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SEISMIC ENERGY RELEASED ALONG A SEGMENT OF THE SOUTHERN CARIBBEAN PLATE BORDER

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ABSTRACT

The accumulation and release rates of seismic moment since 1765 along a 1,300 km long segment of the southern boundary of the Caribbean plate is presented. The upper bound of the liberated energy in terms of the seismic moment rate during the last 2.3 centuries varies between 1.9 and 3.2 x 10^{20} dyne-cm/ year-km^2. Mean rates of displacement obtained from energy, range from 6.2 to 9.9 mm/year which are to be compared to: 12 mm/year at plate-tectonics scale and 9 mm/year for the most active faults. Present restored seismic energy is of the same order of that reached before the Ms 7.9 to 8.0 historical maxima. The extension and duration of the studied period do not seem to allow the identification of areas likely to be affected by oncoming events. Based on the extreme value distribution of seismic moments, a regional b value of 0.806 is obtained, which is considered to be a reliable value for long-term seismic hazard evaluations.

KEYWORDS

Southern Caribbean, seismic energy, energy released, stored energy, fault creep, b-value, strike-slip boundary, Venezuela, slip-rate, historical seismicity.

INTRODUCTION

One of the indexes that quantifies the seismicity of a given region is the mean seismic moment rate per unit time and unit area. This paper evaluates such index for a segment of the southern border of the Caribbean Plate, extending from latitude 61.7 W to 72.5 W, for which main and secondary active faults are essentially right-lateral strike-slip.

For such type of faulting, the seismic moment (M_o) is generally associated to a model where an earthquake is produced along a discontinuity or dislocation of a certain area (A), in a field under shear stress, in an elastic media characterized by the shear modulus of elasticity (μ). Such dislocation is equivalent to a double couple with total moment:

$$M_o = \mu \, S \, u_s \quad \text{(dyne-cm)} \tag{1}$$

Where S is given in cm^2 and u_s is the mean distortion in cm. The adopted (μ) value is equal to 3.1 x 10^{11} dyne/cm^2.

Relations used herein between seismic moment, Richter magnitude (M_S) and released seismic energy (E_S) are:

$$\log(E_S) = 1.5\,M_S + 11.8 \quad \text{(erg)} \tag{2}$$

$$\log(M_o) = 1.5\,M_S + 15.8 \quad \text{(dyne-cm)} \tag{3}$$

Equation (2) is from Gutenberg and Richter (1956) and equation (3) is from Kanamori and Anderson (1975). For the Venezuelan region and with a small data base, Kozuch (1993) proposed:

$$\log(M_o) = 1.128\,M_S + 18.558 \quad \text{(dyne-cm)} \tag{4}$$

Equation (3) fits better for the M_S magnitude range used in this paper.

In the simple model of seismic Moment adopted, the mean rate of accumulated energy per unit time per unit area can be estimated as:

$$\left(\sum M_o\right) \Big/ \left[(\Delta T)\ (A)\right] = \left(\dot{M}_o\right) = (\mu)\left(\sum s\right)\left(\dot{u}_s\right) \Big/ (A) \tag{5}$$

Where units are the same used until now: (ΔT) is the time interval in year and total area (A) is given in km^2. Units of the previous equation are dyne-cm/ year x km^2; ($\dot{u}_S$) is mean rate of displacement in cm/year.

STUDIED AREA

According to present models, the southeastern border of the Caribbean Plate is defined by the following right-lateral strike-slip fault systems: Boconó, San Sebastián and El Pilar (Molnar & Sykes, 1969; Minster & Jordan, 1978; Perez & Aggarwal, 1981; Stephan, 1982; Aggarwal, 1983 and Aggarwal et al, 1984) (see Fig. 1). The total length of the seismogenic area is about 1.300 km long with a total area in the order of 200.000 km^2. Focal depth of the associated seismicity is predominantly less than 15 km deep.

