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Alternative Interpretation for the Active Zones of Cuba[1]

Mario Octavio Cotilla Rodríguez
Departamento de Física de la Tierra, Astronomía y Astrofísica I. Facultad de CC Físicas, Universidad Complutense de Madrid
e-mail: macot@fis.ucm.es
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Abstract—An alternative explanation to the seismoactivity of Cuban faults is presented. The model is a consequence of the interaction between Caribbean and North American plates. It is made with 12 geodynamic cells form by a set of 13 active faults and their 14 areas of intersection. These cells are recognized morphostructural blocks. The area between Eastern Matanzas and Western Cauto–Nipe is excluded because of the low level of seismic information. Cuba has two types of seismogenetic structures: faults and intersection of faults.

Keywords: active zones, Cuba, fault, neotectonics, seismicity, seismotectonics
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INTRODUCTION

Seismic activity in Cuba is known almost since the arrival of the first Europeans to America. This knowledge is associated with stable human settlements in different parts of the Cuban archipelago (Fig. 1). The first reports of earthquakes appear in the Eastern region, where the colonization began (Table 1).

The population, including the ruling caste, has historically considered that the seismicity of Cuba is, solely and exclusively, associated with the Eastern region and in particular to the Santiago de Cuba city (see Fig. 1). For this reason, the occurrence of seismic events in other areas of the country produces stupor and astonishment in citizenship. Cuba has been affected differently by strong earthquakes that occurred in La Española (Haití and República Dominicana), Jamaica, and Islas Caimán (Fig. 2b, Table 2). Such earthquakes are not themselves and should be not used for the determination of the activity of Cuban faults.

In 1880 Viñes and Salteraín indicated with an extensive field-work in Western Cuba a scientific procedure to associate an earthquake to a fault. The author has shown to Cuba that the low level of knowledge of active faults and the sparse of seismic network have negatively influenced in the seismotectonic and seismic hazard researches. Also in previous papers we discussed perhaps without much success the great importance of Cuban historical documents and in particular their relationship with the faulting. This is the main goal of our paper.

[1] The article is published in the original.

TECTONIC AND SEISMICITY

We mainly used the following data in order to present this part [1–4, 9, 15–17, 22, 59, 62, 81, 83, 85, 87, 88, 90, 91, 94, 97–99, 106, 110, 114, 120, 135, 137]. Also, recent results [11–13, 75, 136] allowed sustain our former proposals about the complicate Caribbean plate structure and regime [34, 55]. This is the initial support to develop our model.

The relative motion between the Caribbean and North American plates (Fig. 2a) controls the tectonic regime of the area at a regional scale. It was argued that the eastward motion of the Caribbean plate relative to the North American plate occurs at a rate of 12–40 mm/yr. It was estimated 18 ± 3 mm/yr for Southeastern Cuba [59, 62]. The eastward motion of the Caribbean plate produces a left-lateral strike slip deformation along the Bartlett–Caimán fault zone (BCF) and left-lateral strike slip along the Walton–Plantain Garden–Enriquillo fault zone. There are four important local structures affect the tectonic

Table 1. Main Cuban historic earthquakes

No.	Date	M/I (MSK)	Coordinates
1	18.10.1551	6.6/9	19.6 N/77.8 W
2	11.02.1678	6.75/8	19.9 N/76.0 W
3	11.06.1766	7.5/9	19.9 N/76.1 W
4	14.10.1800	6.4/8	19.9 N/75.9 W
5	18.09.1826	6.4/8–9	19.75 N/75.35 W
6	07.07.1842	6.8/8	19.75 N/75.35 W
7	20.08.1852	6.5/8	19.75 N/75.33 W
8	28.01.1858	6.5/7	19.9 N/76.0 W
9	23.01.1880	6.2/8	22.7 N/83.0 W
10	23.09.1887	7.9/9	19.4 N/73.4 W

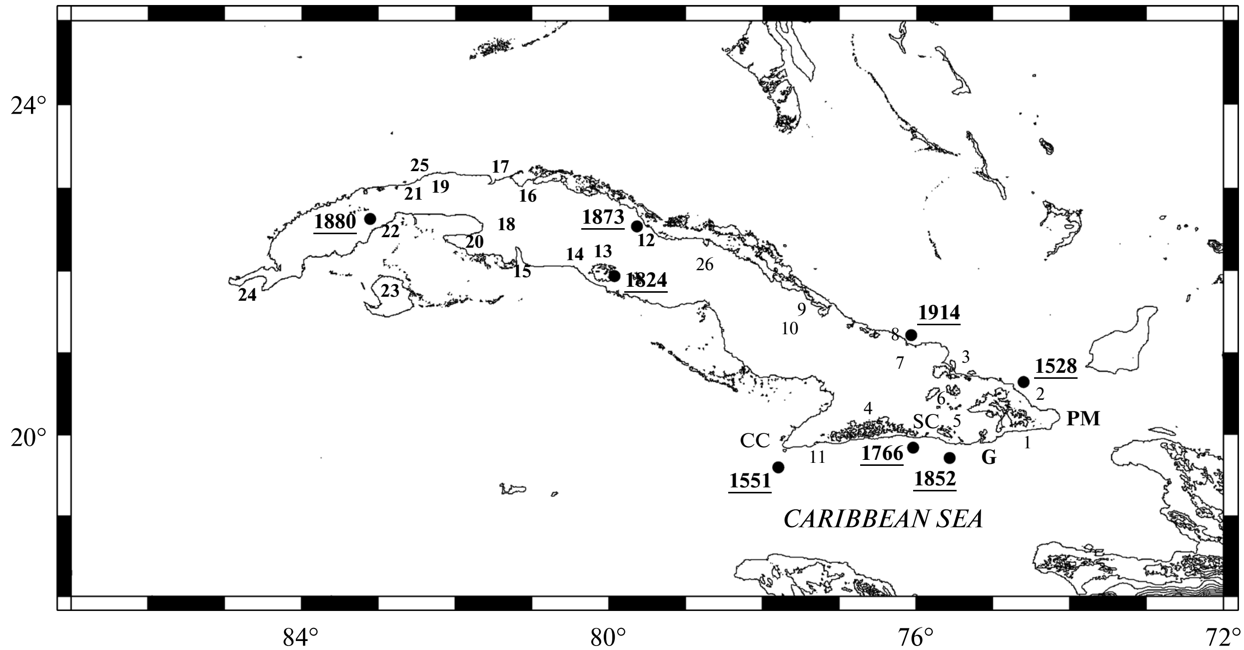


Fig. 1. Historical Cuban earthquakes. Earthquake: black circle—epicenter; 1551—year. Locality: CC—Cabo Cruz, G—Guantánamo, PM—Punta de Maisí, SC—Santiago de Cuba, 1—San Antonio del Sur, 2—Moa, 3—Nipe, 4—Sierra Maestra, 5—Gran Piedra, 6—Sierra de Nipe–Cristal, 7—Holguín, 8—Gibara, 9—Puerto Padre, 10—Camagüey, 11—Pilón, 12—Remedios–Caibarién, 13—Guamuhaya, 14—Cienfuegos, 15—Bahía de Cochinos, 16—Bahía de Cárdenas, 17—Bahía de Matanzas, 18—Torriente–Jagüey Grande, 19—San José de las Lajas, 20—Ciénaga de Zapata, 21—Soroa, 22—San Cristóbal, 23—Isla de la Juventud, 24—Cabo de San Antonio, 25—Ciudad de La Habana, 26—Cubitas.

regime in the area: (1) the Mid-Cayman rise spreading center, (2) the Cabo Cruz basin, (3) the Santiago de Cuba deformed belt, (4) the Maisí area (Fig. 3a). These structures account for more than 85% of the seismicity along this part and related with BCF and included in the Plate Boundary Zone (PBZ) (Fig. 3b). The general pattern of the seismicity in the Caribbean region is in Fig. 3. Large earthquakes occur along the plate boundary near La Española, Jamaica and Puerto Rico islands but since the 18th century only one event has reached a magnitude of 7.0 (12.01.2010, Haití) (see Fig. 2b).

Table 2. The strongest Caribbean earthquakes near Cuba

No.	Date	Magnitude	Seismic source
1	18.10.1751	7.25	Puerto Príncipe, Haití
2	04.06.1770	7.5	Puerto Príncipe, Haití
3	12.01.2010	7.0	Puerto Príncipe, Haití
4	07.05.1842	8.2	Cabo Haitiano
5	23.09.1887	7.9	Mole de San Nicolás, Haití
6	29.12.1897	7.5	Puerto Plata, R. Dominicana
7	08.08.1946	8.1	Matanzas, R. Dominicana
8	07.07.1852	7.7	Islas Caimán
9	06.05.1905	7.0	Islas Caimán
10	20.02.1917	7.4	Islas Caimán
11	14.10.2004	6.8	Islas Caimán
12	07.06.1692	7.7	Port Royal, Jamaica
13	14.01.1907	6.5	Port Royal, Jamaica

Cotilla [27, 28] considers quite important the results obtained to Cuba by Álvarez et al. [3, 4]. They allowed developing the best way for the knowledge of the seismicity and were a second step after the initial period of the Cuban sciences (1492–1960). So, Álvarez et al. [3, 4, 34, 50] studied the focal mechanisms of earthquakes along Southeastern Cuba. They obtained a NE compressive axis on a transpressive scenario. Using geological methods, Calais and Mercier de Lepinay [15–17] studied approximately the same region. They found a composite transtensive–transpressive regime. All these results were confirmed by Cotilla [31]. Also, Cotilla et al. [54] assumed there was only one tectonic stress tensor for the current period, on the basis of the delimited neotectonical structures and their deformations and of the analysis of the focal earthquake mechanisms the existence and influence on the Cuban megablock. After that, data from slickensides, striations, joints and tension gashes were collected at 1600 stations within Miocene–Quaternary formations to evaluate the kinematics and stress history of Cuba. The tensor was obtained by the inverse method. That means the strike and the senses of slip of the fault population was measured in the field. Therefore, it was proposed that there was a transcurrent predominance to the left with reverse faulting

