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Seismic Activity in Brazil in the Period 1560–1980

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Abstract. Most of the Brazilian territory occupies the South American pre-cambrian shields, having a low level of seismic activity typical of intraplate regions. Earthquakes occurring in Brazil since 1560 have been analysed in the present study by using, in most cases, macroseismic data contained in historical documents, newspaper reports and early compilations of Brazilian tremors published since 1859. Original reports were consulted, whenever possible, in order to define the seismic parameters of these events. For some significant events occurring during the last 100 years further search was carried out in the localities where the tremor was felt, obtaining additional information from local newspaper or through personal reports of some witnesses. This permitted the construction of isoseismal maps and definition of felt areas. Instrumental data has been used for more recent events, especially those occurring after 1975 when most of the Brazilian seismographic stations were installed.

During the period of study, not a single catastrophic seismic event has occurred in Brazil and few events have produced intensities up to VII MM, causing more emotional effects and concern than any considerable material damage. Most of the reported events were tremors felt mainly near the Atlantic coast line, which is also the region with the highest population density. A list of all seismic events collected in this study includes an evaluation of the type of each event and in some cases values of intensity and magnitude, and information of the date and place of occurrence. These events were plotted on a tectonic map of Brazil in order to correlate the seismic activity with the main tectonic features of the Brazilian territory.

1. Introduction

Interest in Seismology, as well as in other branches of Geophysics, has significantly increased in Brazil during the 1970s. The establishment of the Brazilian Nuclear Programme and the impounding of large water reservoirs during those years has given great impulse to the development of Seismology in Brazil. These projects required a better knowledge of the seismic activity in different regions of the Brazilian territory in order to determine the existing seismic risk, as well as propitiate the installation of seismographic stations in those regions.

The main results of the compilation of seismic activity in Brazil until 1980 are presented in this paper. This compilation was carried out by the Instituto Astronômico e Geofísico (IAG) of the Universidade de São Paulo by using macroseismic and instrumental data.

The main objective of this research was to compile the greatest possible amount of information about seismic events occurring in Brazil, which covered a large number of books, newspapers, journals and seismic bulletins, some of them very old editions,

in order to determine the actual level of seismic activity in the Brazilian territory.

In spite of efforts to make this compilation as complete as possible there may exist information about other Brazilian earthquakes not included in this work, also macroseismic information contained in publications not yet consulted by the authors and instrumental data recorded by some Brazilian seismographic stations which is not yet published.

One of the tasks was to estimate the intensity and/or magnitude and the probable epicentre of the Brazilian earthquakes by using the macroseismic data compiled in the present work. During the detailed analysis of the compiled data the information corresponding to some events was questioned, both in relation to the date of occurrence and in relation to the localities affected and observed effects. In several cases errors were found in published compilations and in some cases data from different sources, supposedly attributed to different events, were in fact referring to the same event.

Some historical reports which give account of incredible effects caused by probable earth tremors and especially sensationalist newspaper information have been subjected to careful scrutiny by the authors in order to arrive at a consensus on the interpretation of the data. Thus the results obtained in this work is the outcome of a careful analysis of the existing macroseismic data and represents in almost all cases the interpretation of the authors. It must be remembered in addition that intensity evaluation from macroseismic data is rather subjective and therefore, some results obtained in this work may not coincide with those obtained by other researchers from interpretation of the same collected information.

For events with instrumental data there is less controversy, specially for more recent events recorded by Brazilian seismographic stations.

2. Data Source and Quality

Most events studied in this research have been obtained from macroseismic information, specially those occurring before 1975 when the number of seismographic stations in Brazil was very small.

The utilization of macroseismic information apart from being the only way to study old seismic events is also useful in studying more recent earthquake in regions with a low density of seismographic stations. Sometimes when instrumental data from local stations is not available, the epicentre inferred from macroseismic information is more precise than that calculated from teleseismic instrumental data. Besides, macroseismic information permits the construction of isoseismal lines, the shape and size of which are related to the depth, magnitude and focal mechanism of the earthquake, as well as to the geological and tectonic features of the affected area. In some regions with low level of seismic activity and without strong motion records, the parameters used in engineering seismology, to develop design earthquake response spectra, are mainly obtained from macroseismic information.

In this research, all published compilations on Brazilian seismicity were consulted, among which the most important are those of CAPANEMA (1859), GAMA (1910), BRANNER (1912, 1920), SADOWSKI *et al.* (1978) and HABERLEHNER (1978). Seismicity studies

belonging to particular regions of Brazil were also consulted, such as those of SILVEIRA (1906, 1920) for Bom Sucesso, state of Minas Gerais, SAMPAIO (1916, 1919, 1920) for Recôncavo Baiano, state of Bahia, and STERNBERG (1953) for the Amazonian region.

Whenever possible, the original information sources mentioned in those compilations were consulted. Many events, especially those occurring during the present century, are described in newspapers, both of local or of national circulation. To get all this information it was necessary to consult libraries and newspaper archives in the capital and other towns of the states of São Paulo, Rio de Janeiro, Minas Gerais, Rio Grande do Sul, Santa Catarina, Paraná, Espírito Santo, Bahia, Pernambuco, Rio Grande do Norte and Ceará. During visits to these places, it was also possible to collect personal reports from witnesses of some recent tremors.

For several earthquakes it was possible to compile enough macroseismic information to determine the epicentre and to define the area where the tremor was felt. In some cases it was possible to draw isoseisms. However, in most cases there is not enough information for a detailed macroseismic study. There are still some cases for which the information is so vague that the very occurrence of such events could be questioned.

All original macroseismic information, which was usually in journalistic style mixed with irrelevant information, were condensed in short descriptions, containing only the relevant data. These descriptions can be found in BERROCAL *et al.* (1983).

Instrumental information was obtained from different sources. Older Brazilian earthquakes occurring during the period 1913–1963, were compiled from ISS bulletins, some of which had their locations revised by GUTENBERG and RICHTER (1954) and ROTHÉ (1969), and CGS epicentral determinations. More recent events were compiled from CGS and GS determinations (contained in the "Earthquake Data File Summary" compiled by the U. S. National Geophysical and Solar-Terrestrial Data Center) and from ISC bulletins. Smaller magnitude events recorded by Brazilian stations after 1967 have been located by the Estação Sismológica de Brasília (ESB) and by IAG. The quality of the instrumental data is represented by the assumed error of the epicentral determinations given in Table 1.

3. Compiled Data

In the present work, macroseismic information covering 460 probable seismic events was compiled. In some cases one reference may represent more than one probable earthquake and in a few other cases may represent even swarms of small tremors or seismic noises.

From this total, 26 references correspond to repeated information referred to already listed events or to misinformation and transcription errors, 21 belong to effects of large Andean earthquakes felt in Brazilian territory (as east as São Paulo), and 69 descriptions were questioned and considered as doubtful seismic events. There remain, therefore, only 347 descriptions belonging to reliable earth tremors occurring in Brazil during the period studied. Some of these earthquakes were also recorded by international network stations and more recent ones by Brazil stations.

Table 1. Earthquakes Occurred in Brazil up to 1980 with $m_b \geq 4.0$ or Intensity $\geq$ V MM.