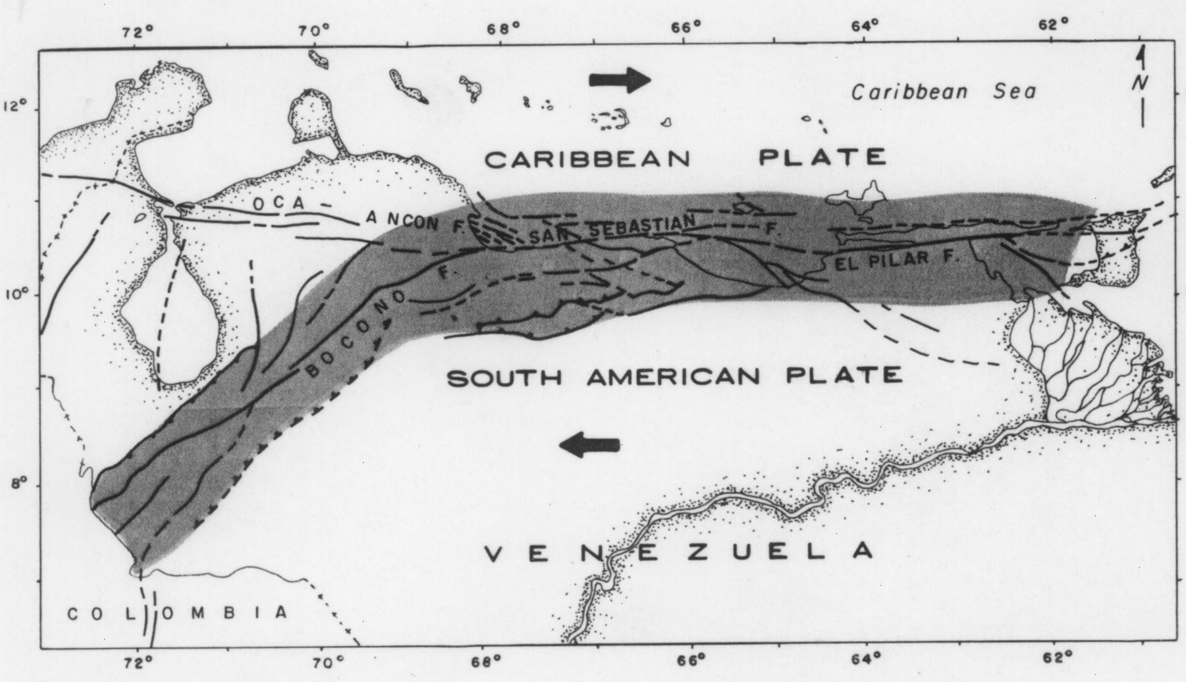

Fig. 1. Studied Segment of the Caribbean Plate Border (Simplified map after Soulas, 1986a).

Along the mentioned systems, maximum rate of fault displacements has been estimated to be 9 mm/year based on postglacial morraines evidences overlaying active faults (Schubert and Sifontes, 1970; Soulas, 1986b). At a plate tectonic scale, relative plate motion has been estimated to be in the order of 12 mm/year.

SEISMIC DATA BASE

The seismic history of the selected area begins with a destructive quake in 1530; the associated tsunami being probably the first post-Columbus one in America. Although for well known reasons, data should extend as backward as possible, in order not to loose completeness and homogeneity, the considered period in this study starts in 1765.

The seismic catalogues of the area used are: CERESIS (1986, with 1993 adenda) and FUNVISIS-INTEVEP (1994), both covering essentially the same period: 1530-1990; FUNVISIS Bulletins up to 1993; and SNV (1992), which covers June-August 1990. Magnitudes and epicentral locations for events belonging to the pre-instrumental period stem from historical seismicity studies based on the pattern of isoseismal atenuations (see for instance: Grases 1980). Information related to focal depth has inconsistent back up and no distinction of such paremeter has yet been done.

Consideration of magnitude uncertainties is beyond the scope of this paper and magnitude used are summarized in Table 1.

Table 1. Ms ≥ 6.2 Seismic Events Within the Studied Region

YEAR OF EVENT	Ms	log (M_0) (dyne-cm)	YEAR OF EVENT	Ms	log (M_0) (dyne-cm)
1766	7.9	27.65	1878	6.2	25.10
1775	6.5	25.55	1888	6.2	25.10
1797	≥ 6,2	≥ 25.10	1894	7.0	26.30
1812 (1)	7.2	26.60	1900	7.6	27.20
	7.2	26.60	1910	6.2	25.10
	6.8	26.00	1929	6.6	25.70
1812 (2)	8.0	27.80	1932	6.7	25.85
1823	6.4	25.40	1950	6.8	26.00
1834	≥ 6.2	≥ 25.10	1957	6.9	26.15
1849	≥ 6.2	≥ 25.10	1967	6.9	26.15
1853	6.7	25.85	1968	7.2	26.60
1869	6.3	25.25	1975	6.8	26.00
1875	7.3	26.75			

Note (1) and (2) correspond to hypotheses (1) and (2) respectively.

