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An overview on the seismicity of Cuba

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Abstract

The seismicity of Cuba is briefly presented together with a few fundamental neotectonic elements of the adjacent Caribbean region. The Cuban seismicity catalogue has been extended back to 1528 and it shows that the largest earthquakes occurred in 1766 and 1852 (I = IX MSK). Two types of seismicity (intraplate and interplate) can be distinguished in Cuba. Western and Eastern Seismotectonic Units correspond to intraplate type and the South-eastern Seismotectonic Unit to interplate type. Western Cuba is characterized by a low frequency of earthquake occurrence. Distribution of epicenters is not regular and the most important events mainly concentrate along two regional active fault system (Nortecubana and Surcubana). Due to the lack of seismic stations in this region, the characterization of seismicity is frequently done on the grounds of historical data available from 1693. The main seismogenic source for Cuba is the Bartlett-Cayman fault system, but inland there are other active structures. Some issues about historical and present day Cuban seismological research are also showed.

Introduction

From a geographical point of view, Cuba is the largest island in the Caribbean region. The most important mountain range in the country is Sierra Maestra located in the southeastern part of the country. In its south border is the oceanic trough Bartlett-Cayman which is considered the most important seismic zone in this region. Earthquake occurrence in the Caribbean region is related to the interaction of very different blocks and plates of the lithosphere (Molnar and Sykes, 1969). Neotectonical investigations carried out by Mann and Burke (1984) in the northern segment of the Caribbean show that a remarkable contrast exists between Cuba and the rest of the Caribbean region concerning earthquakes' magnitude or intensity occurrence.

Since 1959, scientific studies in Cuba have been directed and accomplished only by state institutions. The majority of seismic studies has been presented or published in journals and reports that are not very accessible outside the country. For this reason, this paper tries to summarize some of the most important data about Cuban seismicity.

Tectonic regime

The Caribbean plate is a middle lithospheric plate that acts as a discontinuity between the North-American and South-American plates (Mann and Burke, 1984; Heubeck and Mann, 1991). According to Mann and Burke (1984) the Caribbean plate moves eastwards in relation to the North-America plate with a relative speed of 2 to 4 cm/year. In the plate boundary zone Eastern Cuba moves with a speed of 2 cm/year and Jamaica with 1 to 2 cm/year. In the western boundary of the Caribbean plate a clear subduction process of Cocos and Nazca plates is observed (DeMets et al., 1990; Deng and Sykes, 1995). Nazca and Cocos plates belong to the lithospheric Pacific system. In the eastern part of the Caribbean plate a different process takes place with both American plates subducting under the Caribbean one. This subduction process can be clearly recognized around the Barbados island (Westbrook et al., 1973). In the northern boundary of the Caribbean plate a combination of left lateral movement of Motagua-Bartlett-Cayman (Swan and Oriente)-Septentrional fault system with a small subductive component can be found near the His-

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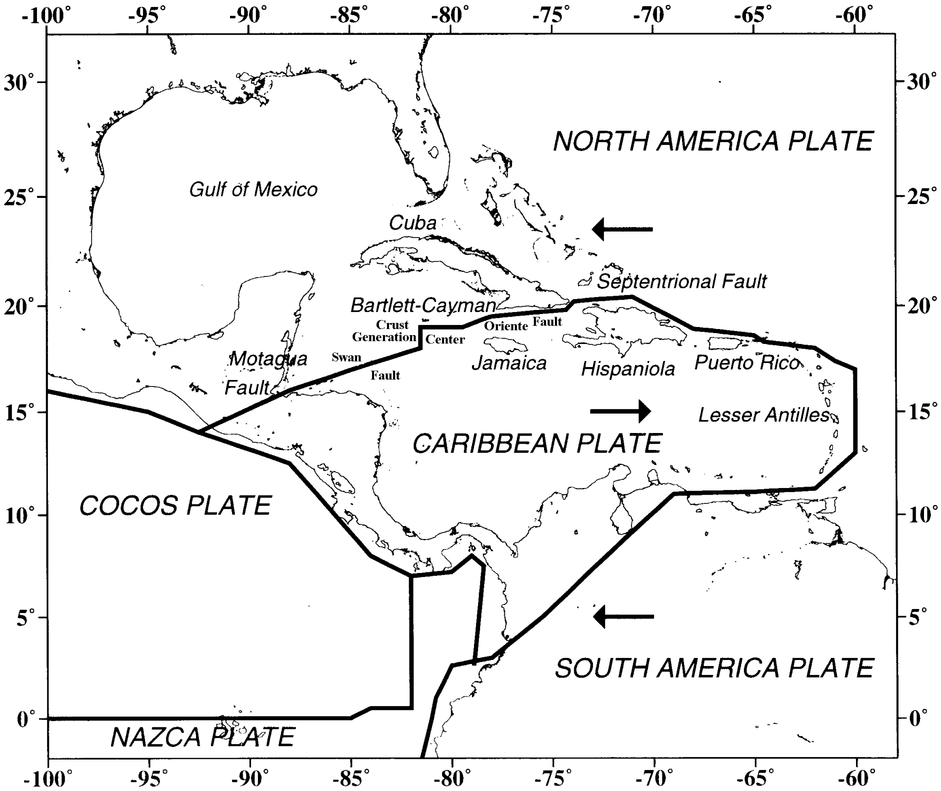

Figure 1. Geodynamic scheme of Caribbean and surrounding regions.

paniola island (Bracey and Vogt, 1971) and Puerto Rico-Virgins Islands (McCann and Sykes, 1984). The southern boundary has a more complex structure. This border is characterized by the presence of two fault systems, of lateral and subductive type (Burke et al., 1978; Mann and Burke, 1984; Molnar and Sykes, 1969; Wolters, 1986) (Figure 1).