Date			Local time			Coordinates		E km	Locality	S	MM Int.	CAT	Magnit.		Area 10^3 km^2	Comments (source)
Y	M	D	H	M	S	Lat.	Long. W						m_b	type		
1767	08	01	20			20.31S	40.33		VITÓRIA	ES	V	C				EPI. AT Vit.—Trindade high?
1789	05	09				25.01S	47.94		CANANÉIA	SP	V–VI	C				
1808	08	08	08			05.70S	37.70	100	AÇU	RN	VI	B	4.8	4	230.0	
1811	10	28	19	30		08.08S	34.87	50	RECIFE	PE	V	C				
1811			20			30.04S	51.30		PORTO ALEGRE	RS	V	C				Doubtful EPI.
1854	01	10	07			05.20S	35.46	50	TOUROS	RN	V–VI	C				
1855	07	25	06						S. J. M. GRANDE	MG	V	C				S. J. B. Da Glória
1861	07	31	01			22.60S	45.20	50	LORENA	SP	V	B	4.5	4	52.0	
1871	04	05	01	30		03.40S	44.35		ITAPICURU-M.	MA	V–VI	C				
1874	10	30	09	30		23.50S	47.50	10	SOROCABA	SP	V	B	3.6	4	1.7	
1879	03	01				15.60S	56.10		CUIABÁ	MT	V	C				
1879	07	24	17	25		05.77S	35.21	20	NATAL	RN	V	C	3.3	4	0.7	
1886	05	09	15	15		22.66S	43.69	20	S. PEDRO-S. P.	RJ	V	A	4.2	4	23.0	
1899	12					13.03S	39.60		AMARGOSA	BA	V	C				
1903	02	10				04.38S	38.97	30	BATURITÉ	CE	VI	C	3.9	4	5.5	
1903	02	12				04.38S	38.97	30	BATURITÉ	CE	VI	C	3.9	4	5.5	
1903	02	14				04.38S	38.97	30	BATURITÉ	CE	VI	C	4.1	4	12.0	
1903	02	15				04.38S	38.97	30	BATURITÉ	CE		C	4.1	4	12.0	
1903	02	16				04.38S	38.97	30	BATURITÉ	CE	VI	C	4.1	4	12.0	
1905	07	18	19	30		10.20S	40.40	100	S. DO BONFIM	BA	V	B	4.8	4	180.0	Year uncertain 1904?
1905			12	30	0	11.20S	42.30	100	XIQUE-XIQUE	BA	IV	B	4.7	4	140.0	
1906	10	24	23	52		19.00S	57.64		CORUMBÁ	MS		C	4.2	4	20.0	Registered by RDJ
1911	03	22	15			12.92S	38.67	20	ITAPARICA	BA	VII	C	3.3	4	0.7	
1912	04	19	05			13.20S	38.89		BR. JEQUIRIÇÁ	BA	V–VI	C				
1915	11	06	15	30		12.67S	38.63	20	I. DAS FONTES	BA	VI	B				
1917	05	05	04	50		21.60S	41.50	50	CAMPOS	RJ	V	B	4.5	4	70.0	
1917	11	07	20	25		12.48S	38.66	10	RIO FUNDO	BA	VI–VII	B	4.3	4	28.0	
1918	01	12	08			12.45S	38.62		RIO FUNDO	BA	V–VI	C				Two shocks
1919	06	01	18	30		18.00S	56.00	100	CORUMBÁ	MS	V	C	4.9	4	280.0	Felt at STA. LUZIA—GO?
1919	11	13				12.55S	38.70		SANTO AMARO	BA	V	C				Two shocks
1919	11	23	01	20		12.65S	38.62	10	M. RECONCAVO	BA	VII	B	4.0	4	8.0	
1919	11	24	03			03.87S	38.92	50	MARANGUAPE	CE	IV	B	4.5	4	70.0	
1920	01	31	08	10		21.03S	44.75	10	BOM SUCESSO	MG	VI	B	4.0	4	9.5	
1922	01	27	03	50	40	22.17S	47.04	40	MOGI GUAÇU	SP	VI	A	4.9	4	250.0	
1928	04	14	21	59		04.56S	37.76		ARACATI	CE	VI	C	4.0	4	10.0	Approx. felt area

1935	10	21	07	40		21.03S	44.75	10	BOM SUCESSO	MG	V–VI	C	3.7	4	2.8	
1939	06	28	08	32	27	29.11S	49.09	50	TUBARÃO	SC	VI	A	5.4	3	1400.0	Origin time and MAG (G—R)
1941	04	05	07	30		16.45S	54.64		RONDONÓPOLIS	MT	V	C				Probable date 11.04.41
1946	07	18	04	15		25.10S	47.70	30	CANANÉIA	SP	IV–V	A	4.5	4	60.0	
1949	09	17				03.83N	51.84	100	OIAPOQUE	AP	IV	C	5.0	4	450.0	
1949	12	31				05.69S	36.24		LAJES	RN	VI	C				
1950	02	27				21.82S	46.71	20	P. DE CALDAS	MG	V	C	3.9	4	6.0	
1951	04	24				03.83N	51.84		OIAPOQUE	AP	IV	C	4.7	4	150.0	
1954	03	28	16	20	58	07.50S	73.50	100	NW ACRE	AC		I	5.0	5		h=100 km (CGS)
1955	01	31	02	03	02	12.50S	57.40	100	SA. TOMBADOR	MT		I	6.0	3		M(PAS) 6.8; M(BCI) 6.6 Infered I_o=VIII MM
1955	02	28	22	46	13	19.90S	36.70	100	FTE. VITÓRIA	ES		A	5.6	3		(ISS)VITÓRIA V MM, Infered I_o=VIII MM
1957	04	16	15	17	12	09.50S	67.00	50	SUL AMAZONAS	AM		I	5.0	5		(CGS)
1960	05	12	09	09	24	09.00S	72.50	50	W ACRE	AC		I	5.0	5		h=60 km (CGS)
1960	10	21	01	18	44	07.20S	73.80	50	NW DO ACRE	AC		I	5.0	5		h=100 km (CGS)
1961	10	03	17	35	54	00.40N	63.00	100	N AMAZONAS	AM		I	4.0	0		(TRN)
1962	01	16	23	27	44	22.93S	43.23	3	R. DE JANEIRO	RJ	V	B	3.1	4	0.3	
1963	08	27				05.69S	36.24		LAJES	RN	V–VI	C				
1963	10	02				05.69S	36.24		LAJES	RN	VI	C				
1963	12	13	21	05	40	02.30S	61.20		MANAUS	AM		C	4.8	0		h=36 km (GS)
1964	01	19	11			08.28S	35.96		CARUARU	PE	V	C				Three shocks
1964	02	13	08	21	44	18.05S	56.75	30	NW DE MS	MS		I	5.5	0		h=16 km (ISC)
1964	06	16				08.28S	35.96		CARUARU	PE	V	C				Several shocks
1965	06	26	02	55	13	09.14S	73.07	50	W ACRE	AC		I	4.5	0		h=52 km (ISC)
1965	08	15	16	36	57	02.71N	60.24	30	SE DE RR	RR		I	5.0	0		h=42 km (ISC)
1967	01	21	15	59	48	08.20S	35.98	10	CARUARU	PE	V	B	3.9	1	7.0	(NAT)
1967	03	22	21	12	15	23.30S	45.00	20	CUNHA	SP	VI–VII	A	4.4	4	30.0	
1967	05	11	23	21	43	07.17S	73.30	50	SW DO AM	AM		I	4.4	0		h=73 km (ISC)
1967	08	05	06	56	10	22.85S	43.12	10	SÃO GONÇALO	RJ	V–VI	B	3.7	1	2.7	
1968	01	12	22	55	51	06.09S	38.44	10	PEREIRO	CE	VI	C	3.9	2	25.0	(NAT)
1968	01	18	07	40		06.09S	38.44		PEREIRO	CE	V	C				Day uncertain
1968	02	15	10	20	48	06.09S	38.44	10	PEREIRO	CE	VI	B	4.1	2	11.0	(NAT)
1968	02	23	11	23	02	06.09S	38.44	5	PEREIRO	CE	VII	A	4.5	2	84.0	(NAT, IAG, ISC)
1968	03	18				06.04S	38.46		PEREIRO	CE	V–VI	C				
1968	08	27	02	17	36	08.90S	72.89	30	W DO ACRE	AC		I	4.8	0		h=50 km (ISC)
1969	07	16				18.18S	42.41		S. M. SUAÇUI	MG	VII	C				Very shallow focus?
1970	01	12	01	43	08	01.32S	48.48	30	BELÉM	PA	VI–VII	B	4.5	2	10.0	(ISC, IAG, ESB), +4 Shocks
1970	01	29				07.96S	36.21		S. C. CAPIBARI	PE	VI	C				Two shocks

