RECENT SEISMICITY ($m_b \geq 5.4$) IN NORTHWESTERN VENEZUELA: REGIONAL TECTONIC IMPLICATIONS

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RESUMEN: El análisis de la sismicidad de magnitud moderada ($5.4 \leq m_b \leq 5.9$) ocurrida recientemente en el Occidente de Venezuela, ha permitido determinar los parámetros focales de esos sismos y su relación con la tectónica regional. Los resultados obtenidos muestran que dicha sismicidad está asociada principalmente a los sistemas de fallas secundarios y no a los principales sistemas de fallas de Oca-Ancón y Boconó, los cuales han sido postulados como la antigua y actual frontera entre las placas Caribe y Sur América en esta región.

KEY WORDS: Caribbean, Venezuela, Andes, seismicity, tectonics, inversion.

INTRODUCTION

The border between the Caribbean and South American plates in western Venezuela has been a source of controversy in understanding the tectonics of the Caribbean region. The motion on the southeastern Caribbean plate boundary is accommodated mainly by major right-lateral, strike-slip faults like El Pilar and Morón. Towards the west, the continuation of the plate boundary is not clear. The Boconó fault is a right-lateral, strike-slip fault systems which has been postulated to be the boundary between these two plates in western Venezuela (e. g., Dewey, 1972; Schubert, 1982; Soulas, 1986). Most of the seismotectonic studies in this area are based on the analysis of the microseismicity recorded locally by temporary networks, neotectonic field work, and first-motion focal mechanisms. The occurrence of seismicity of moderate to large magnitude ($M \geq 5.0$) associated with this plate boundary is relatively poor. Furthermore, the low relative velocity between the Caribbean and South American plates implies long recurrence periods for large earthquakes, rendering more difficult the evaluation of the seismic hazard in this zone.

In this study, we analize the seismicity $m_b \geq 5.4$ which has occurred in western Venezuela from 1964 to 1992 (15 earthquakes) in order to correlate it with the active faults in the area. The source parameters were determined by the epicentral relocation and the formal inversion of the long period body waves (Nábelek, 1984) recorded at teleseismic stations. Because of a low signal to noise ratio, some of the events were studied through the waveform inversion of the short period body waves. The results show that only the July 19, 1965 earthquake nucleated on the Boconó fault system. The other earthquakes are apparently associated with secondary fault systems. Another important point of this work was to determine the depth of the earthquakes. Most of the events studied here, in particularly those in the soutwest area of Venezuela, have been reported with a depth of 40 km on average, whereas the maximum depth determined by the inversion is of 27 km. The only exception is the intermediate depth earthquake of November 11, 1968.

TECTONIC SETTING

The main tectonic features of Western Venezuela are associated with the interaction between the Caribbean and South American plates. There are several models that explain the relative motion between the Caribbean and its neighboring plates (Jordan, 1975; Sykes et al., 1982; Stein et al., 1988). In general, those models agree that the Caribbean plate has a low absolute velocity in a hot-spot reference frame, and that it is moving predominantly eastwards with respect to both the North and South American plates (Dewey and Suárez, 1991). The relative motion between the Caribbean and South American plates does not seem to be concentrated along a single fault system. Apparently it is distributed over a wide zone of deformation along the Boconó, Morón, and El Pilar fault systems (e. g., Soulas, 1986).

Slip-rates measured at the Oca-Ancón and Boconó fault systems are lower than the predicted relative velocities between the Caribbean and South American plates. Slip-rates of the Boconó fault, measured from the offset of Pleistocene moraines, range from 0.3 cm/yr to 1.4 cm/yr (e. g., Schubert, 1982; Soulas, 1986), whereas the predicted slip rate ranges from 2 to 4 cm/yr. The last great earthquake (Ms=7.8) along the Boconó fault was on March 26, 1812. Aggarwal et al. (1983) suggested that the present movement observed on the Boconó fault began probably during the Plio-pleistocene. The present rate of motion of the Oca-Ancón fault system is in the range of 2.5 to 4.0 mm/yr. However, it appears that during the last 4 m. yr. the Oca-Ancón fault system was moving faster than it is doing at present (Soulas et al., 1987).