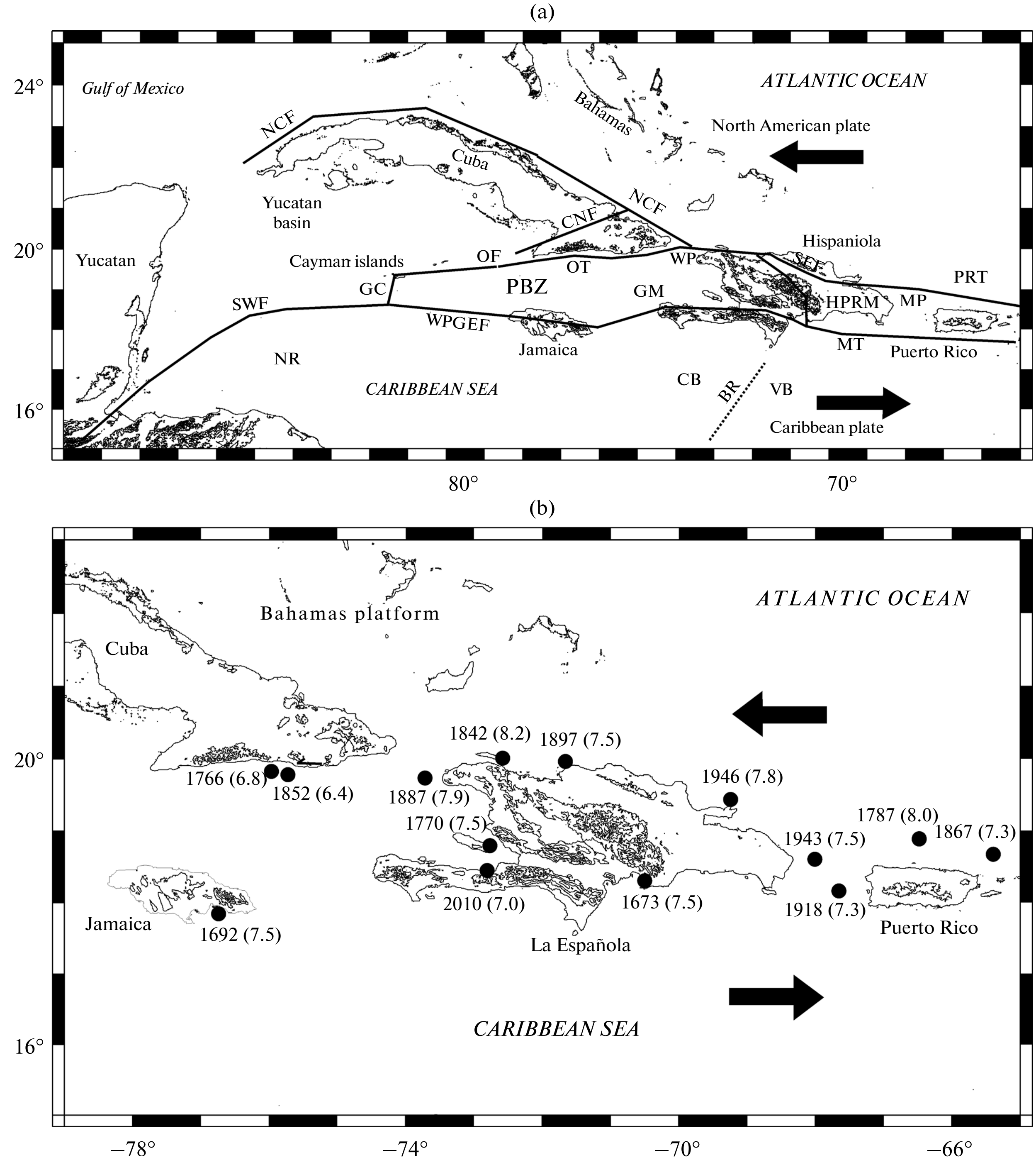
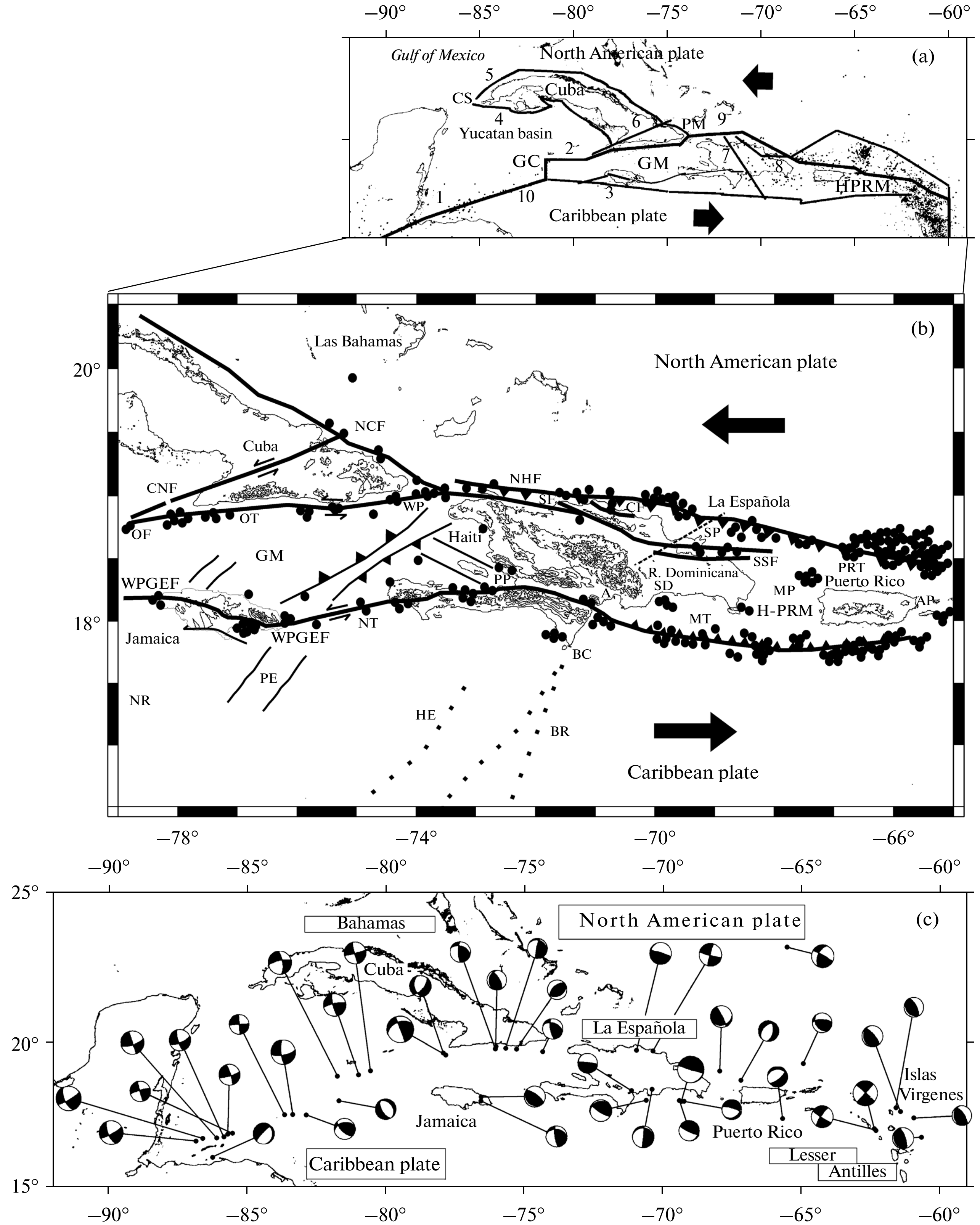


Fig. 2. Caribbean tectonic characteristics. (a) Main tectonic elements and regions of Caribbean—North American plates. Heavy black arrow–sense of the plate movements. With points trace appear the ridge BR—Beata. Other structures: (1) the main fault: CNF—Cauto–Nipe, NCF—Nortecubana, OF—Oriente, SEF—Septentrional, SWF—Swan, WPGEF—Walton–Plantain Garden–Enriquillo; (2) passage: MP—Mona, WP—Windward; (3) island: Cuba, Hispaniola, Jamaica, Puerto Rico; (4) basin: CB—Colombia, VB—Venezuela; (5) microplate: GM—Gonave, HPRM—Hispaniola–Puerto Rico; (6) trough: MT—Muertos, OT—Oriente, PRT—Puerto Rico; (7) PBZ—Plates boundary zone, 8—Mid Cayman Spreading Center (GC).

(b) Most important earthquakes in the surrounding of eastern Cuba. Heavy black arrow: sense of the plate movements. Earthquake: black circle—epicenter; 1766—year; (6.8)—magnitude.


(a)
Gulf of Mexico
North American plate
Cuba
CS
Yucatan basin
GC
GM
PM
HPRM
Caribbean plate
1
2
3
4
5
6
7
8
9
10
(b)
Las Bahamas
North American plate
Cuba
NCF
CNF
OT
OF
GM
WP
NHF
SF
CF
La Española
SP
SSF
Haiti
PP
R. Dominicana
SD
MP
PRT
Puerto Rico
AP
H-PRM
MT
WPGEF
Jamaica
NT
BC
PE
NR
HE
BR
Caribbean plate
(c)
Bahamas
North American plate
Cuba
La Española
Jamaica
Puerto Rico
Islas
Virgenes
Lesser
Antilles
Caribbean plate

component. Also, main axis orientation is close to those obtained by right-dihedra diagrams.

Using focal mechanism data Cotilla and Córdoba [40] (Fig. 3c) obtained the maximum horizontal compression stress (σh_{max}, 90% confidence) for five sectors (Caimán, Cabo Cruz, Sierra Maestra, Santiago de Cuba–Guantánamo and Haiti) following the ideas of Zoback [145]. Also, they applied the Rivera and Cisternas [115] method to those sectors in order to determine the stress tensor in the entire region. A total of 50 focal mechanisms were used. The regional stress directions and the axial ratio that fit best with the available focal mechanism are determined by a grid search of stress ellipsoids under the assumption of uniform stress in the source region. These results confirm what was obtained previously.