A set of oceanic structures and interrelated island arcs exists in the Caribbean. Between the former, there are two deep troughs, Bartlett-Cayman (Cayman and Oriente) and Puerto Rico. The crust under the Bartlett-Cayman trough is thinner than elsewhere in the Caribbean (Rosencratz and Mann, 1991). An oceanic crust generation center (called Mid-Cayman spreading center) exists on the northern boundary of the Caribbean plate (Holcombe et al., 1973). The spreading center has been active since the Middle Eocene and is currently spreading at a rate of about 15 mm/year (Rosencratz et al., 1988). It is a short (110 km) spreading ridge at a left-step between the Swan Islands and Oriente fault zones. The structure of the spreading ridge is typical of slowly spreading oceanic ridges and consists of a V-shaped axial valley that separates two areas of normal faulting.

Table 1. Largest earthquakes of the Cuban and adjacent areas

Date			Coordinates		Magnitude
Day	Month	Year	Lat. N	Lon. W	M_S
07	06	1692	(17,8)	(– 76,8)	(7,5)
04	06	1770	(18,6)	(– 72,6)	(7,9)
07	05	1842	(19,8)	(– 72,2)	(8,2)
23	09	1887	(19,4)	(– 73,4)	(7,9)
29	12	1897	(20,1)	(– 71,2)	7,5
11	10	1918	18,5	– 67,5	7,5
29	07	1943	19,25	– 67,5	7,75
04	08	1946	19,5	– 69,5	8,1

Macroseismic datermination is represented in brackets.

The North America-Caribbean plate boundary zone consists of a 100–250 km wide seismogenic zone of mainly left lateral strike-slip deformation extending over 2000 km along the edge of the Caribbean

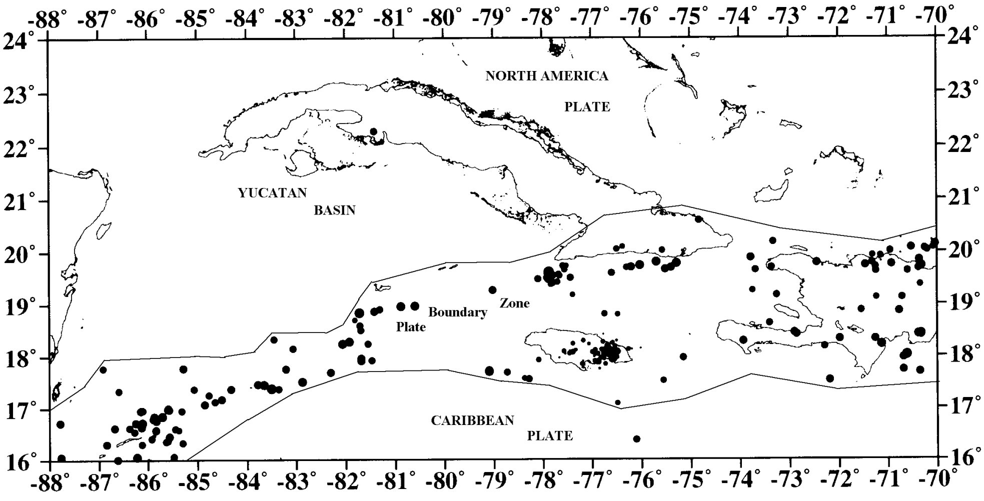

Figure 2. Seismicity of Cuba and its sourroundings (From NEIC, 1970–1996, $M_S > 3$).

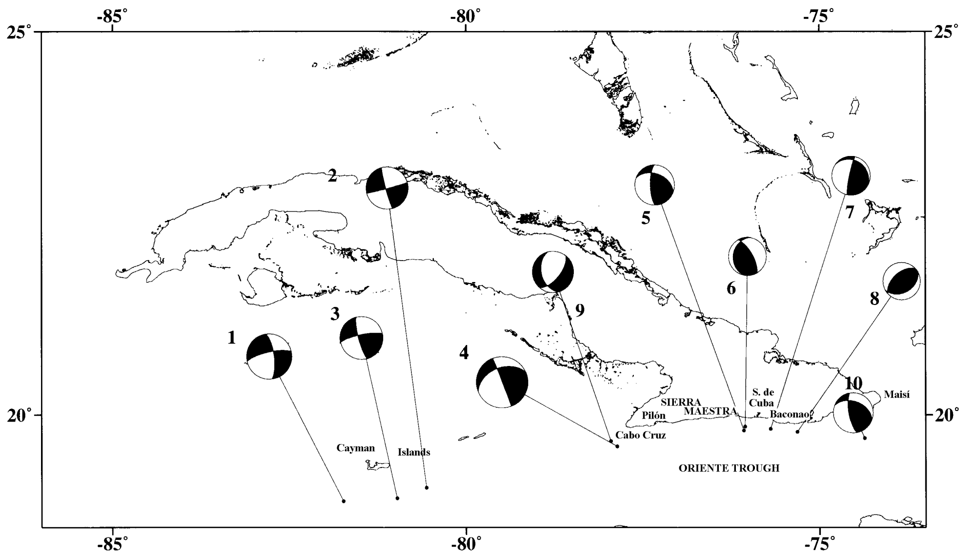

Figure 3. Focal Mechanisms of a Sector of the Northern Boundary of Caribbean Region (From CMT, 1977–1996) including a selection of Moderate and Strong Earthquakes of Cuba (See Table 1).