Figure 2 shows the extension of the observational period for completeness, essentially valid for the eastern part of the studied area. Its validity has been extrapolated to the whole area, though it maynot be strictly valid for less populated areas.

According to the above given criteria, a total of 24 events with $M_S \geq 6.2$ were identified within the period 1765-1990 (Table 1); from which, 62% occurred before 1900. For each event, Table 1 also gives the associated seismic energy in terms of equation (3). Note that two hypotheses have been considered for the March 26th 1812 destructive earthquake: (i) a three different foci event, after Fiedler (1961), Centeno (1969) and others, with a total log $M_O = 26.95$ (Hypo 1), and (ii) a single rupture event with M_S 8 (log Mo = 27.8) (Hypo 2), in which case the number of events is reduced to 22.

LIBERATED AND ACCUMULATED ENERGY. REGIONAL VALUE

Total Energy Liberated

According to Table 1, the total energy liberated in the studied area along 2.25 centuries is equal to: (a) 893.7×10^{25} dyne-cm (Hypo 1), and (b) $1.435.1 \times 10^{25}$ dyne-cm (Hypo 2).

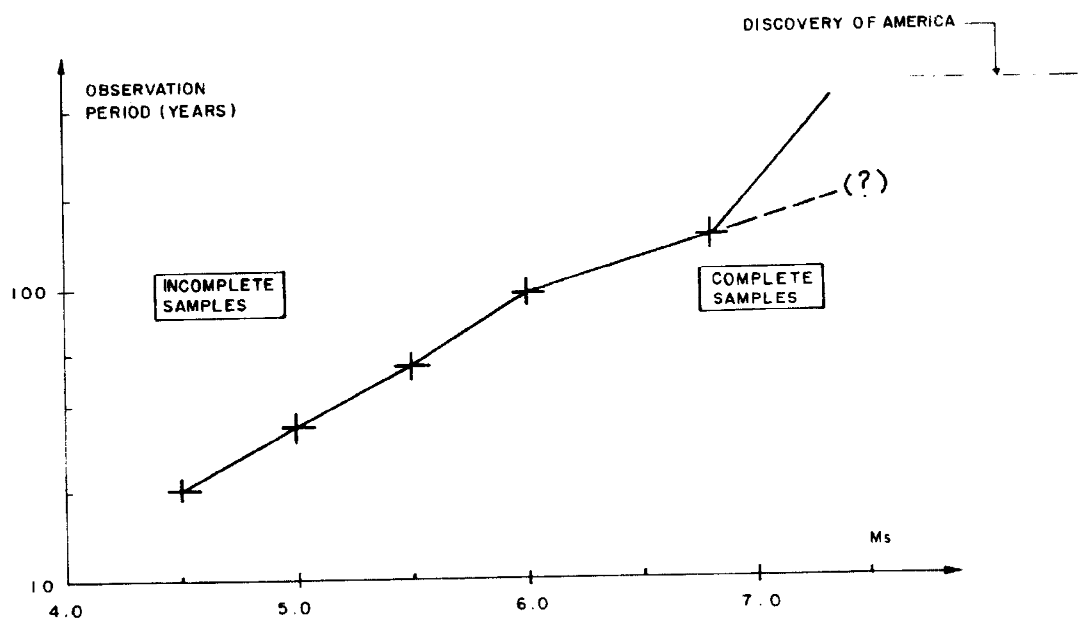

Fig. 2. Extension of the Observational Period

From Table 1, it is clear that the rate of energy liberated along the last 9 decades (1.1×10^{23} dyne-cm/year) is several times smaller than mean value: 3.6 times for Hypo 1 and 5.8 times for Hypo 2.

Mean Slip Rate

According to equation (5) the mean slip rate is 0.62 cm/year for Hypo 1, and 0.99 cm/year for Hypo 2; these values are comparable to the already quoted rates.

Sequence of Energy Release

The history of energy release along the studied sector of the Caribbean plate boundary in terms of the seismic moment, is presented in Fig. 3 for the two hypotheses. The mean rates of strain accumulation along the whole length of the considered sector have been obtained with the mean slip rates given above.

The historical sequence given in Fig. 3 for either hypothesis, shows that enough strain energy has buildt up in order to liberate single events of magnitude larger than M_S 6.0. The length of the studied period, however, does not seem to allow the identification of areas likely to be affected by oncoming events.

