rifted continental margins). However, according to Schulte and Mooney (2005), if we

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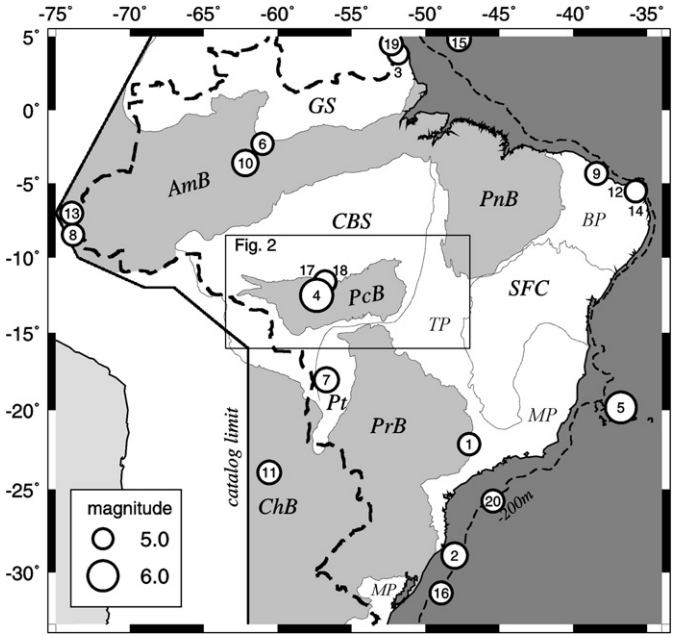

Fig. 1. Brazilian earthquakes with magnitudes ≥5.0 m_b since 1922, numbered as in Table 1. Circle sizes vary with the magnitudes. Lines show the main Brazilian geological provinces (Almeida et al., 2000): GS and CBS denote the Guyana and Central Brazil shields, respectively (which compose the Archean to Mesoproterozoic Amazon craton); Phanerozoic basins are: AmB Amazon Basin; ChB Chaco Basin; PnB Parnaiba Basin; PcB Parecis Basin; PrB Paraná Basin; Pt Pantanal Basin; SFC is the Archean to Mesoproterozoic São Francisco Craton. Neoproterozoic/Paleozoic foldbelts are: BP Borborema, TP Tocantins, and MP Mantiqueira Provinces. The dashed line offshore is the 200 m bathymetry. Thick dashed line is the Brazilian border. Epicentres from the catalogue of Berrocal et al. (1984), USGS bulletins and the references cited in Table 1.

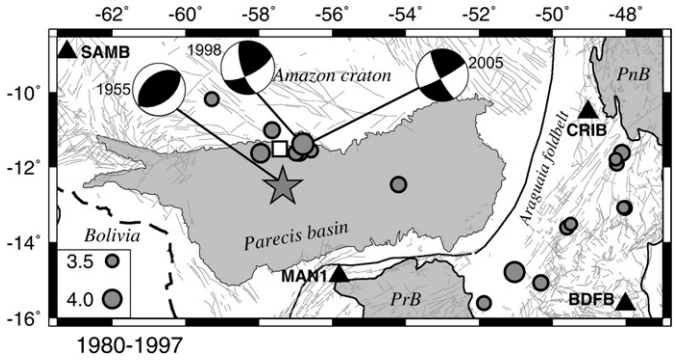

Fig. 2. Regional seismicity from 1980 to 1997 for magnitudes larger than 3.5 (circles). The source of epicentres is the catalogue of Berrocal et al. (1984) complemented with the Brazilian Seismic Bulletins published by the Brazilian J. of Geophysics. Epicentral uncertainties are a few tens of kilometers. The star denotes the large 1955 earthquake. The triangles are the permanent seismic stations in operation since the early 80s. The focal mechanism solutions shown in this figure, as well as in subsequent figures, are for the 1955 earthquake (Mendiguren and Richter, 1978), and the 1998 and 2005 sequences (this paper). Light gray areas are sedimentary basins; dark gray lines are geological lineaments (CPRM, 2001) and thick solid lines are the limits of the main geological provinces from Fig. 1. The square indicates the town of Porto dos Gaúchos. The SW–NE oriented lineaments south of station CRIB are called TransBrasiliano Lineaments.

consider continental interior earthquakes only and exclude continental margin events, it is observed that non-rifted crust has experienced more earthquake than rifted crust. So, on a global scale, the correlation of seismicity within SCRs and ancient rifts may have been overestimated in the past. Schulte and Mooney's (2005) new catalogue increased the previous one in 58% and has more reliable data covering the period of 1994 to 2003. However, Schulte and Mooney's results agree with previous studies for earthquakes with magnitudes larger than 6.0: most of them are associated with extended crust (interior rift and rifted continental margins). The earthquakes in non-rifted crust occur mainly in Precambrian basement (Gangopadhyay and Talwani, 2003).