Besides these two major fault systems, there are several faults in western Venezuela that appear to be seismically capable (Soulas, 1986). Some of them have a NE-SW direction, parallel to the Boconó fault (e.g., Caparo, NW Piedemonte, SE Piedemonte) and others have a N-S orientation and splinter off the Boconó fault (e. g., Valera, Humocaro, Icotea). Soulas (1985) suggested that the lower velocity observed on the southwest segment of the Boconó fault takes place because the Caparo fault absorbs a fraction of the right-lateral, strike-slip relative motion between the Caribbean-South American plates.

DISCUSSION OF RESULTS

A summary of the results obtained in this study are shown on Table 1 and Figure 1. The recent shallow seismicity in western Venezuela is apparently associated with the secondary fault systems of the region and not with the main fault systems such as Oca-Ancón or Boconó. Only the July 19, 1965 earthquake (event 1 on Figure 1) appears to take place on the Boconó fault system, indicating a right-lateral, strike-slip focal mechanism. The Caparo fault has been the most active feature in the region during the last three decades. The earthquakes of January 27, 1970, May 5,1979, and July 4, 1982 (events 4, 9, and 11) show a right-lateral, strike-slip-faulting mechanisms and were generated probably on this fault. This assumption agrees with the hypothesis of Soulas (1985) that the Caparo fault plays an important role in absorbing a fraction of the Caribbean-South American relative movement. Other faults that show frequent activity in the zone are SE Piedemonte and Humocaro. The events of March 5, 1975 (6) and December 11, 1977 (8) could be attributed to the SE Piedemonte fault. They both show reverse-faulting focal mechanisms, indicating the presence of E-W horizontal compression, oblique to the Venezuelan Andes. The most recent earthquake of magnitude $m_b \geq 5.4$ in Western Venezuela occurred on August 17, 1991 (16). Both this event and that of April 5, 1975 (7) appear to have nucleated on the Humocaro fault, with a left-lateral, strike-slip-faulting displacement. There was an important seismic secuence in northwestern Venezuela during April-May 1989 (events 14 and 15). Those earthquakes have the peculiarity of being multiple rupture processes that originated long body wave trains and induced intense liquefaction in many of the towns located near the epicentral area (Malavé and Suárez, 1993). These earthquakes were generated probably on a fault system trending in the NW-SE direction, with a right-lateral, strike-slip mechanism. The event of October 20, 1969 (3) apparently occurred on the northern end of the El Tigre fault, showing left-lateral, strike-slip solution. This motion agrees with that postulated by Rod (1956) for that fault. The earthquake of July 18, 1986 (event 12) is a reverse faulting focal mechanism. It is not very clear to which fault it could be related, since the motion observed on faults in this region is right-lateral strike-slip, tensional, or a combination of both. On July 12, 1988 (13) a predominantly tensional event occurred inside Lake Maracaibo. Unfortunately, the epicenter of this earthquake lies in a highly faulted zone, where it is difficult to correlate it with a specific fault. However, the regional trend in Lake Maracaibo shows several en-echelon, left-lateral strike-slip faults oriented in a N-S direction, and pull-apart basins developing between the faults. We suspect this event beneath Lake Maracaibo was probably associated with one of these pull-apart basins. The event of October 18, 1981 (10) is located near the place where Soulas (1985) has postulated that right-lateral, strike-slip motion on the Boconó fault system changes to reverse faulting. There are several faults in this region showing reverse faulting with an important component of strike-slip motion, in agreement with the focal mechanism of this earthquake. The event of November 17, 1968 (2) is different from all the other mentioned above. All of them are shallow earthquakes, whereas this is an intermediate-depth event (166 km). Its fault plane solution shows the T axis dipping at 44° to the southeast. This event probably occurred within the slab subducted in northern Colombia and Venezuela. In order to compare this event and those of the Bucaramanga nest, 200 km to the south, we modeled the event of August 30, 1973 (5) that occurred in the nest. Both earthquakes show a very similar orientation of the T axes. Finally, examining the direction of principal stresses, the results of this study consistently show horizontal compression in the E-W direction in southwestern Venezuela and in a NW-SE to NNW-SSE direction in northwestern Venezuela.