Cuba is a megablock in the southern part of the North American plate (see Fig. 3). The active plate boundary runs along the southeastern coast. Álvarez et al. [4] identified two types of seismicity: (1) interplate (or plate edge); (2) intraplate. The first type is due to the direct interaction of the Caribbean and North American plates. It is located in the BCF (or Oriente fault, OF) where occur the greatest number of seismic events and those of greatest magnitude (M_s > 7.0). The intraplate earthquakes take place in the rest of the island territory and the adjacent marine area out of the PBZ. They are significantly less strong and less frequent than the previous mentioned type. Low-magnitude seismicity (M_s < 4.0) occurs throughout the Western region of the island and particularly around Santiago de Cuba city.

Historical earthquake data indicate that the past 500 years Southeastern Cuba has been affected by at least 13 destructive seismic events [27–29, 40, 41, 43]. The seismicity registered in the Eastern region in 1979–1994 by the Cuban network (more than 6 stations) (Fig. 4) indicates that 93% of the earthquakes occur with h < 40 km. Deep seismicity for this region ($h \geq 70$ km) seems to be restricted only to the Sierra Maestra–Santiago de Cuba segment. In general, the seismicity along the PBZ is shallow in the west but increases in depth eastward. It is mainly concentrated along three sectors: (1) Cabo Cruz, (2) Sierra Maestra–Santiago de Cuba, and (3) Maisí. Also the rate of seismicity appears to be different on either side of the Mid-Cayman rise spreading center, 62 and 38% until the Punta de Maisí, respectively. More exactly the rate is ~25% in Cabo Cruz, 9% between Pilón and Uvero, 55% between Uvero and Baconao, and 11% between Baconao and San Antonio del Sur. On this basis we conclude that the OF is seismically active and is very close to two densely-populated centers (Santiago de Cuba and Guantánamo cities). Also, there are other two transversal small structures (Cauto–Nipe and Baconao faults) seismically active that constitute a set of active pull-apart basin and push-up, respectively.

There are at least two main characteristic features of the contemporary seismicity in Eastern Cuba: (1) the occurrence of many earthquakes in clusters or swarms as: (A) Cabo Cruz, (B) Sierra Maestra, (C) Santiago de Cuba, (D) Maisí, (E) Nipe, and (F) Manatí (Fig. 4); (2) The major quantity of seismic energy is released during a relatively small number of strong earthquakes. All of them are associated with OF.

PREVIOUS RESULTS

Various specialists have proposed a block structure for Cuba [5, 14, 47, 48, 52–58, 60, 61, 67–69, 76–80, 82, 89, 92, 109, 123, 124, 128, 129, 131, 132]. There are also similar results for the Caribbean [30, 34, 35, 40, 46, 48, 49, 51, 94, 121, 134]. These results allow sustaining the presence of faults with their interceptions as well as the tilting blocks within the framework of the interaction between Caribbean and North American plates [34, 40, 41, 45, 46, 53, 54].

Benito Viñes Martorell S.J. (19.09.1837–23.07. 1893) and Mariano Gutiérrez Lanza S.J. (26.05.1865–24.12.1943) presented their ideas on the seismicity of Cuba in some conferences and papers [27, 28]. They highlighted the unscrupulous manipulation of data, speculation, the low level and rigor of some scientific publications, newspapers, etc. Also, these specialists showed some differences of activity to the Western and Eastern regions but never ruled out the possibility of occurrence of strong earthquakes in Western Cuba. Also, Pastor [107] discussed this topic

Fig. 3. Simplified tectonic maps of the Caribbean.

(a) Scheme of the plates and microplates locate in the Caribbean and North American contact.

Heavy black arrow: sense of the plate movements. Fault: 1—Chixoi–Polochic–Motagua, 2—Bartlett–Caimán, 3—Walton–Enriquillo–Plantain Garden, 4—Surcubana, 5—Nortecubana, 6—Cauto–Nipe, 7—Bonao, 8—Camú, 9—Septentrional, 10—Swam. Microplates: GM—Gonave, HPRM—Hispaniola–Puerto Rico. Site: Mid Cayman Spreading Center (GC), Cabo de San Antonio (CS), Punta de Maisí (PM).

(b) Localization of Eastern Cuba, Jamaica, La Española and Puerto Rico Islands in the Caribbean—North American Plate Boundary Zone.

Heavy black arrow—sense of the plate movements. Black circle—epicenter. Heavy black line—main fault system: CF—Camú, CNF—Cauto–Nipe, NCF—Nortecubana, NHF—Northern Hispaniola, OF—Oriente, SSF—South Samaná, WPGEF—Walton–Platain Garden–Enriquillo. Microplate: GM—Gonave, HPRM—Hispaniola–Puerto Rico. Trough: MT—Muertos, OT—Oriente, PRT—Puerto Rico. Passage: AP—Anegada, MP—Mona, WP—Winward. Escarpment: HE—Hess, PE—Pedro. Localities: A—Azua, BC—Beata, PP—Puerto Príncipe, SD—Santo Domingo. Ridges: BR—Beata, NR—Nicaragua.

(c) Selection of focal mechanisms.

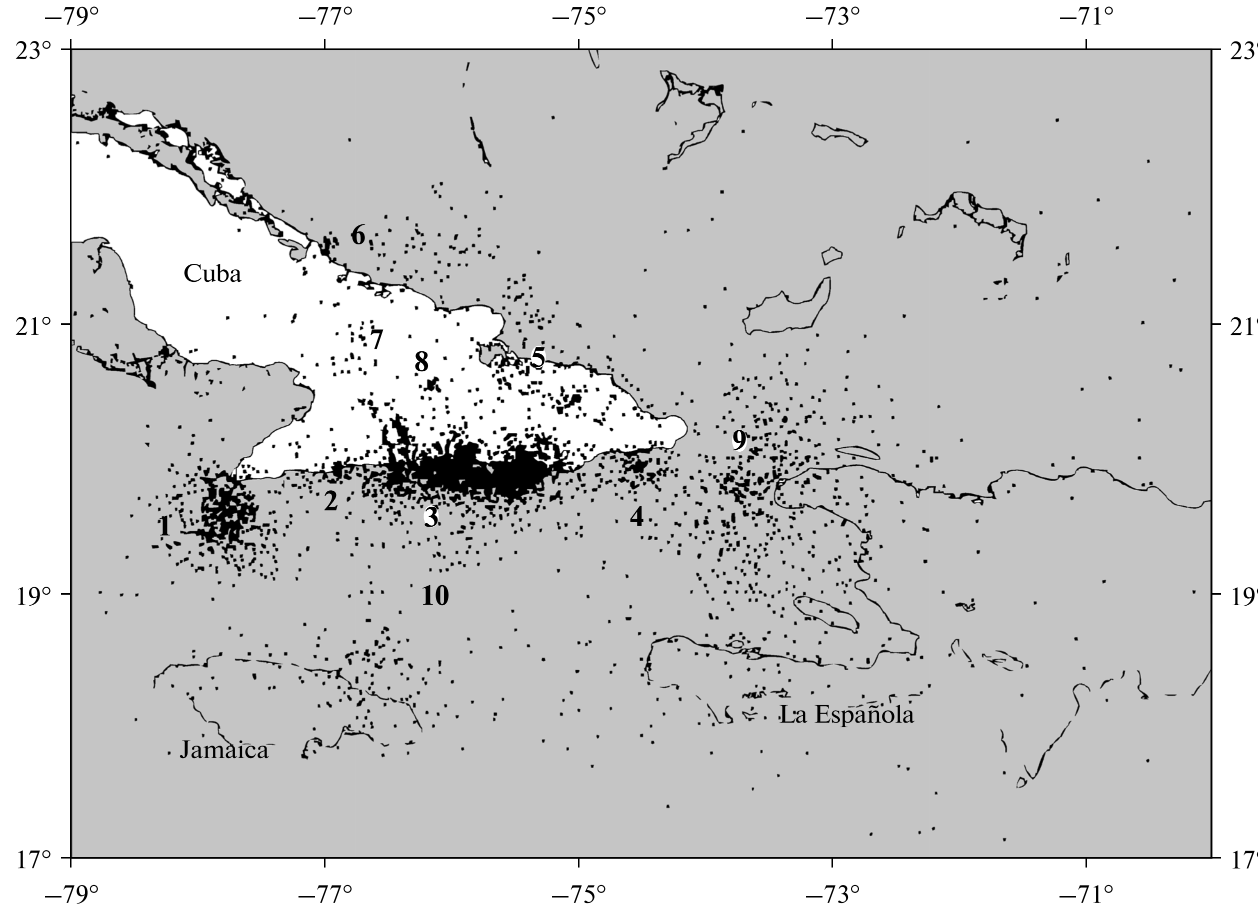


Fig. 4. Seismicity of Eastern Cuba (determinate with the Cuban network) and the earthquake clusters.
Black circle—epicenter. Cluster: 1—Cabo Cruz, 2—Pilón, 3—Uvero–Baconao, 4—Imías–San Antonio del Sur, 5—Nipe, 6—Puerto Padre, 7—Tunas, 8—San Germán, 9—Haití, 10—Jamaica.

on the example of 1914 earthquake in Gibara [28]. The author has analyzed similar cases [30, 31, 34–36, 56].

Díaz and Lilienberg [61] and Hernández et al. [80] identified significant variations in the intensity of recent tectonic movements for the morphostructures of Western Cuba and Eastern Cuba, respectively. Later, Emma et al. [63] showed new geodetic data for Santiago de Cuba. In general, all these results are adjusted quite well to those obtained for the neotectonic stage by González et al. [67–69]. Then, there is a defined differential mobility space-time between the Cuban blocks.

Cuba from the morphostructural perspective is made up of three regions; (1) West, (2) East, and (3) Southeast [67] (Fig. 5a). The Eastern region has the highest altitudes, courses of rivers of higher order, the predominance of mountainous relief, most of their coasts are faulted, etc. The Western region is the largest. In it there is a clear predominance of plains, many water reservoirs and swamps, and the main dividing line of water is practically without deformations. These two major regions have been considered so far of a same tectonic and seismic behavior. The third region, the Southeastern, shows the highest values of seismicity and faulting, and accordingly it is clear differentiated with the previous ones. Then, according to morphostructural data is possible to ensure that there is a stress regime differentiation in the two Cuban macroregions: (1) West, and (2) East. Also, Cotilla and Córdoba [40] considered that only one stress regime exists in the East and Southeast regions because they are included in the PBZ. But it is clear that the efforts field varies significantly and is divided into at least two parts the Southeastern region (Cabo Cruz–Baconao and Baconao–Punta de Maisí).