Fig. 1 and Table 1 show all known Brazilian intraplate earthquakes with magnitudes 5.0 m_b and above. Half of the epicentres (10 out of 20) lie close to the coast and the continental shelf and have been attributed to a combination of weakness zones (extended crust beneath the continental shelf) and amplification of the regional stresses due to local forces such as crustal inhomogeneities at the continent/ocean transition and flexural stresses (e.g., Johnston and Kanter, 1990; Assumpção, 1998a; Ferreira et al., 1998). Of the remaining epicentres in the continental interior, three are located in the centre north of the Parecis basin, including the large 1955 Serra do Tombador earthquake (event 4). The epicentral area of this earthquake was uninhabited in 1955, and the maximum epicentral intensity has been tentatively inferred as IX MM (Berrocal et al., 1984) or VIII MM (Johnston, 1989).

Table 1
Brazilian earthquakes with magnitudes ≥5.0 m_b since 1922.

Event number	Date mm/dd/yyyy	Origin time (UT)	Epicentre Latitude	Epicentre Longitude	Depth	Epicentral error (km)	Location	Magnitude	Source
1	01/27/1922	06:50:40	−22.17°	−47.04°	N	40	Mogi Guaçu/SP	5.1	1
2	06/28/1939	11:32:22	−29.00°	−48.00°	N	90	Tubarão/SC	5.5	1
3	09/17/1949	–	03.83°	−51.84°	N	100	Oiapoque/AP	5.0	1
4	01/31/1955	02:03:07	−12.52°	−57.35°	N	30	Serra do Tombador/MT	6.2	2
5	28/02/1955	22:46:18	−19.84°	−36.75°	N	30	offshore Vitória/ES	6.1	2
6	12/13/1963	21:05:42	−02.30°	−61.01°	45	30	Manaus/AM	5.1	3
7	02/13/1964	08:21:46	−18.06°	−56.69°	5	30	NW of Mato Grosso do Sul	5.4	3
8	08/09/1967	07:14:08	−08.45°	−73.83°	42	30	Peru–Brazil/AC	5.1	8
9	11/20/1980	00:29:42	−04.30°	−38.40°	5	10	Pacajus/CE	5.2	4
10	08/05/1983	03:21:42	−03.59°	−62.17°	23	20	Codajás/AM	5.5	3, 4
11	04/12/1985	11:34:57	−23.94°	−60.55°	21	30	Paraguay	5.3	8
12	11/30/1986	02:19:50	−05.53°	−35.75°	5	10	João Câmara/RN	5.1	5
13	10/24/1987	21:23:40	−07.01°	−73.94°	N	30	Peru–Brazil	5.2	ISC
14	03/10/1989	01:11:21	−05.46°	−35.69°	5	10	João Câmara/RN	5.0	6
15	04/12/1989	04:09:29	04.80°	−47.72°	N	30	N. Atlantic shelf	5.3	ISC
16	02/12/1990	20:56:39	−31.19°	−48.92°	13	30	Cont. Shelf/RS	5.2	7
17	03/10/1998	23:32:44	−11.53°	−56.86°	3	5	Porto dos Gaúchos/MT	5.2	This study
18	03/23/2005	21:12:13	−11.60°	−56.77°	3	5	Porto dos Gaúchos/MT	5.0	This study
19	06/08/2006	16:29:13	04.66°	−51.90	N	20	French Guyana	5.1	USGS
20	04/23/2008	00:00:48	−25.74°	−45.42 °	17	20	Cont. Shelf/SP	5.2	USGS, USP

Sources: 1 — Berrocal et al. (1984); 2 — Relocated by Enghdal 2002; 3 — Assumpção and Suarez (1988); 4 — Assumpção et al. (1985); 5 — Ferreira et al. (1987); 6 — Takeya et al. (1989); 7 — Assumpção (1998a); 8 — Assumpção (1992). USP = University of São Paulo.