Sea (Figure 1). *En echelon* folds and thrust faults define a narrow zone with transpressional deformation (called Santiago Deformed Belt by Calais and Mercier de Lépinay, 1990) that extends along the Oriente fault in the eastern half of the southern Cuban margin. Not all Caribbean-North American motion has occurred across the Mid-Cayman spreading center (Burke et al., 1980; Mann et al., 1984; Sykes et al., 1982). Motions of the order of tens of kilometers for several million years probably has been occurring along the southern margin of the eastern Cayman trough. This motion has not been recorded by the signature of ocean crust formed at the Mid-Cayman spreading center.

The island of Cuba can be considered as a block (Iturralde, 1977) with a complex base of continental crust as well as subcontinental and oceanic crust types (Prol et al., 1993). It is located in the southern margin of the North America plate in direct contact with the Caribbean plate, where a mechanism of differential uplift since at least the Upper Eocene has been recognized (Iturralde, 1977). The interaction between plates takes place along the Bartlett-Cayman

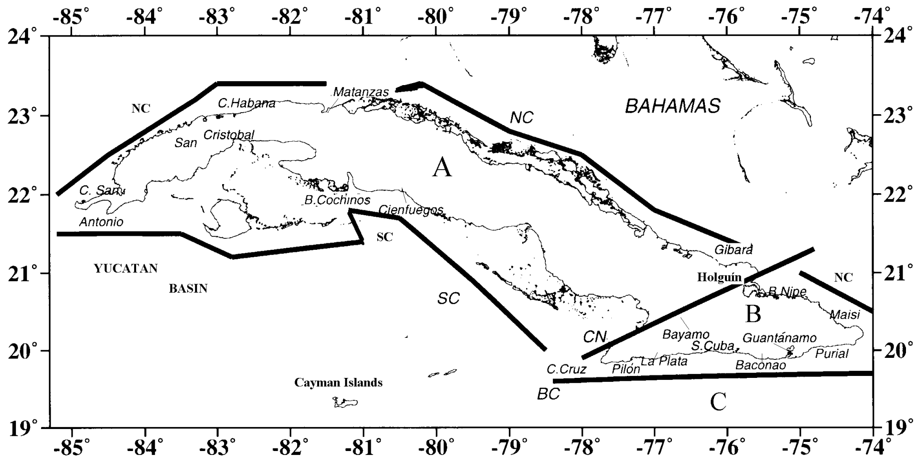

Figure 4. Map of Seismotectonic Units of Cuba. (Seismotectonic Units: A – Western, B – Eastern, C – Southeastern; Seismogenic Structures: BC – Bartlett-Caimán, NC – Nortecubana, SC – Surcubana, CN – Cauto-Nipe).

transform fault system (Sykes and Ewing, 1965) (Figure 1), with earthquake epicenters of different magnitudes and focal mechanisms associated to it. Figure 2 shows a general picture of Cuba and adjacent regions seismicity (1979–1996) using the data of NEIC for earthquakes with $M_s > 3$. The Bartlett-Cayman fault system constitutes a very active boundary (Molnar and Sykes, 1969).

Shallow earthquakes associated with the Swan and Oriente faults west of Cuba exhibit pure left-lateral strike-slip displacement along east-west trending vertical fault planes (Mann and Burke, 1984), but the pattern of faulting changes drastically along the southern Cuban margin (Cotilla, 1993). In the Oriente fault earthquakes show a combination of strike-slip and thrust faulting (Figure 3). All these events have a nodal plane that trends between N30E and N130E and dips between 21° and 69° to the north (Perrot et al., 1997). This nodal plane can be correlated with north dipping/south verging thrust faults that have been mapped in that area. The focal mechanism of August 26th, 1990 in the south of Cabo Cruz (south-western of Sierra Maestra) (No. 4 in Figure 3) shows a clear east-west extension, in an area where normal faults have been mapped by Mossakovsky et al. (1989).

Transpressional strain regime along the southern Cuban margin is not restricted to the Santiago Deformed Belt (Mann et al., 1995). It extends along the whole margin, including Cabo Cruz basin area, where the surficial tectonic structures (Cauto-Nipe) indicate transtensional regime (Cotilla and Franzke, 1994). The discontinuous trace of the Oriente fault with left-stepping offsets generates local tensional strain and causes pull-apart subsidence (Cotilla, 1993). This effect does not preclude the existence of a regional compression component along the fault zone (Figure 4) (Cotilla and Franzke, 1994), necessary to explain geological observations and earthquake focal mechanisms.

The strongest earthquakes occurred and reported in the Greater Antilles (compilation by Cotilla, 1993 using various sources as Alvarez et al., 1995) are listed in Table 1.

Neotectonics has been studied in Cuba by different authors who have used different methods, but all of them, without any exception, show the influence of neotectonic movements in the present conditions of the Cuban relief. Cotilla et al. (1991b) suggested the existence in Cuba of two neotectonics units, the Western and Eastern one, which are well differentiated concerning tectonic, geomorphological, geophysical and seismic characteristics (Figure 4). The neotectonic units have evidently a lower range in respect to the Cuban block. These units contact in a flat pull-apart basin (NE–SW) zone called Cauto-Nipe {CN} which is cut at its southern and northern borders by the Bartlett-Cayman {BC} and Nortecubana {NC} fault systems, and are respectively the external southern and northern limits of the Cuban block (Figure 4). The Western unit occupies the greater spatial extension and its neotectonic activity is significantly less than that of the Eastern one, and is also further away from

the Bartlett-Cayman plate limit. In it predominates a distensional stress regime. A compressive regime is characteristic of the Eastern Neotectonic Unit.

Within the Cuban block there are some other smaller blocks with differential movements (Cotilla et al., 1991b; Díaz and Lilienberg, 1989). Considering neotectonic characteristics, spatial, temporal and energy distributions of earthquakes, Cotilla et al. (1991a) defined two seismotectonic units [SU] in the island (Western {A} and Eastern {B}) and a third offshore (Southeastern {C}). The first two coincide geographically with the homonymous neotectonic units and plate limits. Results of Prol et al. (1993) confirm this.