Table 1(continued).

Date			Local time			Coordinates		E km	Locality	S	MM Int.	CAT	Magnit.		Area 10^3 km^2	Comments (source)
Y	M	D	H	M	S	Lat.	Long. W						m_b	type		
1970	01	30				07.96S	36.21		S. C. CAPIBARI	PE	V	C				
1970	02	06	08			18.44S	42.59		S. P. SUAÇUI	MG	VII	C				Very shallow focus?
1970	03	29	05	27	48	08.29S	73.38	50	SA. DIVISOR	AC		I	4.3	0		h=25 km (ISC)
1970	11					06.93S	35.53		ALAGOINHA	PB	VI	C				
1970	12					20.28S	44.75	3	C. DO CAJURU	MG	IV	B	3.3	4	0.7	Reservoir induced
1971	03					25.20S	48.90		CAPIV-CACHOE	PR	V-VI	C				Several; reservoir induced
1971	05	21	13			25.20S	48.90		CAPIV-CACHOE	PR	VI	C				Reservoir induced
1971	08	04	23	30		08.04S	34.90		RECIFE	PE	V	C	3.0	5		5 shocks, (BERROCAL, 1974)
1971	08	08	10	32	39	20.28S	44.75		C. DO CAJURU	MG	V-VI	C	3.6	5		Reservoir induced
1972	01	23	00	03	51	20.28S	44.75	5	C. DO CAJURU	MG	VI	B	3.8	1	3.2	Reservoir induced
1972	03	04	18	45		09.93S	36.49		JUNQUEIRO	AL	V	C	3.3	4	0.7	
1972	08					16.42S	41.64		TUPARECE	MG	VI	C				Several shocks
1972	10	24	12	36	36	21.80S	40.50	20	CAMPOS	RJ	V	A	5.0	2	210.0	(NEIS, ISC, IAG)
1973	07	20	10	35	25	05.28S	35.82		PARAZINHO	RN		I	4.0	1		(NAT)
1973	07	22	18	22	50	05.28S	35.82		PARAZINHO	RN	VI-VII	B	4.4	2	25.0	(NAT) (LAO m_b=4.1)
1974	02	24	00	19	40	20.04S	48.47		CONC. ALAGOAS	MG	VI-VII	B	4.3	1	7.0	Reservoir induced
1974	02	27				20.04S	48.47		CONC. ALAGOAS	MG	V	C				Reservoir induced
1974	03	02	15	15		20.04S	48.47		CONC. ALAGOAS	MG	V	C				4 Shocks, reservoir induced
1974	03					04.18S	38.13		BEBERIBE	CE	V	C				Several shocks
1974	04	11				16.42S	41.64	5	TUPARECE	MG	VI-VII	C	3.7	4	2.8	~200 shocks in April 74
1974	10	20	18	37	32	07.99S	36.06	10	TORITAMA	PE	V	C	3.7	1	0.5	(NAT)
1974	12	15	02	14	46	03.67S	39.24		S. L. DO CURU	CE	VI	C	3.4	1		(NAT)
1976	02	22	00	24	50	00.34N	59.33	30	SE RORAIMA	RR		I	4.9	0		h=33 km (GS)
1976	04	16				22.73S	50.98		B. CAPIVARA	PR	V-VI	C				Reservoir induced
1976	05	18	05	30		14.88S	39.63	20	IBICARAI	BA	VI	B	3.7	4	2.7	
1976	05	25	05	30		14.76S	39.57	20	COARACI	BA	VI	B	3.9	4	6.3	Two shocks
1976	06	12				22.84S	51.01		PRIM. DE MAIO	PR	V-VI	C				Reservoir induced
1976	06	13	02			22.84S	51.01		PRIM. DE MAIO	PR	V-VI	C				Reservoir induced
1976	06	16	17			22.84S	51.01		PRIM. DE MAIO	PR	VI	C				5 Shocks, reservoir induced
1976	06	21	22	48		22.84S	51.01		PRIM. DE MAIO	PR	V	C				24 Shocks, reservoir induced
1976	07	29	15			04.83S	38.80		IBARETAMA	CE	V	C				Other shocks later
1976	08	11	17			14.84S	39.60		IBICARAI	BA	V	C				
1976	10	08	17	05	24	02.00S	59.30	100	NE AMAZONAS	AM		I	4.1	5		(VELOSO and MENDIGUREN, 1980b)
1977	02	25	10	40		05.71S	35.75	10	RIACHUELO	RN	VI-VII	B	3.5	4	1.4	Three more shocks

1977	03	12	04			04.83S	38.80		IBARETAMA	CE	VI	C				
1977	08	02	14	45	52	00.03S	50.06	30	N. I. MARAJÓ	PA		I	4.8	0		h=33 km (ISC)
1978	02	14				06.28S	36.03	15	SANTA CRUZ	RN	V	B	3.7	4	2.4	Day uncertain; More shocks
1978	04	18				10.89S	61.94		JI-PARANÁ	RO	V	C				
1979	03	27	09	54	45	22.84S	51.01	5	PRIM. DE MAIO	PR	V–VI	A	3.7	1	1.3	Reservoir induced
1979	12	20	21	23	34	00.50N	60.00	100	SUL RORAIMA?	RR		I	4.0	5		(VELOSO and MENDIGUREN, 1980a)
1980	03	06	06	46	15	06.09S	71.18	30	W AMAZONAS	AM		I	5.0	0		h=42 km (GS)
1980	05	22	12	30		26.99S	48.62		B. CAMBORIU	SC	V	C	2.5	5	0.5	Several shocks
1980	11	12	18	23	04	08.04S	50.14	20	REDENÇÃO	PA	V–VI	C	4.8	2		(IAG; GS m_b=5.0)
1980	11	20	00	29	46	04.30S	38.40	10	PACAJUS	CE	VII	A	5.2	2	1000.0	(IAG; GS m_b=5.0)
1980	12	14				16.60S	56.20		SA. S. VICENTE	MT	V	C	3.6	4	2.0	(IAG)