In the south coast of East region there are two important bays (Santiago de Cuba and Guantánamo). The Santiago de Cuba bay is located in the eastern part of the Sierra Maestra Mountain Range and is adjacent to the Sierra de la Gran Piedra. It is graben, with a NE normal fault system associated. A more recent E-W structure (Boniato fault, BOF) segmented this system and interrupts the prolongation to the north of the bay [40]. While the Guantánamo bay is not a faulting structure and has not suffered strong seismic events. Its superficial extension is greater than

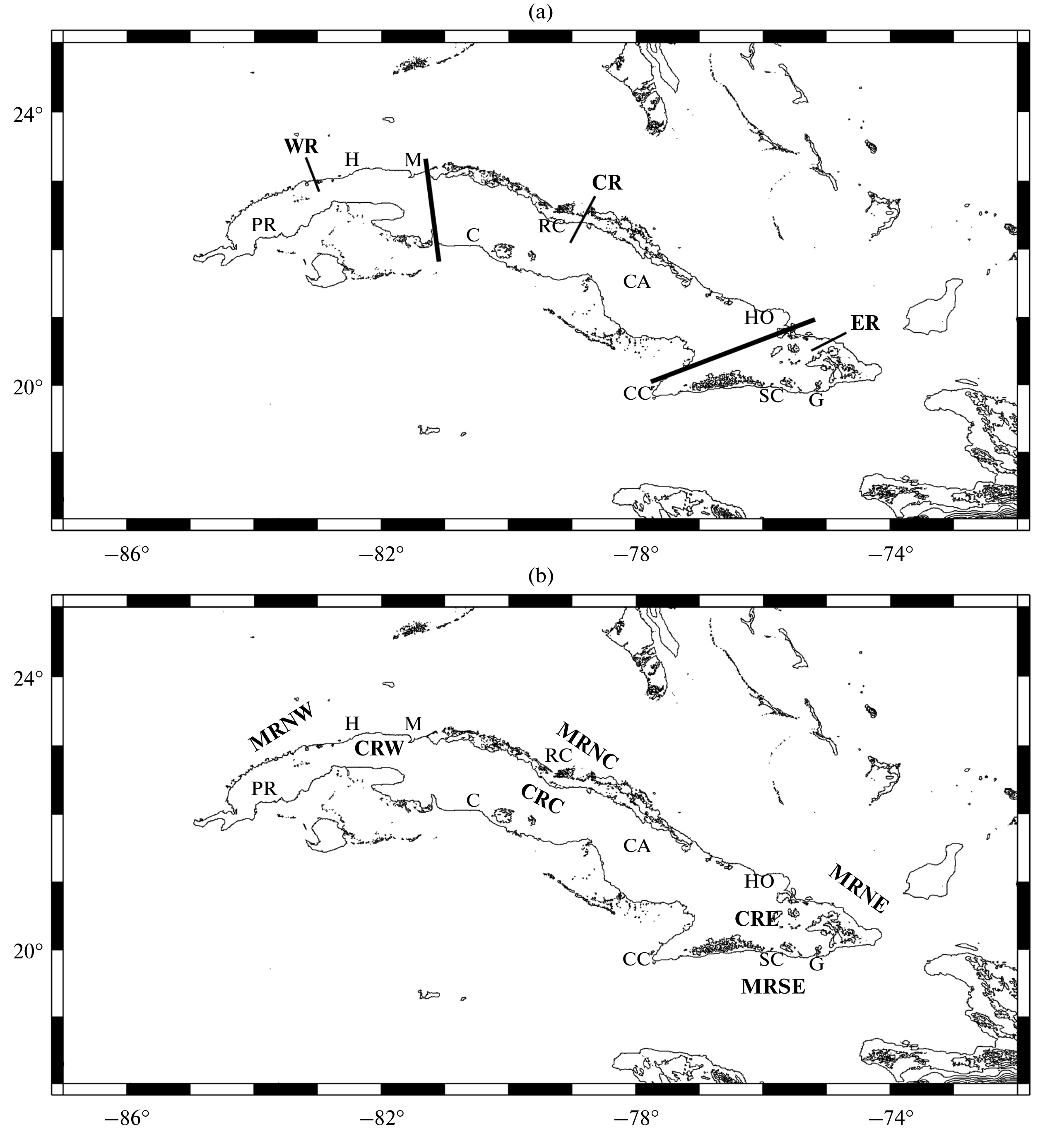


Fig. 5. Cuban morphostructures.

(a) Morphostructural Cuban map [67].

Morphostructural region: CR—Central, ER—Eastern, WR—Western. Black line—morphostructural boundary. Locality: C—Cienfuegos, CA—Camagüey, CC—Cabo Cruz, G—Guantánamo, H—Ciudad de La Habana, HO—Holguín, M—Matanzas, PR—Pinar del Río, RC—Remedios–Caibarién, SC—Santiago de Cuba.

(b) Seismic regions of Cuba.

Seismic region: MR—Marine: NW—Northwestern, NC—North Central, NE—Northeastern; CR—Continental: C—Central, E—Eastern, W—Western. Other symbols see Fig. 5.

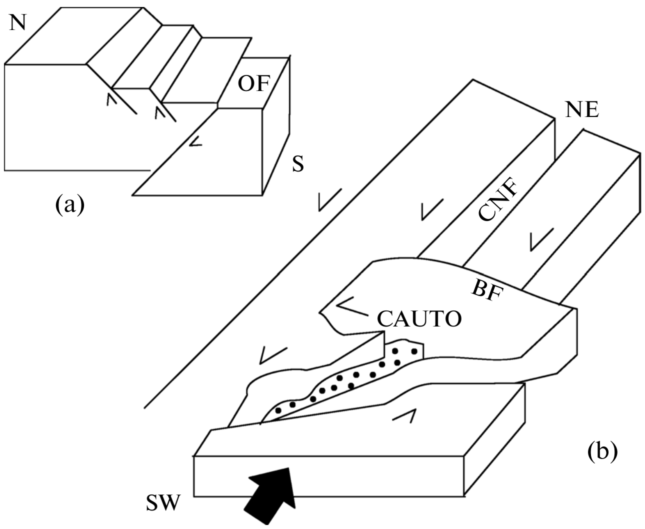


Fig. 6. Block models: (a) Sierra Maestra–Oriente trough; (b) Cauto–Nipe basin and Bayamo city.

Arrow—sense of block movements. Black circle—basin. BF—Baconao fault, CNF—Cauto–Nipe fault, OF—Oriente fault.

Santiago de Cuba. But, the seismic activity and epicentre density maps show that the highest values are in the surrounding areas of Santiago de Cuba, to the west [34]. These cases are included in the paragraph before exposed.

Cotilla et al. [54] and González et al. [68] applied to the Sierra Maestra Mountain Range geomorphological indicators of Mayer [96] and Turko and Knuefer [133]. These results permitted the segmentation of the southern margin in four parts: (1) Cabo Cruz–Pilón, (2) Pilón–Uvero, (3) Uvero–Santiago de Cuba, (4) Santiago de Cuba–Baconao. And the relief cartography of the adjacent underwater part (Southeastern region) also allows the morphostructural differentiation [17, 24, 54, 77, 78, 80]. These permit assured that Southeast region of Cuba result the most complex, and in particular the Cabo Cruz–Baconao segment where it is developed the Oriente trough (depth ~7.5 km). Cotilla [34, 40, 53] proposed the existence of a scissor fault system and some small pull-apart basin and push-up blocks in this area. The scissor fault can explain the local variations of seismicity and focal mechanisms determined.

It is known that a rotation fault (or scissor) is formed by the effect of the blocks tilting on the fault plane. So, each block has a movement of rotation with respect to the other. This permits appreciating on the fault plane two different types of fault: (1) normal, and (2) reverse. This means that the blocks rotate around a fixed point. Such situation can be detected from the geodetic leveling and the relief morphometric data [40]. While, tilted mountain blocks have one gently sloping side with an exposed scarp and one steep side. They are common in the basin and mountainous range regions. Very often the movements of these blocks are accompanied by tilting due to compaction and stretching process of the earth crust at that area. Cotilla and Franzke [40, 45, 54, 67, 68] located tilted blocks in the following Mountainous Ranges: Sierra Maestra and Nipe–Sagua–Baracoa–Cristal (Figs. 1, 6a, 6b). Cotilla [30–32, 34, 36, 49] discussed about it. CNF (~150 km length) also has two important clusters of earthquakes (of low energy) in its NE (Nipe) and SW (Cabo Cruz) extremes. Nevertheless, Cabo Cruz sector is the largest and produce the strongest earthquakes. They are located the intersection of OF and CNF. This fault shows the spatial differentiation of the Cuban structure and has facilitated the development of a continental pull-apart basin in the surrounding of Bayamo and Manzanillo cities [40]. Cotilla et al. [54] state that CNF has two very well differentiated segments following the intersection with the BF, in the surrounding of San Germán. It was verifies by Cotilla and Córdoba [41].

The morphologically more prominent disruptive structure of Sierra Maestra macroblock is Baconao fault (BF) (Fig. 7). It is an active NW-SE reverse and strike-slip fault (~240 km of length) that intersects the OF obliquely under an acute angle in its southeastern extreme (Baconao lagoon). BF appears in the Baconao River which drains to the SE on the southeast coast and in the Guananicum River which drains into the Cauto River on a NW strike. This fault could be associated with some earthquakes (Table 3). Cotilla and Córdoba [41] considered that BF is part of a push-up structure.

Furthermore, westward of Cabo Cruz the OF is connected with the Mid-Cayman rise spreading center, already mentioned. In this part there are strong seismic events (see Table 2). To the east of the Punta de Maisí the E-W faulting of OF extends to northern Haiti and then enters the Dominican Republic, as the Northern fault [48, 51, 55]. The strongest earthquakes occur at these sites of the PBZ (see Table 2).