In general, the relationship of earthquakes with the general plate structure of the area is understood, but the detailed association between destructive earthquakes and active tectonic features is extremely complex and not known in depth (Cotilla, 1993). In this sense, there is not a close correlation of seismic events with individual faults in Cuba (Alvarez et al., 1985) but intraplate seismicity appear to be localized along the pre-existing zones of crustal weakness (Sykes, 1978).

Seismographic instrumentation

The Cuban seismograph network is operated by the National Seismological Research Center (CENAIS = Centro Nacional de Investigaciones Sismológicas) founded in 1992 in Santiago de Cuba. It developed from the Institute of Geophysics and Astronomy (IGA = Instituto de Geofísica y Astronomía) in which a Department of Seismology existed since the 1960s. In Cuba there are generally problems to find good sites for stations with a low level of noise. Although Cuban seismograph regional stations are all located on very good, unweathered rock (granite, gneiss and limestones), it is obvious that their sensitivity is different.

The first Cuban seismological station was installed by the Jesuits of Belén Observatory in 1907 and remained in operation until the 1920s (in Luyanó nearby Ciudad de La Habana). Unfortunately, not even a single seismogram remains. It had two seismometers of Bosch-Omori type (with recording on smoked paper) oriented N–S and E–W. This instrument permitted the recording and analyzing of earthquakes, as for example the 28 February 1914 Gibara event. That event (Table 2) had its epicenter in the northern part of the Holguín province. The seismogram of this event was destroyed in 1961. The only remaining witness is the report of Gutiérrez – Lanza to the press (‘La Nación’, 1914).

The initial objective of the Cuban seismic network was fundamentally to monitor the Bartlett-Cayman structure, the main seismic zone of Cuba (Table 3). Technical and material supports came from the former Soviet Union and German Democratic Republic. Nevertheless, setting up of seismological stations in the country has been mainly aimed towards the needs of nuclear industry (Nuclear Power Plant = CEN Central Electronuclear) like Juraguá in the Cienfuegos province and Gibara-Bariay in the Holguín province. The trend has been to remove these stations from their sites once the research period is over and to relocate them in order to complete the national network. For this reason, the seismological stations Pinares, Las Mercedes and Maisí were built with the equipment of Cienfuegos at the end of the 1970s. This allowed a greater and better coverage of Eastern Cuba, and in particular of the Bartlett-Cayman seismogenic zone. The stations used three component electromagnetic seismometers SKM-3 (maximum dynamic magnification {mdm} of 30000–80000 and at 0,1–1 s period) and SK (mdm of 1000 and at 2–20 s period) with galvanometric recorders (in photographic paper).

The seismotectonic investigations at the northeastern part of the Western SU (Holguín province) showed the need to build a seismological network to study mainly the Nortecubana structure. It recorded from 1988 to 1990. The equipment of the five new stations (Bazán {BAZ}, Holguín {HOL}, Manatí {MAN}, Tumbadero {TUM} and Cauto) was the same as for the other stations. Due to very bad soil conditions Cauto was removed and it is not represented in Figure 5.

The second seismological station Soroa (SOR) started to work in 1964. It is located in the touristic area of the same name and close to the epicentral zone of the 1880 San Cristóbal event, very close to the Pinar fault, considered an important seismic zone (Chuy et al., 1988a; Orbera et al., 1990). This station has proved to possess a good level of detection for regional and teleseismic events, but no local event has been registered or reported.

Cascorro (CCC) has turned out to be the best located of all Cuban stations and also that with the best technical characteristics. It allows the detection of near and far events. It possesses both photographic and visual recorders. Both have seismometers KS-M1 (mdm of 45000 and 100000–500000, respectively).

Table 2. Selection of moderate and strong earthquakes by regions of Cuba

Date			Locality	Intensity	M_s	Coordinates		No.
Day	Month	Year	(Province)	(MSK)		Lat. N	Lon. W	
–	–	1551	Bayamo (Granma)	8	(5.8)	(20.4)	(– 76.6)	1
12	06	1766	S. de Cuba (S. de Cuba)	9	(7.5)	(19.90)	(– 76.10)	2
05	01	1824	Trinidad (s. Spíritus)	6	(4.3)	(21.8)	(– 79.98)	3
20	08	1852	S. de Cuba (S. de Cuba)	9	(7.3)	(19.75)	(– 75.32)	4
12	08	1873	Remedios (Las Villas)	6	(4.5)	(22.48)	(– 79.55)	5
23	01	1880	San Cristóbal (P. del Río)	8	(5.9)	(22.8)	(– 83.0)	6
24	01	1909	Trinidad (S. Spíritus)	6	(4.3)	(21.8)	(– 79.98)	7
28	02	1914	Gibara (Holguín)	7	(6.2)	(21.30)	(– 76.20)	8
03	02	1932	S. de Cuba (S. de Cuba)	8	6.75	19.82	– 75.50	9
15	08	1939	Remedios– Caibarién (Las Villas)	7	5.6	22.5	– 79.25	10
30	07	1943	Trinidad (S. Spíritus)	6	(4.6)	(21.85)	(– 80.10)	11
07	08	1947	S. de Cuba (S. de Cuba)	7	(6.3)	19.75	– 75.20	12
08	04	1974	Esmeralda (C. de Avila)	6	(4.5)	(21.80)	(– 78.05)	13
19	02	1976	Pilón (Granma)	8	5.7	19.88	– 76.87	14
24	10	1976	La Felicidad (Las Villas)	5–6	(4.1)	(21.97)	(– 79.98)	15
11	06	1981	Alonso de Rojas– La Coloma (P. del Río)	5	(3.7)	(22.20)	(– 83.48)	16
16	12	1982	Torriente– Jagüey Grande (Matanzas)	6	5.0	22.6	– 81.25	17
26	08	1990	Suroeste de Cabo Cruz (Granma)	7	5.1	19.59	– 77.87	18
25	05	1992	Suroeste de Cabo Cruz (Granma)	7	6.9	19.61	– 77.87	19

Macroseismic determination is represented in brackets.