E: error in epicentral determination.
S: Brazilian State.
MM Int.: Modified Mercalli Intensity.
CAT: seismic event category.
A, B, C (see text), I: instrumentally located epicentre.
Magnit. type: Type of magnitude.
0: m_b from teleseismic data (NEIS, ISC).
1: m_R, value corresponding to m_b determined with data from local and regional stations (see text).
2: average between m_b and m_R values.
3: m_b deduced from M_S (see text).
4: m_b calculated from felt area (see text).
5: m_b inferred value.
EPI.: Epicentre.
h: focal depth.
M: M_S.
I_o: epicentral intensity.
Source: Source of instrumental locations.
BCI: Bureau Central International Seismologique.
CGS: United States Coast and Geodetic Survey.
ESB: Estação Sismologica de Brasília.
G-R: GUTENBERG and RICHTER (1954).
GS: United States Geological Survey.
IAG: Instituto Astronômico e Geofísico.
ISC: International Seismological Centre.
ISS: International Seismological Summary.
NEIS: National Earthquake Information Service.
LAO, NAT, PAS, RDJ, TRN: stations code.

The first report on seismic activity in Brazil belongs to a phenomenon occurring in 1560 when a "horrible earth tremor" was reported at the same time that a strong storm hit the town of São Vicente, São Paulo state (VASCONCELLOS, 1865). As the report gives more emphasis to the storm and its effects, the occurrence of a true seismic event is doubtful, as remarked by GAMA (1910).

Two other events, which were attributed catastrophic events, may also be questioned. The first one occurred in June 1690 near the mouth of the Rio Negro, close to the present city of Manaus (FRITZ, 1917): an earth tremor was described as having occurred at the same time that a hurricane and a "horrible surge" of the Amazon river, causing the destruction of nearby forests with large trees uprooted and thrown into the river, the fall of big pieces of rocks and of elevated ground. It was reported that the tremor was also felt on the island of Omaguas (50 km South of the present city of Iquitos, Perú), 1800 km away from the probable epicentre. One possible interpretation is that if it really was an earthquake it was not responsible for the described effects and neither could it be felt at such long distances, the tremor felt in Perú being the effect of a closer event occurring at about the same time.

The other event occurred during the night of November 11th, 1872, close to the town of Serro in the state of Minas Gerais, when earth tremors were felt and landslides occurred, after a prolonged storm, causing the Peixes river to rise 12 metres above its natural level (VEIGA, 1926). One possible interpretation of this phenomenon is that the effects described, including people killed, large loss of property and several other landslides, might have been mostly caused by the overflow of the natural dam formed by the first landslides. The earth tremors could have induced the landslides or, alternatively, they were only vibrations caused by the landslides. In any case they were local seismic events of small magnitude felt only in the epicentral area.

Among the doubtful seismic events there are those including descriptions of associated phenomena such as sea flows, landslides, emanation of gases, appearance of lights, etc., without mentioning clearly the occurrence of earth tremors. There are still some cases of strange phenomena of earth tremors felt at almost the same time in places located hundreds of kilometers away from each other, without being felt in the localities in between, or earch tremors associated with probable explosions or other cultural activities.

The remaining 345 macroseismic quotations belonging to reliable earthquakes have been divided into three groups:

Group A: Earthquakes with enough macroseismic information to draw isoseismal lines and to determine their epicentres accurately (10 events).

Group B: Earthquakes with reasonable macroseismic information to define the area where the events were felt and to determine their epicentres with acceptable accuracy (26 events).

Group C: Earthquakes with information about their occurrence, which in some cases permit intensity evaluation and in some the determination of felt areas or epicentres, however, without accuracy (309 events).

Isoseisms belonging to some typical earthquakes of Group A are shown in the maps of Figs. 1 to 4. In Fig. 1 is plotted the data collected for an old event (May 9th, 1886) occurring in the souhthern portion of the Rio de Janeiro state. Isoseisms

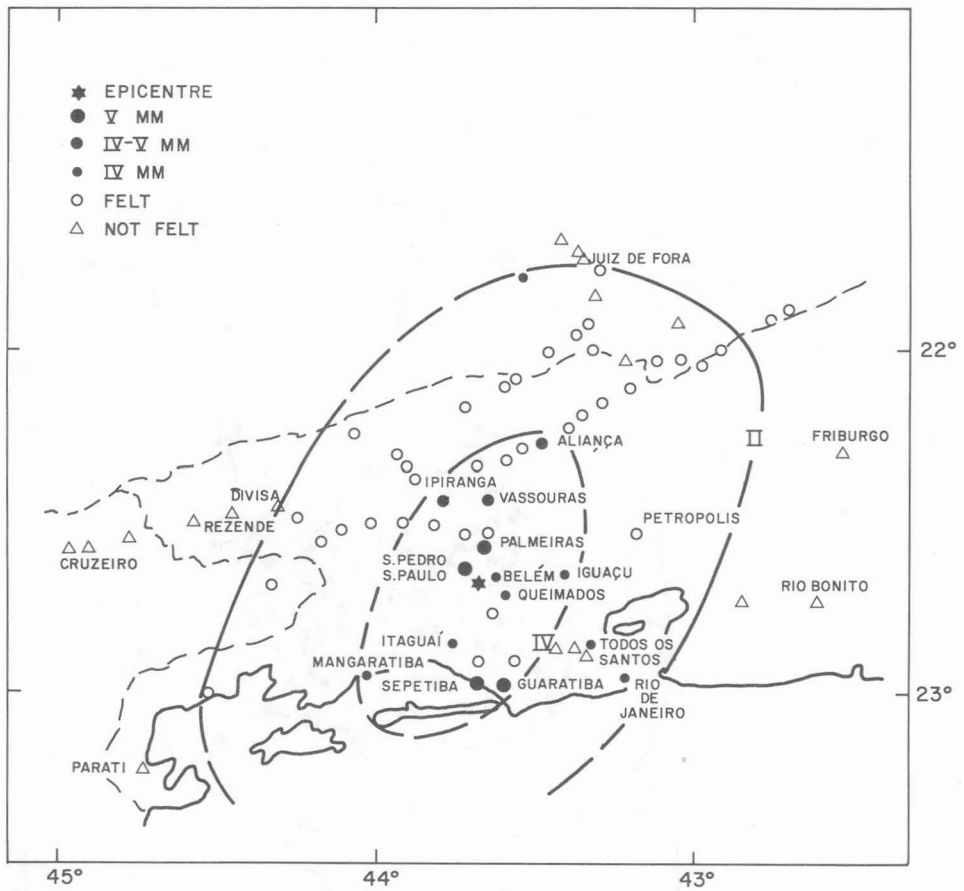

Fig. 1. Macroseismic data and isoseisms of the earthquake occurred on May 9th, 1886, in the Southern portion of the state of Rio de Janeiro.