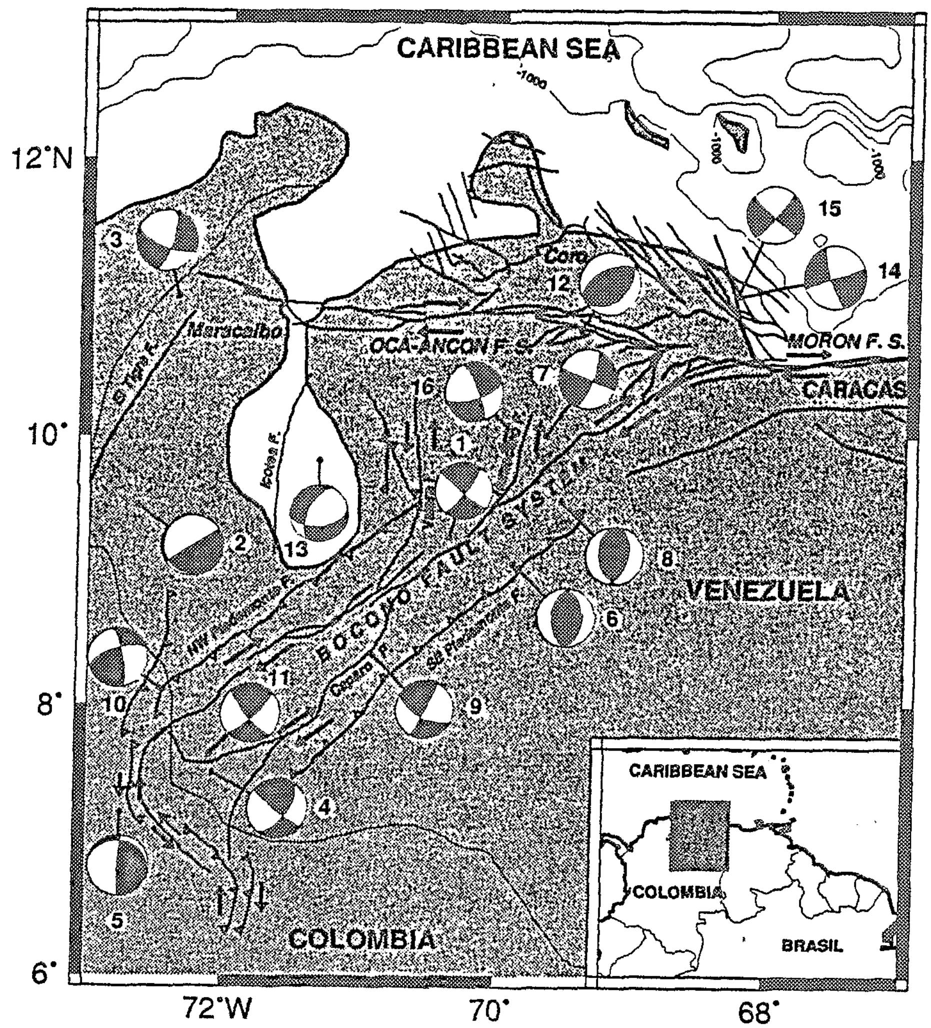

Figure 1. Fault mechanisms determined in this study for earthquakes $m_b \geq 5.4$ occurred in Western Venezuela from 1964 to 1992. The faults are from Soulas, 1986 and Singer et al., 1992. The arrows show the direction of relative motion of the faults. The shadow area in focal mechanisms indicates compressional arrivals. The reference numbers in focal mechanisms are the same on Table 1.

TABLE 1. COMPILATION OF FOCAL MECHANISM SOLUTIONS

Event	Date	Strike°	Dip°	Rake°	Depth(km)	Mo(10^{18}Nm)	Fault
1	650719	38	82	172	14	0.11	Boconó
2	681117	58	90	-82	166	0.81	Subduction
3	691020	16	73	-22	8	0.63	El Tigre
4	700127*	36	61	171	12	-	Caparo
5	730830	183	86	107	175	2.82	Bucaramanga
6	750305	184	47	93	14	0.29	SE Piedemonte
7	750405	21	75	-2	10	0.95	Humocaro
8	771211	173	42	75	8	1.06	SE Piedemonte
9	790505**	28	88	155	16	-	Caparo
10	811018	349	77	28	28	0.82	not known
11	820704*	46	78	166	11	-	Caparo
12	860718	49	41	78	7	0.14	not known
13	880712	83	50	-44	13	0.03	not known
14	890430	162	78	-178	14	3.51	Offshore
15	890504	133	83	-172	12	0.24	Offshore
16	910817	72	69	-169	15	0.12	Humocaro

* Short-period P wave inversion (only waveform), ** Long-period body wave inversion (only waveform)

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