Table 3. Seismological Network of Cuba

Name	Abbreviation	Location (Province)	Year	Coordinates		Type of Station		Altitude (m)
				Lat. N	Lon. W	Regional/ Local	Components/ Seismometers	
Soroa	SOR	Pinar del Río	1964	22,740	– 83,000	R	3 (SKM-3)	206
Río Carpintero	RCC	S. de Cuba	1965	19,994	– 75,696	R	3 (SKM-3)	100
Pinares de Mayarí	PIN	Holguín	1979	20,067	– 75,467	R	3 (SKM-3)	647
Las Mercedes	LMG	Granma	1979	20,167	– 77,017	R	3 (SKM-3)	200
Maisí	MAS	Guantánamo	1979	20,200	– 74,233	R	3 (SKM-3)	350
Cascorro	CCC	Camagüey	1982	21,200	– 77,433	R	3 (SKM-3, KS-M1)	90
Holguín	HOL	Holguín	1985	20,540	– 76,400	R	3 (SKM-3)	50
Tumbadero	TUM	Holguín	1986	21,400	– 75,580	R	3 (SKM-3)	20
Manatí	MAN	Camagüey	1986	21,283	– 76,917	R	3 (SKM-3)	?
Bazán	BAZ	Holguín	1987	20,600	– 75,267	R	3 (SKM-3)	?
La Julia	JUL	S. de Cuba	1988	19,954	– 75,580	L (TLN)	1 (SK)	?
Villalón	VIL	S. de Cuba	1988	20,077	– 75,737	L (TLN)	1 (SK)	?
Boniato	BON	S. de Cuba	1988	20,081	– 75,901	L (TLN)	1 (SK)	?
Baconao	BAC	S. de Cuba	1989	19,920	– 75,455	L (TLN)	1 (SK)	?
La Margarita	MAG	S. de Cuba	1989	20,030	– 76,044	L (TLN)	1 (SK)	?
Loreto	LOR	S. de Cuba	1989	20,095	– 75,588	L (TLN)	1 (SK)	?
Palenque	PAL	S. de Cuba	1989	19,988	– 75,450	L (TLN)	1 (SK)	?
Trucutu	TRU	S. de Cuba	1989	20,010	– 75,500	L (TLN)	1 (SK)	?
Juraguá	JUR	Cienfuegos	1995	22,065	– 80,516	R	3 (SKM-3)	20

R – Regional (conventional); L – Local; TLN – Telemetric.

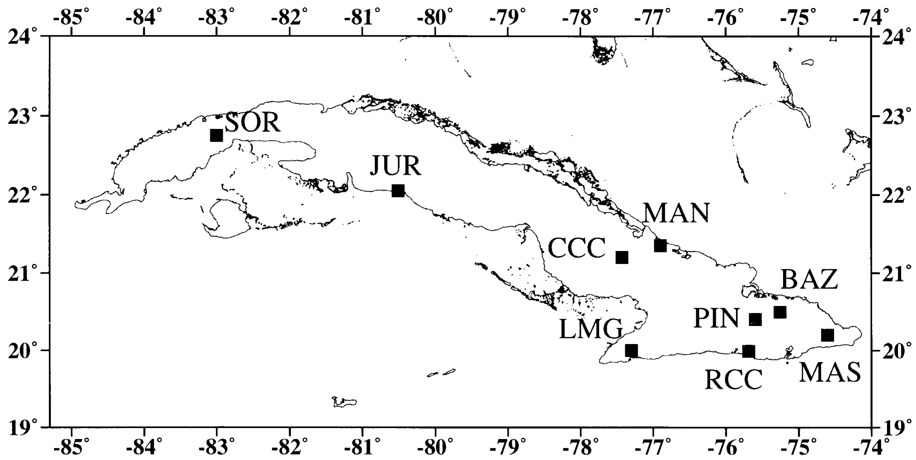

Figure 5. Stations of the Cuban Seismological Network (operating: SOR – Soroa, JUR – Juraguá, CCC – Cascorro, MAN – Manatí, LMG – Las Mercedes, RCC – Río Carpintero, MAS – Maisí, BAZ – Bazán, PIN – Pinares de Mayarí. Around RCC is located the telemetric network but no represented).