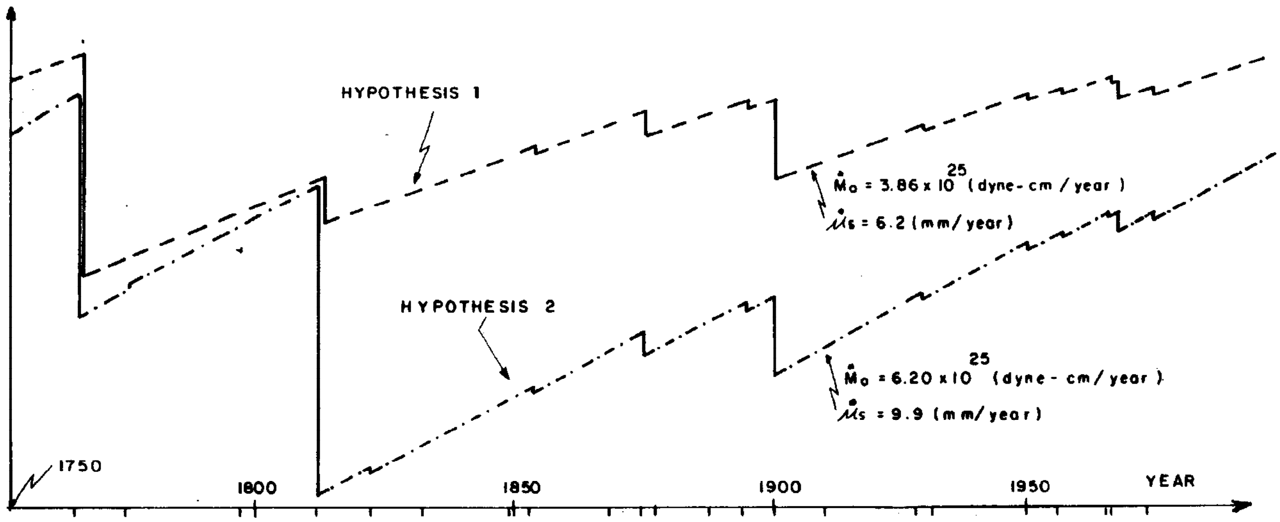

Fig. 3. Energy Liberation (Historical Sequence) and Progresive Accumulation in Terms of Seismic Moment.

Regional b Values

The time span between 1765 and 1990 can be divided in 15 intervals of 15 years each. There is a single interval, 1780-1794, for which no earthquakes with magnitude at least 6.2 are reported; the larger known event during this interval has been estimated to be at least M_S 6.0 (The Cumaná, Sept. 1794 earthquake). For the remaining 14 intervals, the maximum value of log (M_O) has been retained and ploted in Fig. 4 against the estimate of the probability of that value not been exceeded in 15 years, here denoted (p). Note that the estimate of the mean return period (T) has been obtained as:

$$T = 1 / (1 - P^{1/15}) \qquad (6)$$

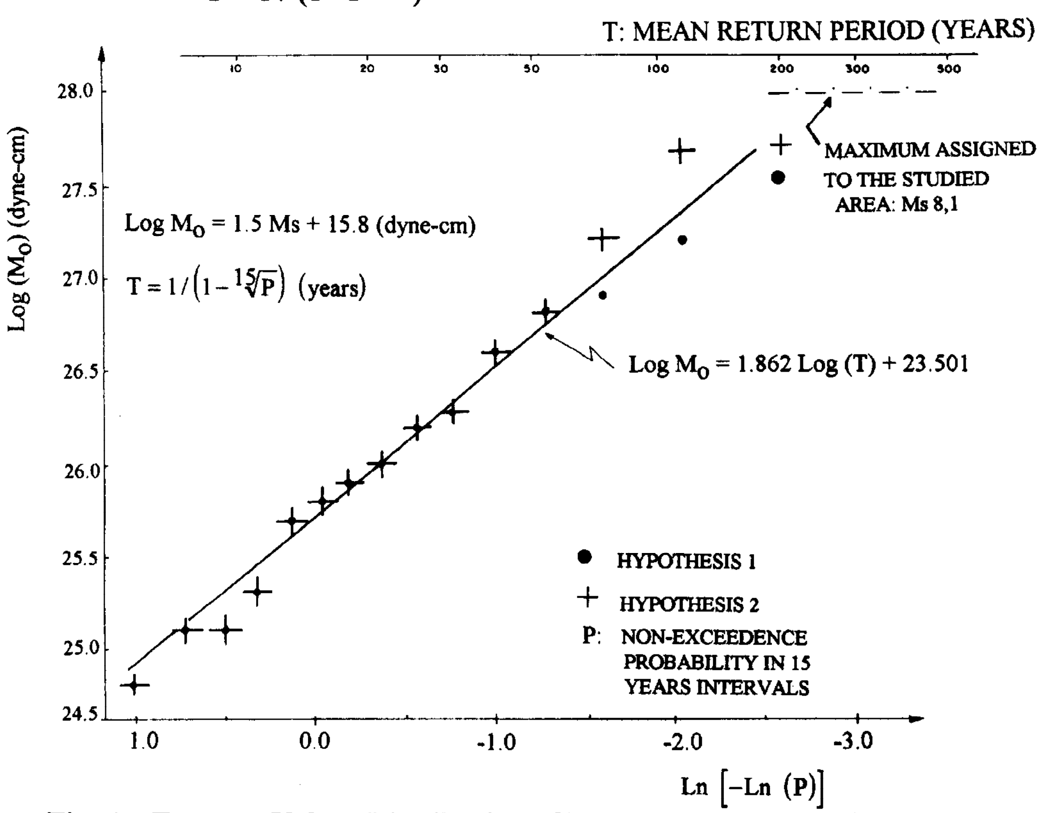

Fig. 4. Extreme Values Distribution of log (M_0) in 15 Years Intervals (1765-1990). Cúcuta-Güiria (~ 1.300 km).

Where the log (T) axis is a simple translation of the Ln (-LnP) axis. Linearity between log (M_0) with this last one, for the central part of the distribution shown in Fig. 4, has been regressed as:

$$\log (M_0) = 23.501 + 1.862 \log T \qquad (7)$$

Substitution of (T) by ($1/\lambda$), and log (M_0) by equation (3), allows to rearrange equation (7) in the form of the frequently used Gutenberg-Richter relation; the following expression is obtained:

$$\log (\lambda) = 4.135 - 0.806\, M_S \qquad (8)$$

Where (λ) is the mean rate of exceedence of (M_S).

Deviation from equation (7) in the lower range of (M_0), can be partly due to underestimates within the data base. In addition to the $M_S \geq 6$ used in the interval 1780-1794, two of the lower values were suspect to be underestimates in the following intervals: 1795-1809 (the $M_S \geq 6.2$, 1797 eastern Venezuela destructive earthquake) and 1825-1839 (the $M_S \geq 6.2$, 1834 southeastern Venezuela, locally-destructive, earthquake).

Equation (8) describes the seismicity of a sector of the southern border of the Caribbean Plate. Other b values are given in the literature for portions of the studied region (see Fiedler, 1968; SNV, 1992; Villaseñor et al. 1992; Franke et al. 1993 and Ramos and Mendoza, 1993).

DISCUSSION

The evaluation of the available data in the studied region, in terms of the applied procedure, leads to three interesting observations. The range of values quoted below are associated to the hypothesis about the 1812 destructive earthquake: a triple event (lower bound of energy release) or a M_S 8 single event (upper bound).

i. The mean rate of liberated energy during the last 2.25 centuries, in terms of seismic moment, varies from 1.9 to 3.2 x 10^{20} dyne-cm/year-km^2. The fact that they strongly depend on one or eventually two events, probably reflects that, when compared to the slow relative slip rate of this active tectonic boundary, the observation span is too short. Since the period of observation begins inmediately after one of the largest events, combined with the possible inclusion of intermediate focus events, the given values should be considered as an upper bound.

ii. Given the limited seismotectonic correlation of the 24 (or 22 for Hypo 2) known largest events ($M_S \geq$ 6.2) within the 1.300 x 150 km^2 active seismic strip, the slip rate used here as reference is at a plate tectonic scale (12 mm/year). Therefore the slip rates obtained imply creep slip from 48% to 18% of the total. Recall is made that, within the studied area, the fastest single-fault slip rate reaches 9 mm/year.

iii. The tectonic style of the studied region is recognized by its uniform-right lateral strike-slip with a very small to negligible vertical component. Therefore the characterization of the regional seismicity by a single b value seems justified. Based on the extreme value distribution of seismic moments, a long-term b value of 0.806 is obtained. Other values given in the literature for portions of the studied region may reflect local and/or time variations, therefore being of limited significance for long-term seismic hazard assessments. According to equation (8), events with Ms ≥ 6 or ≥ 7.5 have mean rates of occurrence of one event per 10 or 160 years per 10^5 km^2 respectively. Maximum expected magnitude earthquakes in the region have return periods of at least 2 centuries.

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