According to the results of Cotilla et al. [54], the Cuban megablock comprises two Neotectonic Units, the Western unit (Weu) and the Eastern unit (Eeu), which are separated by a transverse-diagonal fault (NE-SW), called Cauto–Nipe (CNF) (Fig. 8, Table 3). It is an active fault. Some of the main features to this unit were mentioned in the preceding morphostructural comment. The Weu extends from the area surrounding the Cabo de San Antonio (west edge of Cuba) to the Cauto–Nipe depression, and is characterised by interior plate type seismicity. Sectors of neotectonic rising are considerably less numerous than in the Eeu, and there are large areas where they do not even appear. These uplifted movements are all contained in the Guamuhaya Mountain Range (in the south and centre of Cuba, h_{max} = 1140 m), slightly exceeding 1000 m (see Fig. 1) and ~300 m in Guaniguanico Mountain Range (in the western extreme,

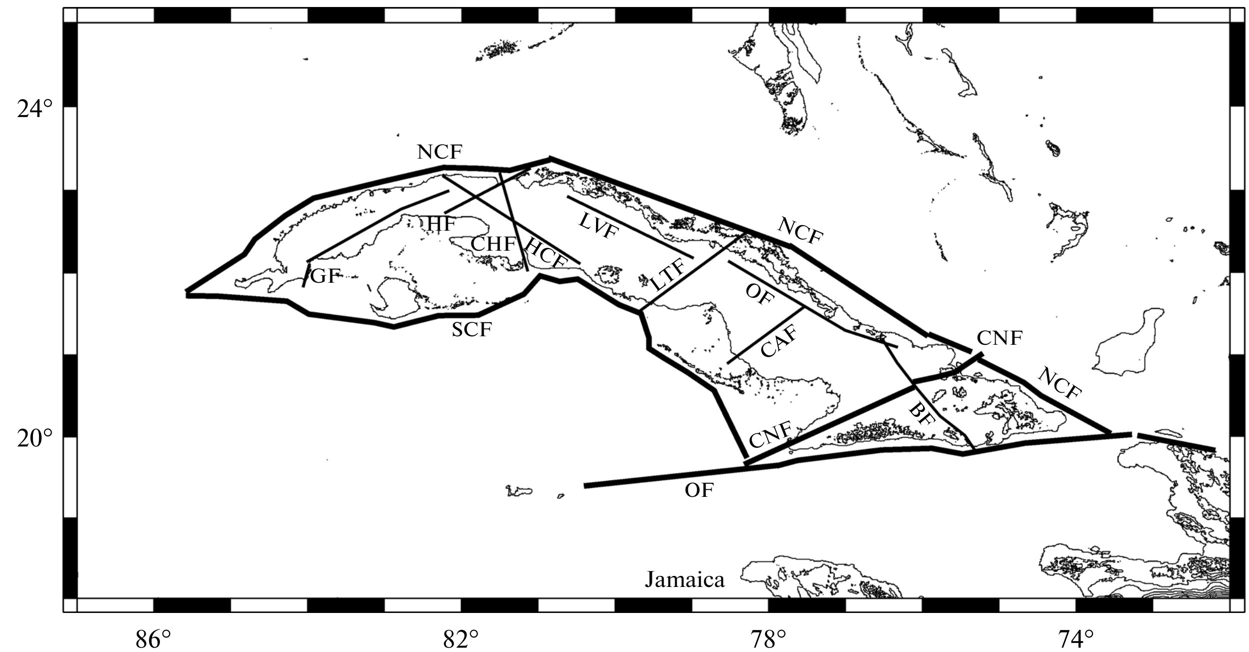


Fig. 7. Cuban active faults.
Black line—fault. Signature: BF—Baconao, CF—Cubitas, CAF—Camagüey, CHF—Cochinos, CNF—Cauto–Nipe, GF—Guane, HF—Hicacos, HCF—Habana–Cienfuegos, LTF—La Trocha, LVF—Las Villas, NCF—Nortecubana, SCF—Surcubana, OF—Oriente.

h_{max} = 671 m) whilst the rest of the Western territory is considerably lower.

The Weu displays relatively homogeneous neotectonic activity from the Upper Eocene to the present, although new uplifting movements in the raised blocks comprising Guamuhaya and the Isla de la Juventud were not initiated after the Maestrichtian, and for those comprising Guaniguanico Mountain Range and the north of Central Cuba, after the Middle Eocene. A system of blocks was formed and a transverse fault system radically modified. In particular, two extensive and heterogeneous active fault systems (Nortecubana, NCF and Surcubana, SCF) are in the marine section (see Fig. 7). They constitute the northern and southern limits, respectively, of the Cuban megablock. The Eeu is in direct contact with the Caribbean plate along the entire length of its southeast edge. To the south is the Oriente trough, with acute seismic activity and earthquakes of up to 9 degrees of intensity, scale MSK. The total extent of the vertical neotectonic movements exceeds 1000 m in the Sierra Maestra macroblock (~2 km of altitude) and the altitude difference is ~10 km. Cauto River is developed in this region and has the biggest order in the country. The continental platform is hardly discernible on the coast.

The NCF is a large submarine structure (>1000 km) which has been identified as the northern boundary of the Cuban megablock (see Table 3). From Cabo de San Antonio to the Punta de Maisí the profile of the NCF changes strike and configuration in the Peninsula de Hicacos. This geometrical change is from NE to NW. It has three segments: Western (from Cabo de San Antonio to the Peninsula de Hicacos), Central (from Peninsula de Hicacos to Cauto–Nipe), and Eastern (from Cauto–Nipe to the Punta de Maisí). The western segment adjoins an oceanic structure (the Gulf of Mexico), the central segment is adjacent to the widest part of the Bahamas Platform, and the eastern segment is adjacent to the Bahamas Platform and the Atlantic Ocean. Each section is associated with seismic events during historical and instrumental periods (i.e., Central: 28.02.1914, Gibara; 15.08.1939, Remedios–Caibarién; Eastern: 05.01.1990, 20.03.1992, 24.09.1992, and 28.12.1998). In Remedios–Caibarién area has been produced two tsunamis [26, 37], therefore the mechanism of faults should be of vertical movement (normal or reverse). Cotilla [34] questioned the differentiation of the eastern and central segments and the operational subjectivity of the Cuban seismic network during the period 1980–1990, which hindered accurate measurement of the seismic potential in the eastern segment. Nevertheless, three fault segments can be differentiated according to the influence of stress regime and the mechanism of the faults.

The area where NCF change of strike is Punta de Hicacos. In it there is a set of transverse active faults in the Cuban insular part. They are Habana–Cienfuegos (HCF, ~310 km length), Cochinos (CHF, ~200 km length) and Hicacos (HF, ~230 km length) faults (see Fig. 7, Table 3). Cotilla [34] had pointed out to the NCF that: (1) the seismicity in the eastern part is greater than to the western part, (2) the neotectonic

Table 3. Faults and earthquakes

Denomination (Signature)	M_{max} (Category/Segments)	Earthquakes
Baconao (BF)	5.1 (4/2)	05.03.1927; 13.05.1951; 23.10.1984; 01.09.1985; 07.01.1986; 16.04.1986; 07.07.1987; 06.06.1990; 03.10.1990
Cubitas (CF)	4.1 (3/2)	22.04.1837; 28.04.1864; 25.05.1941; 29.07.1943; 1948; 16.03.1952; 07.07.1952; 01.01.1953; 25.03.1954;1960; 1964; 1969; 27.06.1972; 08.04.1974; 08.10.1986
Camagüey (CAF)	3.0 (4/1)	1770; 12.04.1776; 28.04.1846; 10.1846; 07.03.1858;
		23.11.1949; 10.11.1952; 09.1955; 12.1966; 16.12.1954
Cochinos (CHF)	5.0 (3/2)	1903; 01.1927; 05.06.1928; 27.03.1964; 1974; 16.12.1982
Cauto–Nipe (CNF)	6.6 (2/2)	18.10.1551; 10.1624; 26.11.1856; 20.01.1858; 03.08.1926;
		16.04.1987; 25.04.1987; 26.08.1990; 25.05.1992; 27.06.1995
Guane (GF)	5.9 (2/3)	23.01.1880; 31.08.1886; 23.09.1921; 09.03.1936; 20.12.1937; 15.02.1939; 24.09.1939; 09.03.1955; 11.09.1957; 1958; 1964; 1974; 10.03.1976; 15.03.1976; 1978; 1982; 09.1988
Hicacos (HF)	3.0 (3/3)	1812; 05.03.1843; 1852; 1854; 10.09.1854; 1880; 27.05.1914; 28.05.1914; 27.04.1974; 1978
Habana–Cienfuegos (HCF)	5.0 (3/4)	1693; 1810; 1835; 08.03.1843; 21.02.1843; 1844; 1852;
		1854; 04.10.1859; 12.1862; 25.03.1868; 1880;
		15.04.1907; 1941; 18.12.1942; 11.09.1947; 10.02.1970; 16.12.1982; 09.03.1995
La Trocha (LTF)	4.6 (4/1)	30.07.1943; 11.11.1970; 26.07.1971
Las Villas (LVF)	4.5 (3/2)	15.08.1939; 03.02.1952; 01.01.1953; 25.05.1960; 22.01.1983;
		04.01.1988
Nortecubana (NCF)	6.2 (2/6)	28.02.1914; 15.08.1939; 25.05.1960; 18.12.1986; 05.01.1990;
		20.03.1992; 24.09.1992; 28.12.1998
Oriente (OF)	7.3 (1/3)	18.10.1551; 08.1578; 1580; 11.07.1670; 11.02.1675; 11.02.1678; 1682; 1762; 13.11.1762; 11.06.1766; 11.02.1775; 01.11.1775; 14.10.1800; 18.09.1826; 07.07.1842; 20.01.1848; 26.11.1852; 20.08.1852; 28.01.1858; 23.09.1887; 19.09.1903; 22.06.1906; 25.12.1914; 20.02.1917; 17.01.1930; 03.02.1932; 07.08.1947; 19.09.1957; 20.04.1962; 25.07.1962; 23.02.1966; 11.10.1968; 16.02.1969; 25.02.1969; 16.03.1970; 23.12.1970: 11.04.1972; 20.05.1973; 19.02.1976; 23.02.1976; 24.02.1976; 17.10.1976; 13.11.1978; 08.02.1980; 01.09.1985; 12.02.1989; 22.05.1990; 26.08.1990; 04.09.1990; 26.08.1991; 25.05.1992; 27.06.1992; 27.06.1995

characteristics are also quite different: reverse type in the eastern and normal one in the western. All these phenomena can be interpreted as a result of the unequal stress transference from the BCF. After, the World-Stress Map [139] proofs the existence of a compressive regime in the NCF. Then, the focal mechanisms mainly should be normal or reverse type.