II MM and IV MM were drawn for this event defining a felt area of approximately $23.0 \times 10^3 km^2$ and a maximum observed intensity of V MM. Most places reported that the event was felt without additional information to evaluate the intensity.

Isoseisms of another relatively old event (January 27th, 1922), which occurred in Mogi Guaçu, state of São Paulo, are shown in Fig. 2. For this event it was possible to get a great quantity of macroseismic information which permitted us to define a felt area of $250.0 \times 10^3 km^2$ (isoseism II MM), to locate the epicentre accurately and to draw the isoseism IV MM as shown in Fig. 2. Maximum observed intensity for this event was VI MM. This event was also recorded by the RDJ station showing a S–P distance in agreement with the macroseismic epicentre.

The data corresponding to the earthquake occurring on March 22nd, 1967 is plotted in Fig. 3. This event occurred near the border, between the states of São Paulo and Rio de Janeiro, and despite its maximum observed intensity of VI–VII MM (it

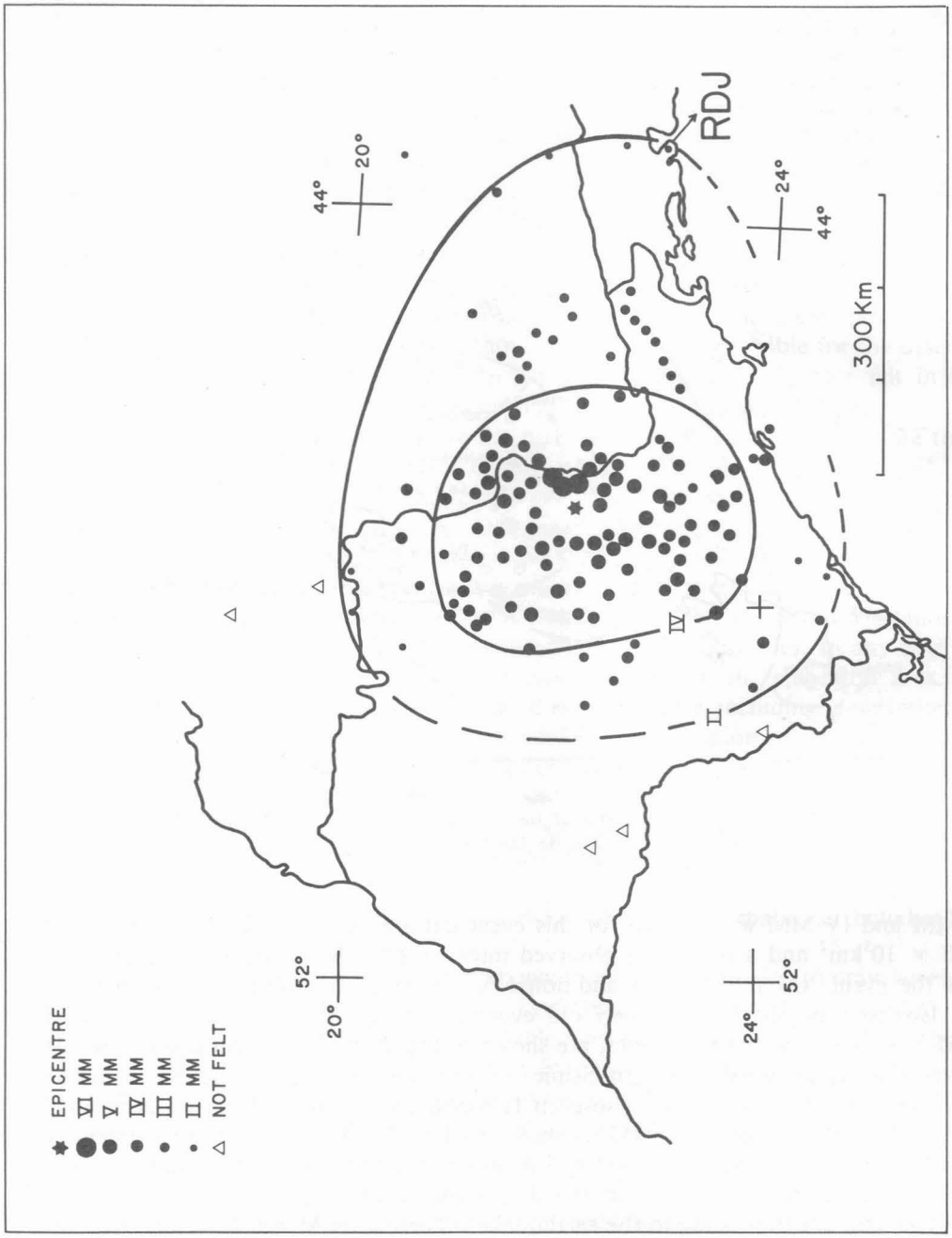

Fig. 2. Macroseismic data and isoseisms of the earthquake occurred on January 27th, 1922, in Mogi-Guaçu, state of São Paulo.

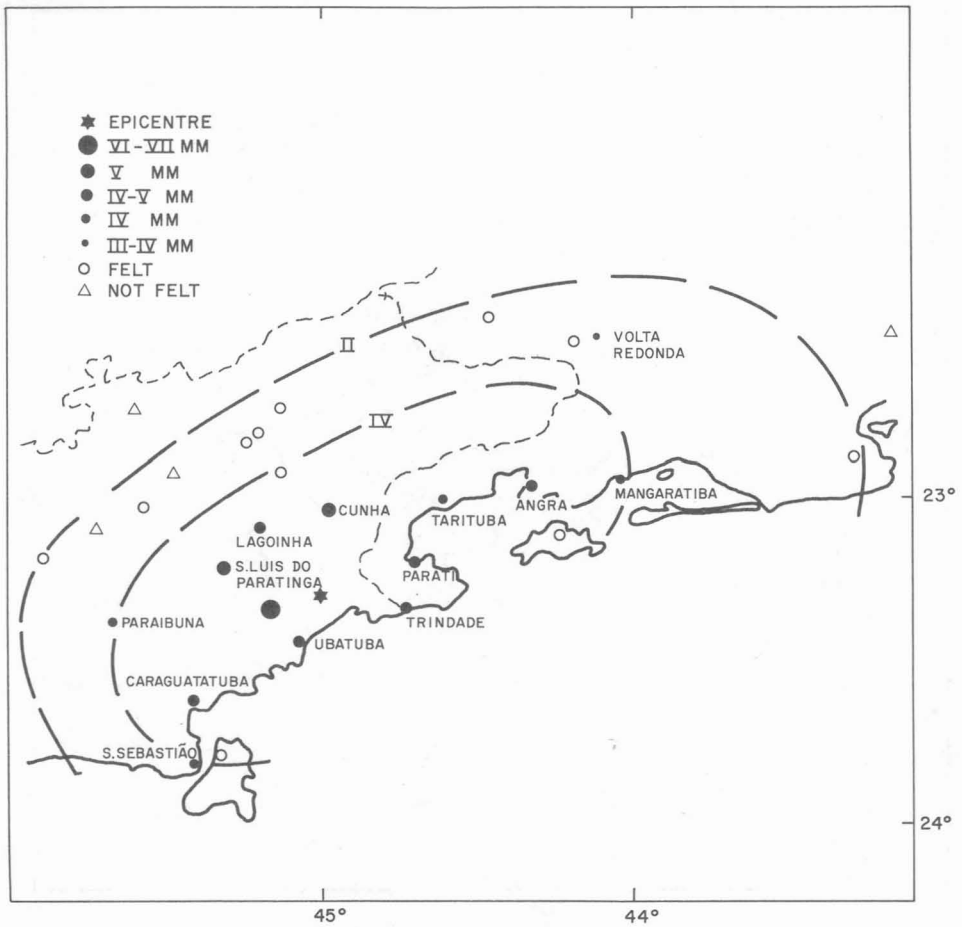

Fig. 3. Macroseismic data and isoseisms of the earthquake occurred on March 22nd, 1967, in the border region between São Paulo and Rio de Janeiro states.