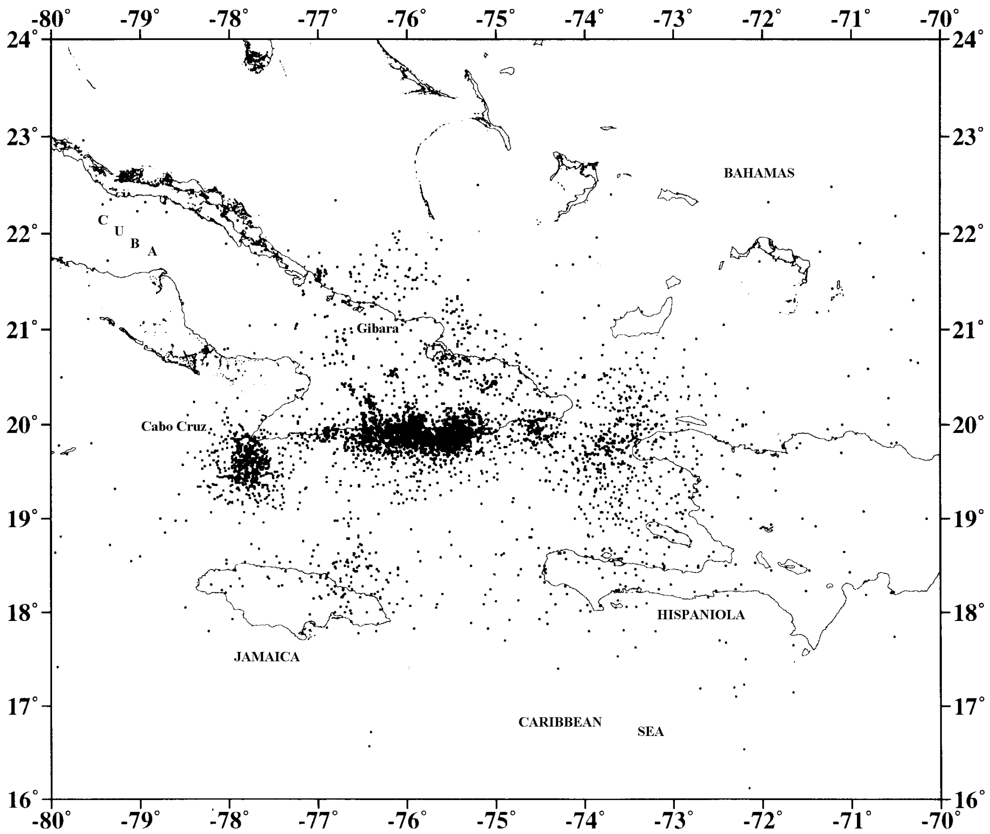

Figure 6. Epicenters Determined by the Eastern Cuban Network (1979–1996, $M_s < 4$).

The Río Carpintero (RCC) station included also an equipment (of the soviet type CHISS with seismometer S-5-S) which permitted recording in eight frequency channels (0,03–4 s). It was in operation from 1983 to 1985 (González et al., 1989).

Recently, in 1995, a seismological station Juraguá (JUR) has been designed and installed by Cuban specialists in the Juraguá nuclear power plant construction area in order to fulfill the requirements of the International Organization of Atomic Energy (0IEA). The obtained records mainly show: (1) the good selection of the noise/signal ratio (with independence of the distance of the station to the coast); (2) an important level of records of local and near events (which is in total opposition with the results of the 1970s network). Nevertheless, Soroa and Juraguá are insufficient to obtain a good coverage of the Western SU.

In addition to the stations listed in Table 3, in IGA-CENAIS has at different stages operated about a dozen temporary stations. These stations were located in places scattered over the whole of the Cuban territory and they have operated only few days each. Due to the present geometric arrangement and the number of Cuban stations a very strong difference in the earthquake determinations exists. The B and C seismotectonic units are therefore the best covered area. Figure 6 shows epicenters determined by the so called Eastern Cuban network and it is possible to observe different clusters of epicenters and their relations with the seismogenic zones indicated in Figure 4.

Seismological reports of Alvarez et al. (1985) allowed to define the immediate and future lines of the National Seismological Service research more adequately (Cotilla, 1984). As a result, first steps towards the development and construction of a small telemetric network (8 stations) (TLN) in the surroundings of Santiago de Cuba were given (López et al., 1988) (Table 3). That network is a result of the joint participation of Cuban specialists from different institutions and constitutes an important step towards better earthquake monitoring (López et al., 1988). All these stations are equipped with SK seismometer (maximum dynamic magnification of 300000–500000 and at 0,05–1 s period) of Z component. They are teletransmitted by radio to CENAIS in Santiago de Cuba city. Other proposals were the substitution and/or adjustment of the photographic registers by those of visual recording in some stations; as well as the aim to carry out earthquakes' analysis in real time.

The Cuban seismic network works at present with great limitations (in electric energy supply, air-conditioning, communication system, electronic devices, etc.). Adequate operation is also hindered by problems of instability of its staff and delays in maintenance and reparations (Cotilla, 1984).

Seismicity and seismic risk

Already in the XIXth century Benito Viñes (Director of the Belén Observatory) had perceived without instrumental data the remarkable difference of seismicity between eastern and western Cuba (Gutiérrez – Lanza, 1914). Similar conclusions were reached by Alvarez et al. (1985), who found that the seismicity of Cuba is of two types: intraplate and interplate. Interplate type affect its southeastern region, where earthquakes occur mainly in the BC zone, and the other one of the interior of plates type affecting the rest of the country, where the events occur in tectonic faults characterized by long periods of inactivity (Cotilla, 1993).

It is important to note that from XIXth century and until the 1950s seismological studies have attracted the attention of many specialists as for example Viñes, Salteraín, Poey, Montelieu, Montesus de Ballore, Morales and others, a fact which allowed the preparation of Cuban catalogues and to carry out field investigations of earthquakes as those of San Cristóbal in 1880 and Santiago de Cuba in 1932.

In modern times the seismicity of Cuba has been studied by different authors in terms of regional seismicity (Alvarez and Menéndez, 1969; Alvarez and Buné, 1977), in terms of historical seismicity (Alvarez et al., 1973; Chuy and Rodríguez, 1980; Chuy et al., 1983, 1983a; Chuy et al., 1988) and also considering both factors (Alvarez, 1983; Alvarez et al., 1985).

Damage reports for several historical earthquakes in the country have been published (Poey, 1855a, b, 1857; Viñes and Salteraín, 1880). Seismological catalogues of Cuba, Hispaniola, Jamaica and the Caribbean region (Mountelieu, 1931, 1932; Morales, 1931, 1933; Poey, 1855a, b, 1857; Tomblin and Robson, 1977) were completed and isoseismal maps prepared and used in different Cuban projects (Chuy et al., 1980, 1983, 1983a, 1984, 1988; González et al., 1994, 1995; Orbera et al., 1990). Nevertheless, the earthquake catalogues are still not complete (Cotilla et al., 1994). The quality of data from macroseismic Cuban catalogues varies from event to event. Even though some earthquakes have been studied and isoseismal maps (with a supposed increase of the epi-

Table 4. Focal mechanism data (1–8 of the CMT; 9 by Perrot et al., 1997).