The faults of the northern continental part of Cuba are spatially analogous to the strike of NCF. Thus, the Pinar del Río (PRF) and Guane (GF, ~280 km length) faults in the Weu have NE strike and are parallel to the western segment of the NCF, whilst Las Villas (LVF, ~250 km length) and Cubitas (CF, ~190 km length) faults, also in the same Weu, are parallel to the central segment of the NCF. La Trocha (LTF, ~200 km length) a NE-SW structure split to LVF and CF [49]. More to the east is Camagüey fault (CAF) a NE structure (180 km length). GF produced the strongest earthquake (28.01.1880, M = 6.2) of Weu [27, 28, 38, 138]. HCF is a large SE-NW structure (~230 km length). All these structures are seismically active (see Table 3).

There are several maps and schemes of seismogenerating zones to Cuba (Table 4). Of this table and its contents can be extracted several appreciations:

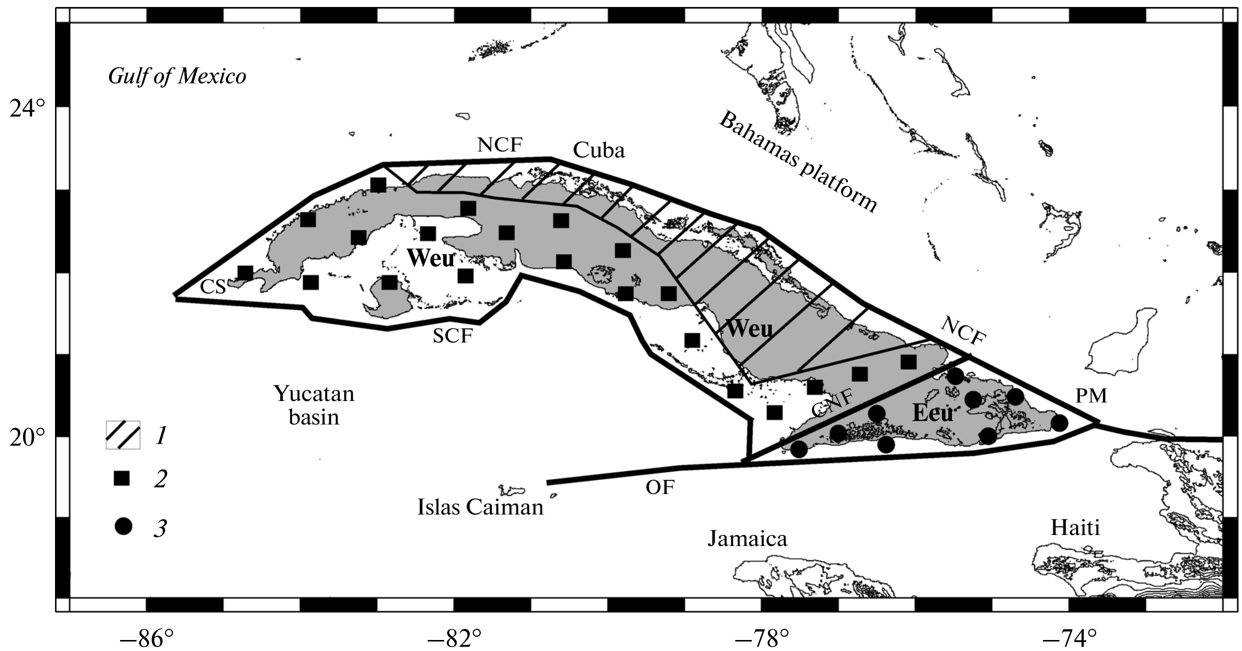


Fig. 8. Neotectonic Cuban map.
Heavy black line—fault: CNF—Cauto–Nipe, NCF—Nortecubana, OF—Oriente, SCF—Surcubana. Appear: (1) Neotectonic units: Eeu—Eastern, Weu—Western; (2) crust type: *1*—post-orogenic complex, *2*—orogenic complex, *3*—volcanic arc complex. Locality: PM—Punta de Maisí, SA—San Antonio del Sur.

(1) there are 26 publications; (2) the first result was obtained in the year 1977; (3) same author has different results and sometimes contradictories; (4) up to now, it does not exist an only one map or scheme. Cotilla [31, 32, 34] discussed about these.

Cotilla et al. [55] developed the first Cuban Seismotectonic Map (Fig. 9a). It contains the active and potentially active fault zones. After, Cotilla and Álvarez [36] and Cotilla and Franzke [44] demonstrated the good accuracy of such result. Cotilla et al. [49] show the activity of more than 15 faults in Cuba. But, the accuracy data only allow discussed 12 faults as seismic actives (see Fig. 8). The set of faults no analyzed are: Batabanó, Boniato, Cienfuegos–Santa Clara, Consolación del Norte, Guamá. Purial and Sudcubana. We assure that Eastern Cuba has four faults that determine its main seismic activity. These faults are OF, NCF, CNF and BF. Thus, the western and eastern extremes of Eastern Cuba, Cabo Cruz and Punta de Maisí, respectively, can be used to establish the links in this segment between the OF and the associated transverse faults CNF and NCF. At both extremes there are seismic events, the strongest in Cabo Cruz (18.10.1551, 26.08.1990, 25.05.1992, and 04.02.2007) [31, 32, 40, 41]. The associated faults mentioned above have a different kinematic: CNF (transpression and left-lateral strike slip), NCF (transtensive and left-lateral) and BF has left-lateral strike slip with a reverse component (01.09.1985, M = 5.1, h = 10 km).

It is worthy that BF and HCF though in different seismotectonic units maintain a similar NW-SE strike. We consider that it favors the block composition and the transmission of the stress, with the consequent seismic energy release. These two faults have a similar geometry to the Bonao fault in Hispaniola [48, 51]. Also we consider that the strike, the geometry and the activity of the CAF, GF, HCF and NCF in the Weu can be explained by the presence of two large depressed oceanic structures, the Gulf of Mexico and the Hoya de Yucatan, opposed in the contemporary tectonic stress field, derivative of the influences of the Caribbean, Cocos and North America plates. Also, the BCF, CAF, CNF, CF, LTF, LVF and NCF, of the Eastern and Central–Eastern Cuba, have been related with the lateral differential collision of the Caribbean plate with the southern part of the North American plate. In the North American plate there is a lateral succession, west-east, of Continental Platform and oceanic crust type structures, respectively, that responds in a different way to the applied tectonic stress. Also, a rough comparative between Figs. 9a and 9b allows seeing that the seismotectonic field is very well expressed in the determined seismic intensities of the Cuban territory.

An earthquake (M_s = 5.0, h = 30 km, I = 6 MSK) hit Torriente–Jagüey Grande (TJG), Matanzas in 16.12.1982. We delimited using photos and space imageries a transverse-diagonal alignment zone (E-W and NW strikes). We checked that the macroseismic epicenter (22°37′ N, 81°14′ W) was in the intersection of the mentioned alignment zone with other alignment zone but the minimal gravimetric values. This

Table 4. Seismotectonic researches

No.	Year	Author/Authors	Region
1	1977	Álvarez and Buné	Southeastern Cuba
2	1980	Orbera	Eastern Cuba
3	1983	Álvarez	Cuba
4		Belousov et al.	Central Cuba
5		Orbera	Western Cuba
6	1984	Chuy et al.	Camagüey and Ciego de Ávila
7		González and Chuy	Western Cuba
8	1985	Álvarez et al.	Cuba
9		Rubio	Cuba
10	1986	Hernández et al.	Sierra Maestra
11	1987	Orbera et al.	Cuba
12	1988	Chuy et al.	Western Cuba
13	1989	Babaev et al.	Eastern Cuba
14		Díaz and Lilienberg	Western Cuba
15		Orbera et al.	Eastern Cuba
16	1990	Orbera et al.	Western Cuba
17	1991	Comisión ad hoc	Eastern Cuba
18		Cotilla et al.	Cuba–La Española–Jamaica
19		Cotilla et al.	Cuba
20	1993	Cotilla	Cuba
21	1994	Cuevas	Central–Western Cuba
22		González et al.	Eastern Cuba
23	1999	Cotilla	Western Cuba
24		Cotilla and Franzke	Cuba
25	2001	Cotilla and Álvarez	Cuba
26	2007	Cotilla et al.	Cuba

basin structure is oriented to NNW and is situated between two bays (Cochinos and Cárdenas). In it is CHF (see Fig. 7). Chuy et al. [21] presented an isoseismal map for that earthquake (Fig. 10a). It shows two main axes of perceptibility (NW and NNW) with and a very strong attenuation to the east. It confirms the existence of the mentioned basin. We have measured the isoseismal area (I = 6 MSK) of 3400 km^2. After that in 09.03.1995 another earthquake was registered ($M_s = 2.5$, $h = 10$ km, I = 5 MSK) and perceived in San José de Lajas (SJL) (Fig. 11), La Habana (see Fig. 10a). This event is also situated on the mentioned alignment zone, but more to the NW. In this locality we found that there is another intersection of the alignment zone but with the GF [33]. The isoseismal map made by González et al. [66] showed that the main perceptibility was toward the NW, but with a near circular tendency (Fig. 12).