was reported that the tremor was noticed in vehicles in motion in two instances) it was only felt in an area of 30.0 $\times$ 10^3km^2. RDJ recorded this event with an S–P distance of about 175 km.

The isoseismal map corresponding to the earthquake which occurred near Pacajus, state of Ceará, on November 20th, 1980, is shown in Fig. 4. This event had a maximum observed intensity of VII MM and was felt in an area of around 1,000.0 $\times$ 10^3km^2. NEIS located the epicentre of this event on 4.58°S and 38.23°W, normal depth, and m_b = 5.0, from data of 65 stations.

The Brazilian earthquakes belonging to Groups A, B, and the events with intensity equal or greater than V MM of Group C, are listed in Table 1.

One hundred and five earthquakes with epicentres in the Brazilian territory determined from instrumental data were compiled during this research (not including the

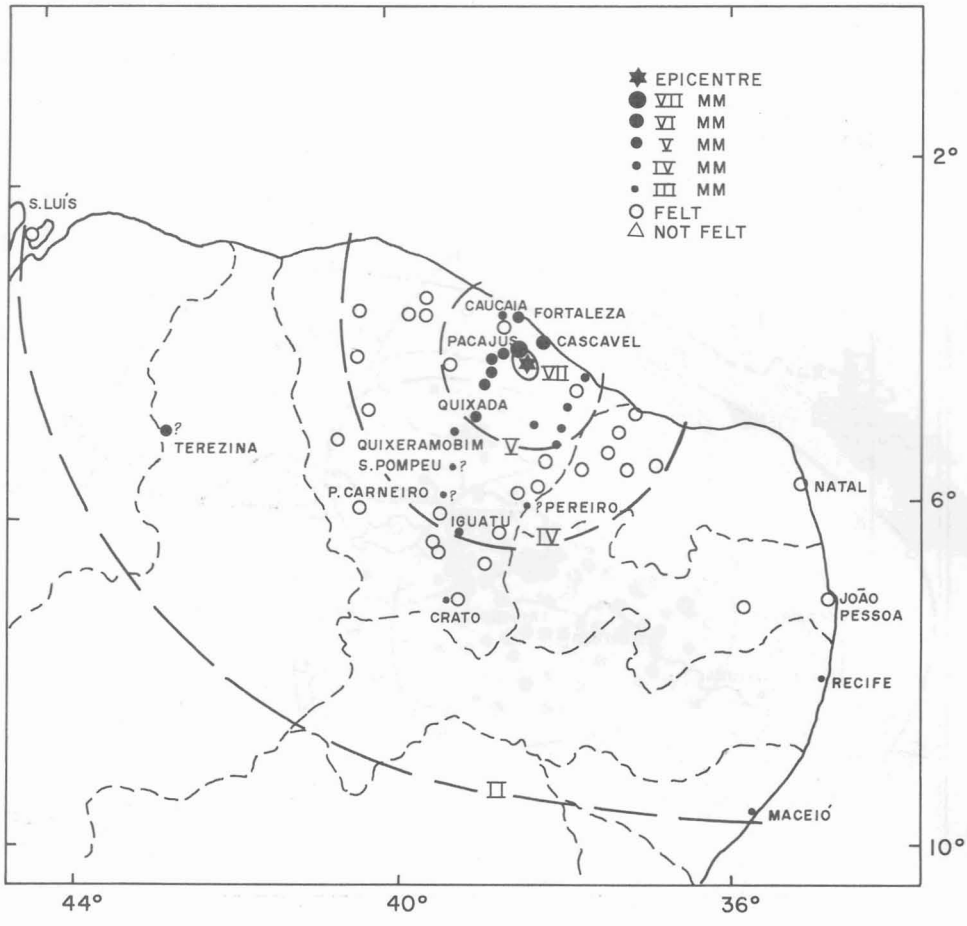

Fig. 4. Macroseismic data and isoseisms of the earthquake occurred on November 20th, 1980, near Pacajus, state of Ceará.

deep events of the Perú-Brazil border region). Seventy percent of that total occurred after 1968 when seismic readings and epicentral determination were started at ESB. However, the number of instrumentally located events is increasing each year with the expansion of the Brazilian network of seismographs (see Fig. 5).

From the 105 instrumentally located events, 23 belong to determinations made by ISS with less than four P readings or to LASA determinations contained in ISC bulletins and therefore are not included in Table 1. Also deleted from Table 1 are 64 instrumentally located events with magnitude less than 4.0 or without magnitude determination.

Thus, in Table 1 are listed only 18 reliably located earthquakes with $m_b \geq 4.0$ compiled from instrumental data together with 99 events compiled from macroseismic information. All events listed in Table 1 are plotted in the map of Fig. 6.