No.	Coordinates		h	Plane 1			Plane 2			Mo	Date
	Lat. N	Lon. W	km	Strike	Dip	Slip	Strike	Dip	Slip	dyn-cm	dd.mm.aa
1	18.85	– 81.73	10	352	71	–163	257	74	–20	1.2×10^{25}	25.07.62
2	19.03	– 80.56	33	165	85	–178	75	88	–5	3.1×10^{24}	27.06.92
3	18.89	– 80.97	10	258	77	12	165	79	166	4.8×10^{24}	26.08.91
4	19.58	– 77.86	33	248	43	–1	339	89	–133	2.0×10^{26}	26.08.90
5	19.79	– 76.07	10	43	27	179	179	72	130	1.3×10^{24}	13.11.78
6	19.84	– 76.05	33	190	26	127	330	69	73	6.3×10^{23}	22.05.90
7	19.81	– 75.69	33	302	21	21	192	83	109	7.3×10^{23}	09.04.90
8	19.77	– 75.31	10	61	38	100	228	53	82	4.5×10^{23}	01.09.85
9	19.61	– 77.87	33	170	89	145	261	55	1	2.0×10^{19}	25.05.92
10	19.74	– 74.36	60	286	29	43	157	71	112	7.5×10^{16}	12.02.89

center determination reliability) obtained most of them have scarce data and do not permit a clear association to a seismic zone. There is no uniform knowledge about the historical seismicity of Cuba, but the reliability of results increases towards the eastern part of Cuba (Cotilla et al., 1997). In fact, only epicenter locations of a small of number event is quite precisely known, while a large number of epicenter locations shows a great uncertainty. Cotilla (1993) showed the limitations of the evaluations of the historical macroseismic data (intensity felt at different localities), and of its subsequent interpretations (epicenters, depth, magnitude, intensity lines, etc.). Furthermore, sources of initial data vary (press, chronicles, reports of eyewitness, immediate post – earthquakes interviews, etc.) and not all of them are equally reliable.

Seismological data of Cuba start with the 1528 earthquake (Alvarez et al., 1990). Historical report located this shock in Baracoa city, the first founded in Cuba by the Spaniards (in 1511) and located on the North coast of the present-day Guantánamo province and it was associated to NC fault system. A selection of moderate and strong earthquakes that have taken place in Cuba appears in Table 2 [taken from (Alvarez et al., 1985; 1995; Chuy et al., 1988) and NEIC]. The largest destructive earthquakes felt in Cuba occurred in a region south of Santiago de Cuba city (B–C fault system) causing widespread material and personal damages (Chuy et al., 1988). Seismic activity in southern Cuba is concentrated south of the coastline which marks the limit of the Southeastern SU (Cotilla et al., 1991a) (Figure 2). One of the strongest concentrations of seismicity is located around Santiago de Cuba city (Figure 6). Besides the events shown on Table 2, there are 10 events of intensity VIII (MSK) and many others of VII in the Eastern region.

Instrumental epicenters (sufficiently large magnitudes) located using world data are limited to the plate boundary zone (Figure 2). In the other hand, epicenters determined ($M_s < 4$) from the cuban network (Figure 5) are limited to eastern region (Figure 6). Their hypocenter determinations are not very precise due to the low relation coverage/geometric arrangement of stations (Alvarez et al., 1990; Cotilla, 1993; Cotilla et al., 1994). In the western region of Cuba the situation is worst and was evident with the two recent seismic events *{16.12.82 (Table 2) and 09.03.95 (I = 5; M_s = 2.5; Locality: Ganuza-San José de las Lajas, both in Western SU)}*. For this reason, we do not attempt a discussion of focal depths. Focal mechanism solutions using Cuban network have not been possible due to the geographical distribution of the stations as lack of reliability in the crust models (Cotilla et al., 1994). For these reasons, nine focal mechanism solutions were taken from CMT and Perrot et al. (1997) (Table 4) and are represented in Figure 4. As expected, a left-lateral strike-slip mechanism is present in the northern Caribbean region (– 74.0°/– 86.0° W, 18,5°/24° N). Data reveal (solution numbers 1, 2, 3) a left-lateral strike-slip mechanism with a small normal component of NE direction associated to the spreading center – Cabo Cruz sector. That result is similar to others obtained before to 1984 which were discussed in Cotilla (1993). In this sector the fault system BC has the same characteristics (Mann and Burke, 1984; Hernández, 1989). Eastwards mechanism solutions change due to the change in structural pattern (also reflected in the relief) (Hernández, 1989; Cotilla