While, the seismic hazard studies to the Nuclear Research Center (NRC) in the locality of Pedro Pí (PP), La Habana by Orbera et al. [105] modified very much the isoseismal map of TJG (Fig. 10b). The modifications allowed reducing the seismic perceptibility of the TJG in PP. With this support they presented a seismogenic zone map (see Fig. 12). This map changed the results obtained before by those specialists without any explanation. These seismogenic zone map excluded events like the 1995 in PP. This locality is nearest to SJL and NRC (~10 km of distance). Cotilla [30] and Cotilla and Álvarez [35] extensity discussed about that result. Then, the earthquakes of TJG and PP may sustain to Cuba the earthquake occurrence in different active structure intersections. The idea of earthquakes in intersection of faults was exposed before by different authors as Guelfand et al.

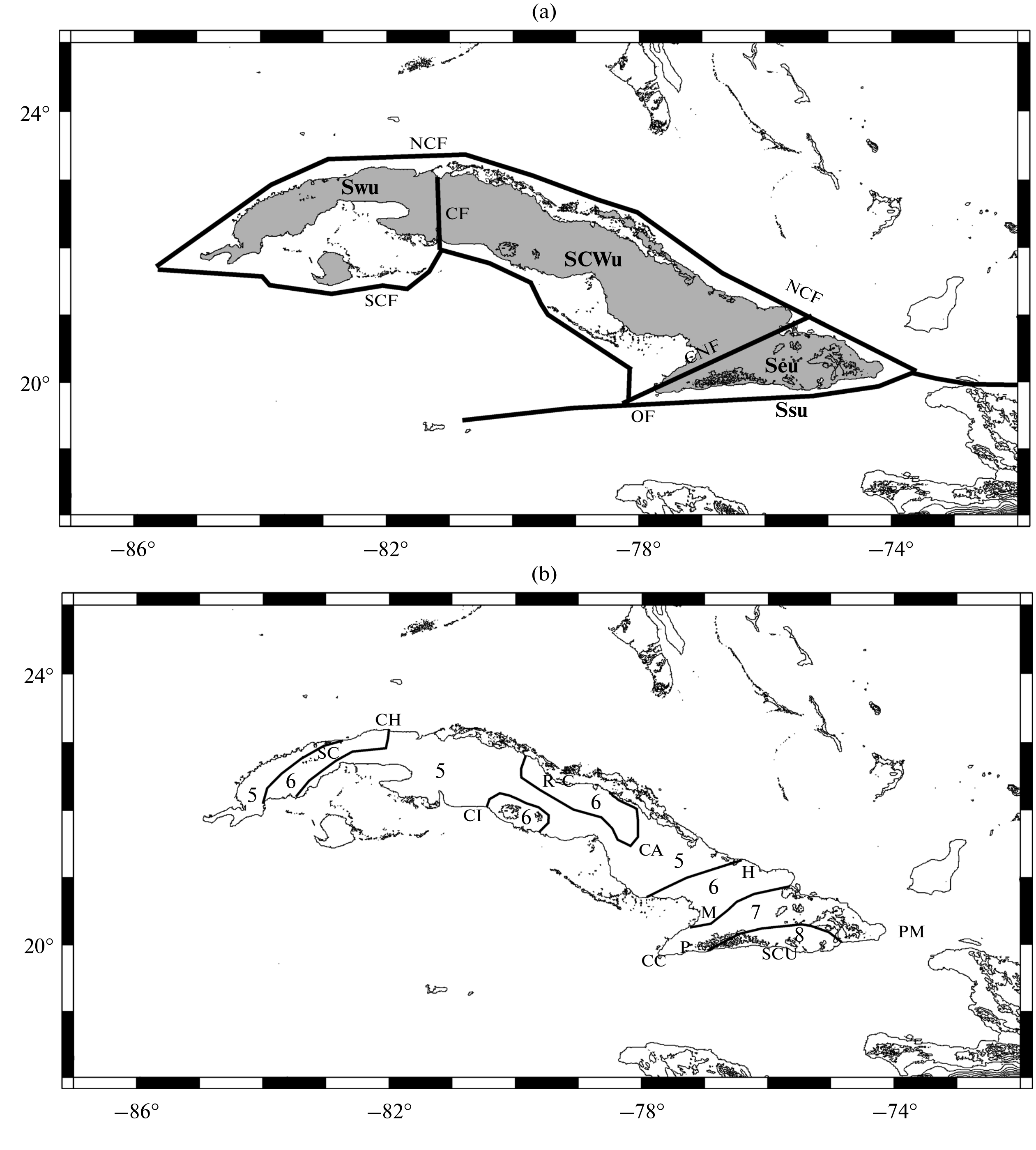


Fig. 9. Cuban seismic regions.
(a) Main regions of the Seismotectonic Cuban map.
Black line—fault. Signature: CF—Cochinos, CNF—Cauto–Nipe, NCF—Nortecubana, SCF—Surcubana, OF—Oriente. Seismotectonic region: SWu—Western, SCWu—Central-Western, SEu—Eastern, SSu—Southeastern.
(b) Seismic intensity Cuban map.
Locality: CH—Ciudad de La Habana, P—Pilón. Intensity—MSK scale. Other symbols see in Fig. 5.

[70], Gvishiani et al. [71–73], Rantsman [112], Zhidkov [143] and Zhidkov et al. [144].

Riznichenko [116] sustained that the epicentral area of seismic events with M = 6.0 and low deep ($h < 30$ km) has dimensions of 23 × 10 km. With such information Cotilla [30, 34] and Cotilla and Álvarez [35] have determined that the seismoactive knots of TJG and PP are in such values range.

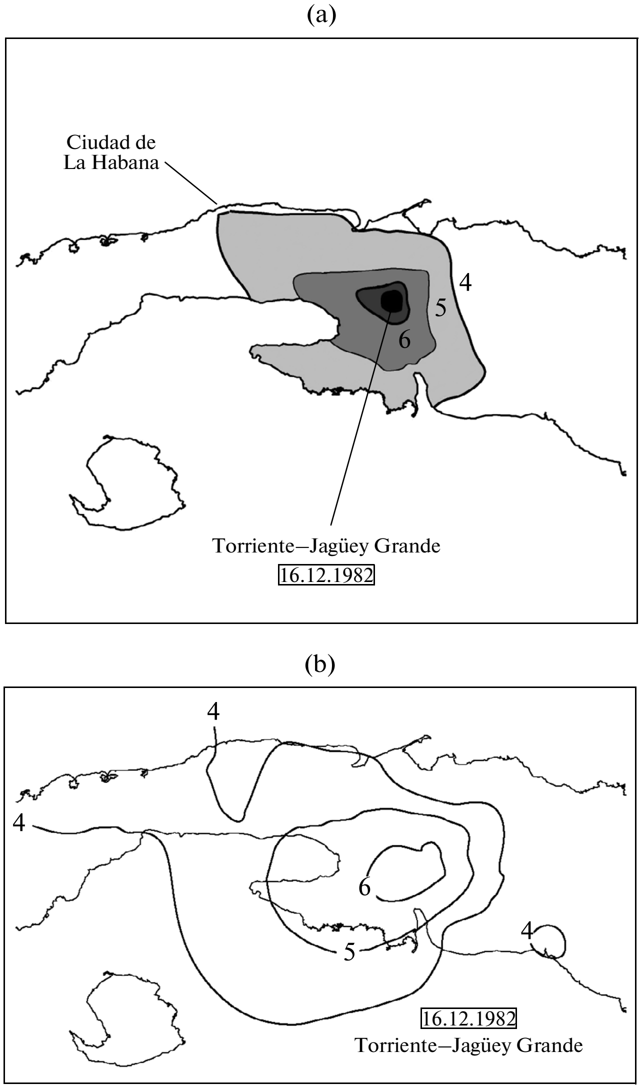


Fig. 10. Isoseismal maps of Torriente–Jagüey Grande earthquake, 16.12.1982.
(a) Made by Chuy et al. [21]. Intensity—MSK scale.
(b) Made by Orbera et al. [103]. Intensity—MSK scale.

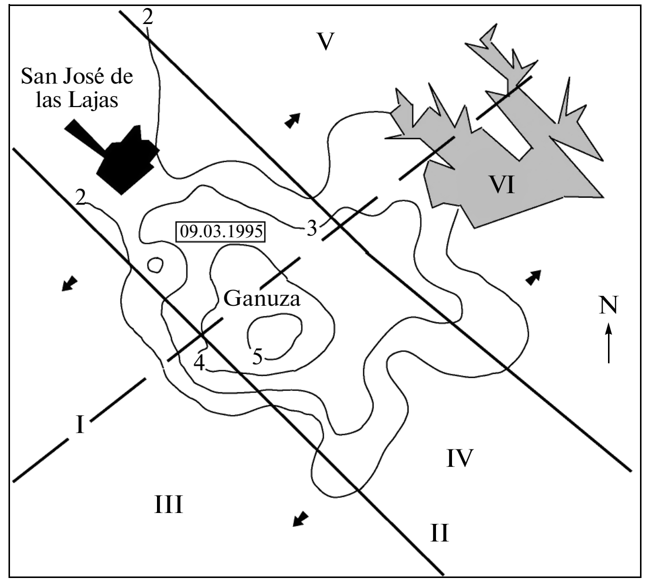


Fig. 11. Isoseismal map of San José de las Lajas earthquake 09.03.1995 [65].
Black line—faults: I—Guane, II—Habana–Cienfuegos. Symbols: III, V—hills, IV—plain, VI—water reservoir. Isoline—Intensity—MSK scale.