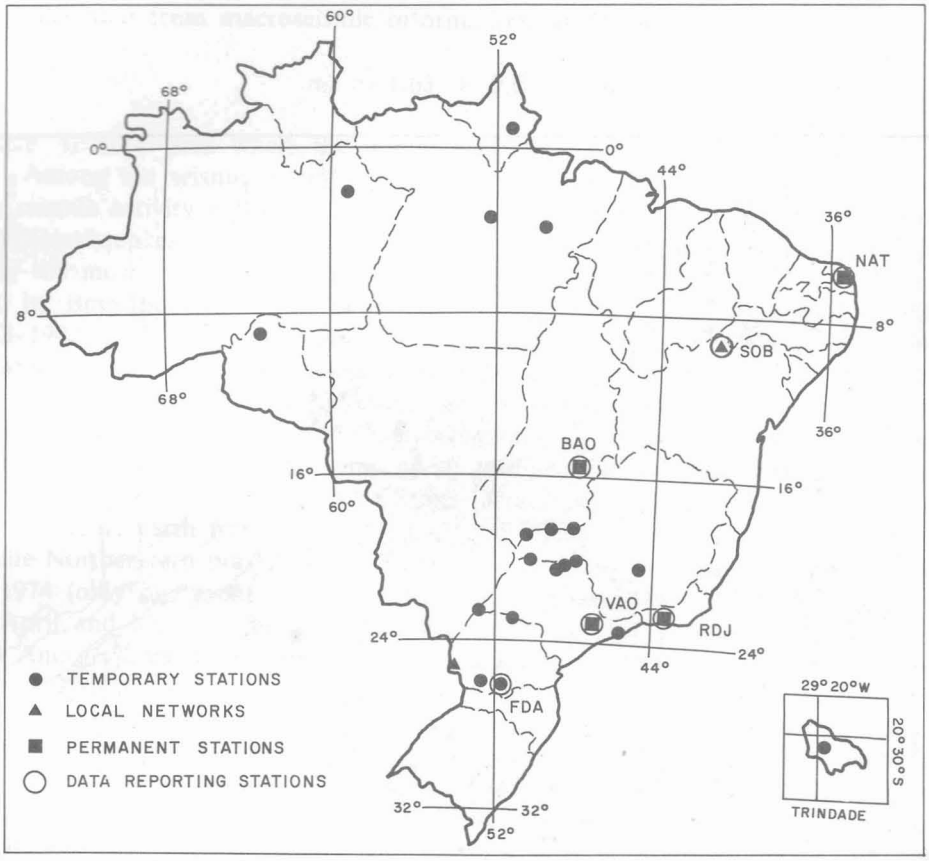

Fig. 5. Brazilian network of seismographic stations in 1980 (except Trindade).

The magnitude values in Table 1 correspond to m_b calculated with teleseismic data, however, they are obtained from different sources:

1) original value included in international bulletins (i.e., NEIS, ISC),
2) calculated with data from local and regional stations, as follows (ASSUMPÇÃO, 1982):

$$m_R = \log (V) + 2.3 \log (D) - 2.2$$

where $V = 2\pi A/T$ (A: amplitude in μ and T: period in seconds), D = epicentral distance in km ($200 < D < 1500$ km);

3) average between m_b and m_R existing values;
4) deduced from M_S value, as follows (BUENO, 1979):

$$m_b = 0.55\ M_s + 2.32;\ \text{and}$$

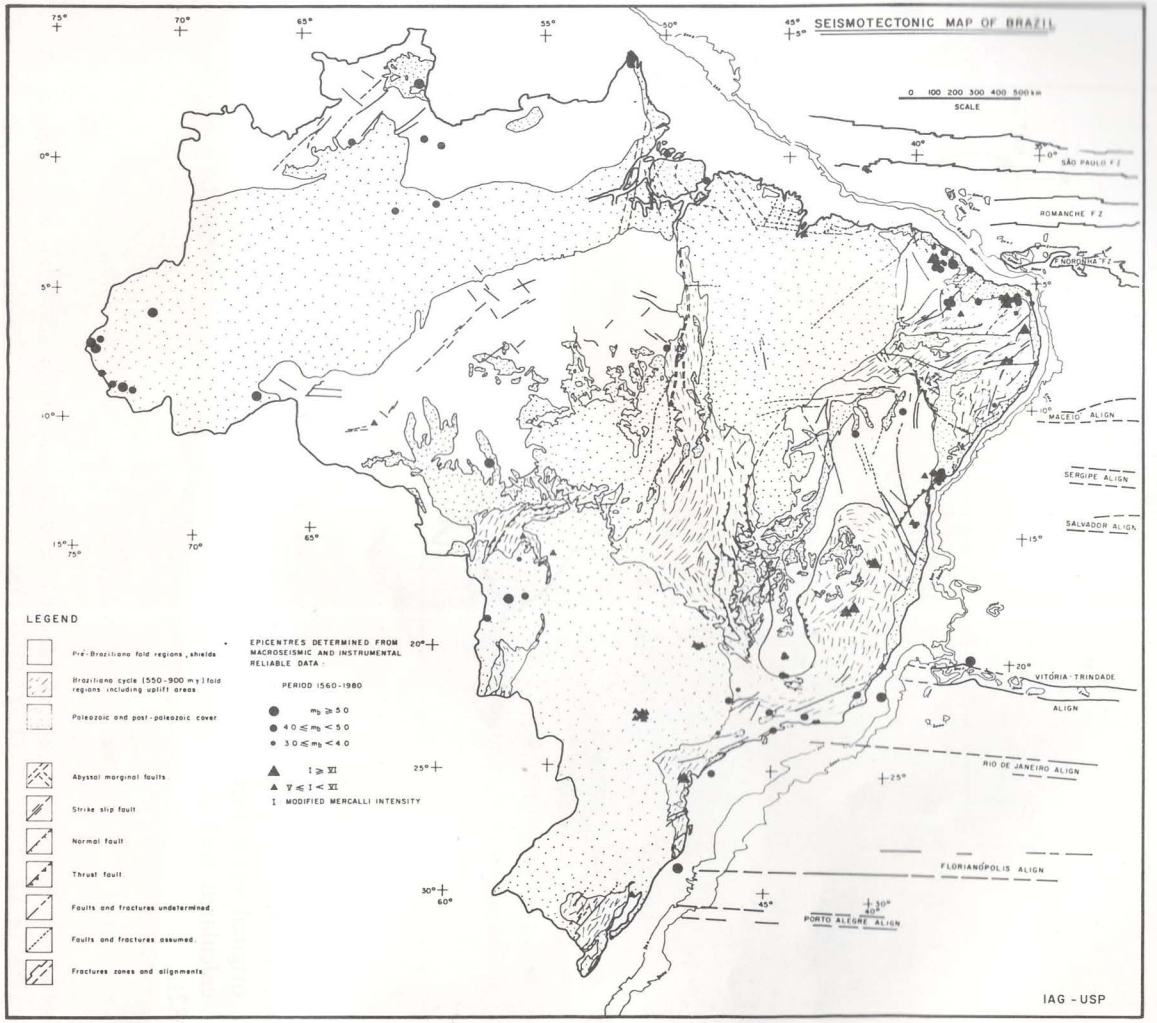

Fig. 6. Seismotectonic map of Brazil, including earthquakes with $m_b \geq 4.0$ or intensity $\geq$ V MM occurred up to 1980.

5) calculated from macroseismic information, as follows:

$$m_b = 1.63 + 0.60 \log (A_f)$$

where A_f: total area where the tremor was felt.

Among the seismic events not included in Table 1, it is necessary to mention the seismic activity noticed in the form of swarms of small magnitude or sporadic small earthquakes occurring in several places within the Brazilian territory, of which only the most significant events are listed in Table 1.

In Bom Sucesso, state of Minas Gerais, small swarms occurred in 1840, 1901–1902, 1919–1920 and 1935, which were studied by SILVEIRA (1906, 1920, 1924), BRANNER (1920), and MORAES and MALAMPHY (1937). The 1919–1920 series was the most active both in number of events and in observed intensities (up to VI MM), however, the great majority of these events and of other series were of intensities less than IV MM or noticed only as subterranean sounds. In other places in the Southeastern portion of the state of Minas Gerais such as Campanha, Caxambu, etc., only sporadic earth tremors, mostly of small intensity have occurred. In Tuparece, in the Northeastern portion of that state, a swarm of small seismic events occurred in 1974 (only one event of VI–VII MM intensity and more than 200 small events in April and May). Some activity also occurred in this area in 1972.