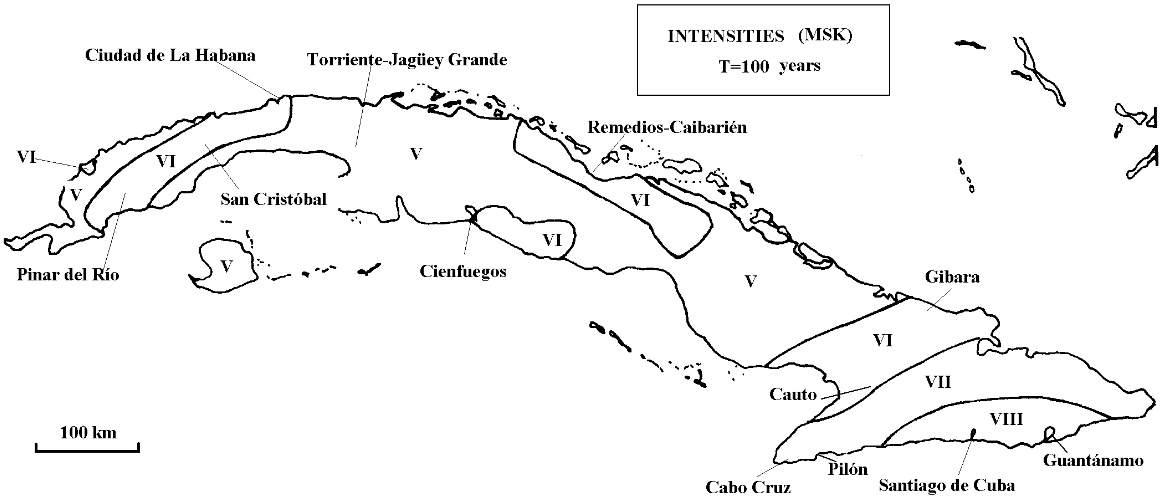

Figure 7. Seismic Hazard Map of Cuba ($T = 100$ years).

and Franzke, 1994). Here, two mechanisms (4, 9), which are related to the knot of faults BC and CN (in Cabo Cruz) show also left-lateral strike-slip, but with a larger normal component of NE direction. Normal faults are mapped in the Eastern Seismotectonic Unit (Cotilla, 1993). For most solutions P axis is orientated to NE–SW. The focal mechanisms (7, 8) are associated to BC and Baconao fault systems (where the event of 1932 occurred). Solutions 5, 6, 7 and 8 indicate a thrust mechanism with a small left-lateral strike-slip component. P axis is near to E–W direction (parallel to Bartlett-Cayman trough). Orientation of focal mechanisms can be interpreted as changes in tectonic stress so Mann et al. (1995) proposed changes in the stress regime to the northeastern Caribbean plate margin and Calais and Mercier de Lépinay (1990) have also described transpressional deformation of Late Pliocene-Recent age along the Oriente fault zone south of Cuba. The orientation of folds and thrust faults suggests their origin by left lateral strike-slip faulting along the Oriente fault rather than north-south closure of this segment of the Cayman Trough. A kinematic analysis by Cotilla and Franzke (1994) showed that displacements along the thrust faults in Baconao area are south-southeast directed, where the largest density of epicenters is located and the major neotectonic deformations are reported (Hernández, 1989; Cotilla, 1993).

One of the basic objectives of the Cuban seismological investigations is to obtain seismic regionalization maps. The first attempt was the 'Map of Seismicity of Cuba, Scale 1:1 000 000' included in National Atlas (Alvarez, 1970). This map is based on historical macroseismic data. A comprehensive study of base materials, taking into account some quantitative aspects of seismicity were used to prepare the 'Seismic Intensity Map of Cuba for Recurrence Periods of 100 years, Scale 1:1 000 000' (Chuy and Rodríguez, 1980). Nevertheless, some zones appear in it without data. In 1981–1982 the occurrence of a small number of events in the surroundings of that zones was used to prepare the new 'Seismic Intensity Map of Cuba by Macroseismic Data, Scale 1:1 000 000' (Chuy et al., 1983). All these maps were used and included in the Cuban code of 1985.

The quantitative evaluations of seismic hazard in Cuba were not accomplished until the mid decade of the eighties with the project of Alvarez and Buné (1985) for the eastern Cuba area [16° N to 24° N and 71° W to 81° W] and the Rubio (1985) one for the whole Cuban territory. Another attempt to obtain a map of seismic regionalization of Cuba was carried out by Alvarez et al. (1991) who combined data from eastern and western Cuba, but they were unable to obtain a uniform quantitative estimate for all the territory (Figure 7). This map coupled the intensity expected in the next 100–300 years in the intraplate zone with the intensity expected for the next 100 years in the eastern region (the latter after Alvarez and Buné, 1985). The unequal treatment of data from different seismotectonic zones moderates the validity of this map, and therefore a new processing of data was carried out by

Rodríguez (1996) who used the seismotectonic model of Cotilla et al. (1994).

Conclusions

1. The seismicity of Cuba as a part of the Caribbean region is a consequence of neotectonic processes.
2. According to plate tectonics two types of seismicity are recognized in Cuba: (a) interplate (in the Southeastern Seismotectonic Unit where a direct interaction between the North American and Caribbean plates is detected and the stress accumulated is released seismically); (b) intraplate (the greatest part of Cuba which comprises the Western and the Eastern Seismotectonic Units).
3. The tectonic regime along the North American and Caribbean plate boundary zone is transpressional. Perturbation of the general stress field in the Southeastern SU is caused by the movement toward NE of the northern part of Caribbean, the plate boundary zone (a deformable element) that overthrust (little) the Caribbean and North American plates and acts like a wedge. This is a deformable element that overthrusts the Caribbean an Northamerican plates and acts like an orogenic wedge.
4. Cuba's recent geodynamics is featured by generally moderate tectonic movements and a spatial differentiation in blocks of distinct sizes as well as a clear arrangement of the seismicity along certain geological faults.
5. The problem of seismic source zones delimitation in Cuba with scarce tectonic and seismic data is not easy to solve with high accuracy. For that reason there exist different seismotectonic interpretations.
6. Hypotheses related to the complex tectonic setting of relatively weak seismicity in intraplate zone must be checked by detailed investigation, mainly for local microseismicity, historical research on badly understood earthquakes and neotectonic field observations.
7. In order to get a better knowledge of the seismicity of the Cuba is important to relocate earthquakes using both World Wide and Cuban stations and new seismographic equipment.

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