Another area that presented swarms of seismic events is the Recôncavo Baiano (the area surrounding the Bahia bay) and the Itaparica island in the state of Bahia. Sporadic earth tremors have occurred in this area since the XVIII century. However, in the present century, between 1911 and 1919, there have occurred two earthquakes of VII MM intensity and many events of smaller intensities, especially in the period 1915–1919 (SAMPAIO, 1916, 1919, 1920). During 1979 and 1980 the network installed at Sobradinho (SOB) recorded quite a few small magnitude ($m_b < 4.0$) seismic events with epicentres in that area. Another place in the state of Bahia where a reasonable number of seismic events have occurred is Ibicarai, in the Southeastern portion of that state. Seismic activity in this area began 1973 with a few shocks during that year and in 1974, a good number of small events in May 1976, including a VI MM intensity earthquake and some events in 1978.

In the state of Ceará, Pereiro is a place where apparently sporadic earth tremors have occurred since the end of the last century reading a peak activity at the beginning of 1968 when a VII MM intensity earthquake and many smaller intensity events occurred followed by some modest activity in 1972 and 1974. Granja and the area including the towns of Baturité, Canindé, Palmacia and Ibaretama are also places in the state of Ceará where occasional small earth tremors have occurred in the past.

Other places experiencing swarms and sporadic small earth tremors are located in the state of Rio Grande do Norte. Touros and the area including the towns of Lajes, João Câmara and Riachuelo has experienced occasional seismic events since the last century and Parázinho in 1973 was shocked by a swarm of small earthquakes and a VI–VII MM intensity event, which were recorded at NAT.

In Caruaru, state of Pernambuco, in the central and Southern portion of the state of Goiás and in Cananéia, in the state of São Paulo, earthquakes of small

magnitude have also occasionally occurred. During the latter years small magnitude events ($m_b < 4.0$) have been located in the Southeastern region of Brazil and in the Continental Platform along the coast of São Paulo and Rio de Janeiro states.

4. Main Features of Brazilian Seismic Activity

Most of the Brazilian territory occupies the South American pre-cambrian shields, having a low level of seismic activity typical of intraplate regions (see Fig. 6). During the last four and a half centuries not a single catastrophic earthquake has occurred in Brazil, and few events produced intensity of VII MM, causing more emotional effects and concern than any considerable material damage or deaths (only one person was killed: during the February 23rd, 1968, earthquake which occurred in Pereiro, state of Ceará).

On the other hand, the results presented in this work show a more realistic level of seismic activity in Brazil modifying the previous picture obtained from world seismicity maps of an almost aseismic country.

During the period of study, 13 events were found with $m_b \geq 5.0$ (excluding the deep events of the Brazil-Perú border region), the largest being the ones occurring on January 31st, 1955, at Serra do Tombador, state of Mato Grosso ($m_b \simeq 6.0$) and on February 28th, 1955, in the Vitória-Trindade oceanic high ($m_b \simeq 5.6$). These events might have produced epicentral intensities as high as or greater than VIII MM.

Observed intensities equal to or greater than VI MM were reported for 37 events, 6 of which had an intensity of VII MM. Some large intensity events were felt in a very small area around the probable epicentres, like those occurring at Itaparica (March 22nd, 19ll), Santa Maria do Suaçuí (July 16th, 1969), São Pedro do Suaçuí (February 6th, 1970), and Tuparece (April 11th, 1974) implying a small magnitude and a very shallow focus for these events. other events have large felt areas, like the ones occurring at Mogi-Guaçu (January 27th, 1922), Tubarão (June 28th, 1939), Campos Basin (October 24th, 1972) and Pacajus (November 20th, 1980), suggesting deeper focus and larger magnitudes than for the events mentioned above.

It can be stated that events felt in small areas are associated with geological superficial features whereas the ones felt in large areas are typical tectonic earthquakes with their foci located at mid crustal depths and may be produced by regional lithospheric stresses, as suggested by MENDIGUREN and RICHTER (1978), based on focal mechanism of some Brazilian earthquakes. At this stage, due to the lack of accuracy in the epicentral determinations, it is not possible to associate the epicentres of the Brazilian earthquakes with any of the tectonic features shown in the map of Fig. 6, except for a very limited number of cases.

There are also cases of induced seismicity both by water reservoirs and by artesian wells. These phenomena have occurred mainly in the states of São Paulo, Minas Gerais and Paraná. Cases of induced seismic activity in Brazil have been recognized in at least five reservoirs: Carmo do Cajuru (VI MM, $m_b = 3.8$), Capivari-Cachoeira (V–VI MM), Volta Grande-Porto Colombia (VI–VII MM, $m_b = 4.3$), Capivara (VI MM, $m_b = 3.7$), and Paraibuna (IV MM, $m_b = 3.4$). Artesian wells drilled in the basaltic layers of the Paraná Basin have produced swarms of small earth tremors

and also seismic noises, as in Nuporanga (IV MM).

In terms of energy, the largest magnitude Brazilian earthquake (m_b = 6.0) released 7×10^{21} ergs, value calculated by using the GUTENBERG and RICHTER (1956) relation and the m_b/M_s relation already mentioned in this paper, whereas all events listed in Table 1 released about 10^{22} ergs, corresponding to a single m_b = 6.1 earthquake (1.3×10^{22} ergs).

It is estimated that at least 1.1×10^{22} ergs of seismic energy is released each year in the Andean region and there occur on an average 65 events with $m_b \geq 5.0$ and at least one event with m_b = 6.0 (BUENO, 1979), corresponding to the seismic activity which has occurred in Brazil over 420 years. Obviously there exists a large difference between the Brazilian and Andean seismicities, corresponding to the tectonic differences of both regions: a region of interaction of continental and oceanic plates and a more stable intraplate region.

The Brazilian seismic activity does not present a dangerous level of risk, comparable with the risk existing in typical seismic regions where eminent catastrophic events are expected and for which prevention measurements must be taken. Nevertheless, the level of seismic activity in the Brazilian territory is not negligible, especially when important engineering projects, such as large hydroelectric dams or nuclear power reactors, are involved. Earthquakes of intensity larger than VI MM certainly occur in the Brazilian territory and even events of intensity VIII MM may be expected.

From the results presented in this work it is possible to identify regions of the Brazilian territory with different levels of seismic activity. The most active is the Northeastern region, mainly the states of Ceará, Rio Grande do Norte, Pernambuco and Bahia, and the Southeastern region, including the states of Rio de Janeiro, Minas Gerais and São Paulo. Other seismic regions with significative number of events are the Mato Grosso region, and the Amazonian region especially in the state of Acre. The regions without seismic activity coincide with the less populated and remote areas of Brazil, and it is not possible, for this reason, to define these areas as completely seismic until the Brazilian network of seismographs is improved and a more complete record of Brazilian seismicity is obtained.

This compilation of seismic activity in Brazil has been possible thanks to the collaboration of staff members of the various libraries and newspaper archives consulted, to whom we express our gratitude. We also acknowledge Joaquim Mendes Ferreira, IAG M.Sc. student, for allowing us to use data and results of his research on seismicity of the Northeastern region of Brazil, and Celia Fernandes, also IGA M.Sc. student, for computing and general assistance. We also thanks Dr. V. Hamza for revising the manuscript of this paper.

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