ACTIVE ZONES

Lay and Wallace [86] identified as a fault any tectonic structure which has a fracture and a differential displacement of the adjacent materials throughout parallel to the plane fracture. Reiter [113] says that a seismic active fault always has associated at least one earthquake. NUREG-1451 [100] describes three types of faults. They consider that a fault is active when it demonstrates displacement in the Quaternary, a directly associated seismicity, a structural relationship with other faults subject to displacement, and a favorable direction regards the current tectonic stress field. Meanwhile, Trifonov and Machette [130] consider that the active faults are those which offer evidence as such in the Holocene or the Late Pleistocene. Hatter et al. [74] consider a fault, fault zone or fault system as seismoactive if one or several of the following criteria are satisfied: (a) direct observation of faulting in connection with at least one earthquake; (b) occurrence of well-located earthquake or microearthquake activity close to a known fault. In addition, a well-constrained fault-plane solution with one nodal plane showing the same orientation and sense of displacement as the fault is requested; (c) close correspondence of orientation of nodal planes and senses of displacement of well-constrained fault-plane solutions with the type and orientation of young faults or fault zones observed in the epicentral region; (d) mapping of hypocenters by high-precision relation location of individual events of a local clusters of earthquakes displaying almost identical signal forms. Control by well-constrained fault-plane solution (s). But, Makarov and Schukin [93] indicated some ways to explain the detected seismicity in certain areas where the existence of fault was not well defined. While Bankwitz et al. [8] showed an alternative methodology to interpreter the seismicity in some areas of Central Europe. All these results have been taken into account by Cotilla et al. [49] in order to explain the existence of compressional and transpressional intraplate structures in Cuba.

In the other side, Sykes [127] observed that the intraplate seismicity areas are located throughout preexisting tectonic weakness zones. Similar are the issues and results of Johnston and Kanter [84]. Also, the Working Group on California Earthquake Probabilities [140] concludes that the hidden (or blind) faults are potentially dangerous structures that future seis-

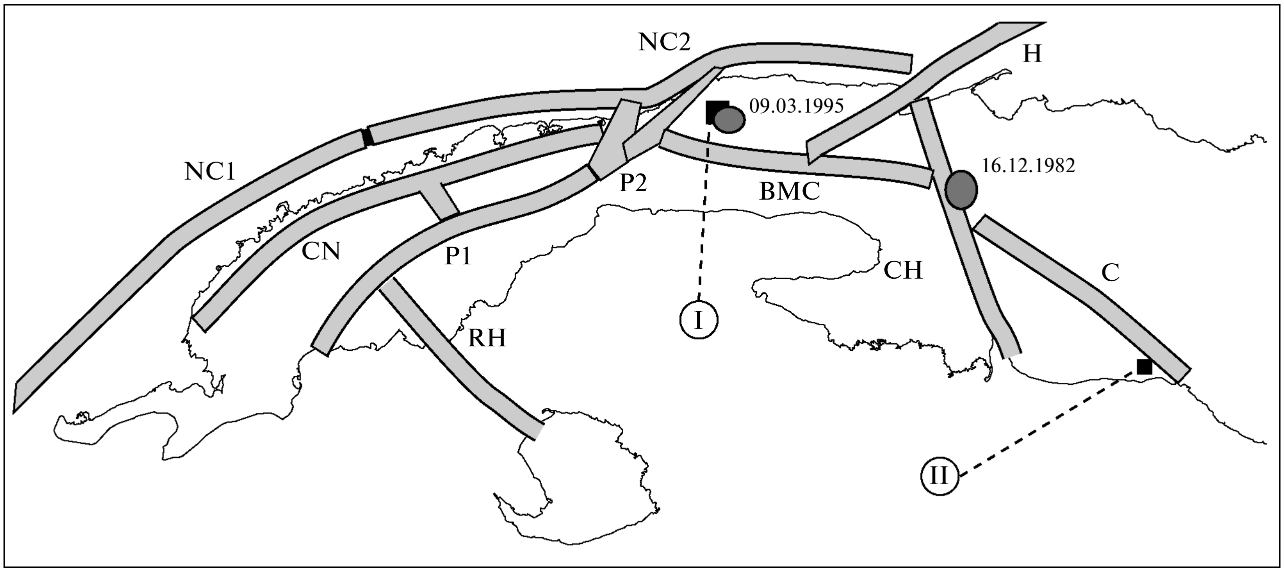


Fig. 12. Seismogenic zones map of Western Cuba [103].

Black square—nuclear research center: I—Pedro Pí, II—Cienfuegos. Grey circle—earthquake, 16.12.1982—Torriente–Jagüey Grande, 09.03.1995—San José de las Lajas. Grey rectangle—Seismogenetic zone: BMC—Batabanó–Madruga–Coliseo, C—Cienfuegos, CH—Cochinos, CN—Consolación del Norte, H—Hicacos, NC1—Nortecubana 1, NC2—Nortecubana 2, P1—Pinar 1, P2—Pinar 2, RH—Río Hondo.

motectonic studies should concentrate on, especially when earthquakes are expected in the immediate future. McKenzie and Parker [97] argued that deformation is concentrated at plate margins whereas plate interiors are rigid and undeform able. Zoback [145] showed that horizontal compressional stresses can be transmitted over great distances through the continental and oceanic lithospheres. Also, Van der Pluijm et al. [135] assured that continental interiors registering plate tectonic activity and intraplate fault reactivation (and earthquake triggering) are mainly dependent on the orientation of (weak) fault zones relative to the plate margin, and that deformation of continental interiors can be represented by relatively simple rheological models. Then, we consider the same to Cuba and with these arguments can assure the earthquake occurrence in Weu and Eau.

It is well established that seismicity is one of the main arguments testifying to the activity of faults [23, 93, 95, 113, 122, 130]. While seismogenic zones of the earthquake foci are confined to locations of active faults. Then it is important the use of active faults as seismogenerating zones for assessment of the seismic hazard. On this base, Cuba most seismically active zones are located in three major distinct marine and continental regions. They are: (1) marine region: (a) south of Eastern Cuba (segments of Cabo Cruz, Pilón–Baconao, and Punta Maisí) (b) north of Eastern Cuba (Moa–Baracoa); (c) north of Central Cuba (Remedios–Caibarién and Gibara); (2) continental region: (a) Western Cuba (Candelaria–San Cristóbal, San José de las Lajas, and Torriente–Jagüey Grande); (b) Central Cuba (Sancti Spíritus, Cubitas, and Ciego de Ávila); (c) Eastern Cuba (Bayamo–Pinares de Mayarí–Puriales) (see Fig. 5b).

The Eastern Cuban seismic network is composed by seven stations [27, 28] (Fig. 13). But, paradoxically in spite of the fact that CNF and BF and the eastern part of the NCF are near to this seismic network, administrative decisions excluded the study of seismic registers of the 1979–1994 period [31]. Nevertheless, we know that the immense majority of the registered events are of low magnitude. More complicate is the situation of the largest area of the Cuban territory (Cabo de San Antonio—Cauto–Nipe) because has only two seismic stations (see Fig. 13). Then the level of earthquakes detection and accuracy determinations are very low. Cotilla [34] assured errors of 20–40 km to epicenter determination.

Cuba has a low level of seismic hazard compared with the neighboring islands as La Española (Haití and República Dominicana), Jamaica, and Puerto Rico [27, 28, 39, 41–43, 47]. Nevertheless, the Southeastern Seismotectonic Unit is the most dangerous in Cuba (~61 fatalities and ~1300 injured) [27, 28]. In the rest of Cuba we determined only 3 fatalities and ~32 injured. The Cuban most active seismogenetic zone is OF. In it were generated ~13 strong earthquakes ($M \geq 6$) [49]. NCF is also active but the seismic activity values are less important than in OF.

We will now refer to some work that from our perspective and data do not allow justify the seismic activity of some structures. At first we will discuss about the PRF. In PRF is located some factories of construction

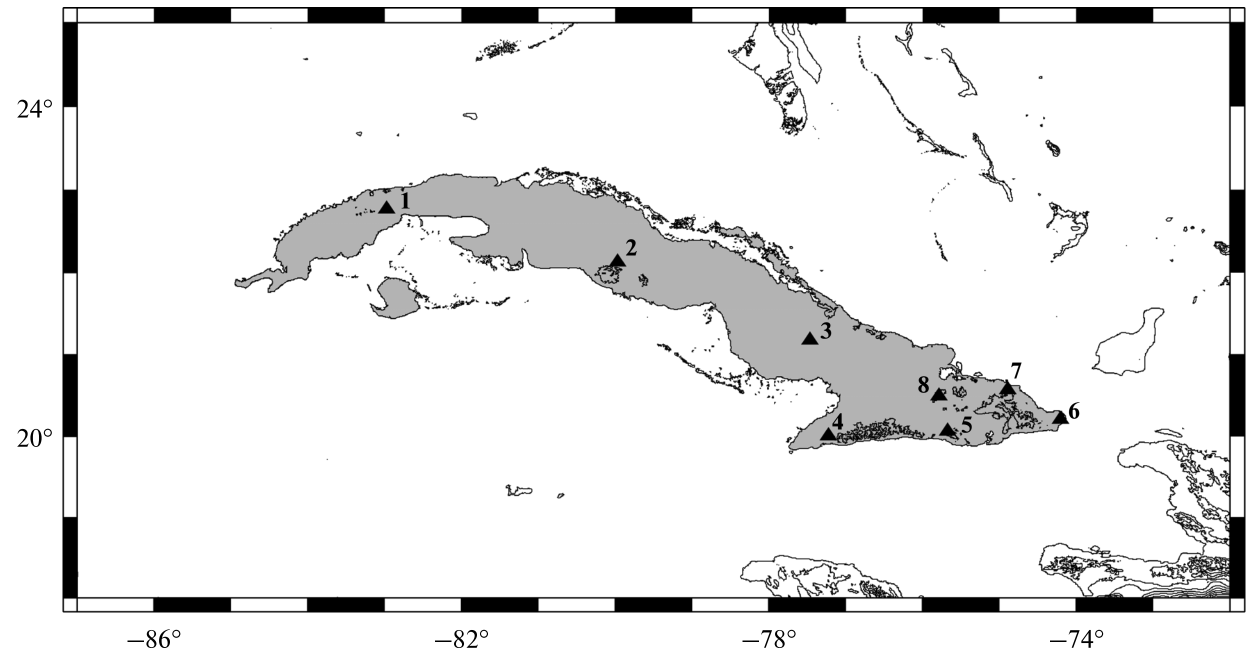


Fig. 13. Cuban seismic network.
Black triangle—seismic station: 1—Soroa, 2—Manicaragua, 3—Cascorro, 4—Las Mercedes, 5—Río Carpintero, 6—Maisí, 7—Moa, 8—Pinares de Mayarí.

materials (limestone) and artificial water reservoirs. This fault is quite well expressed in the southern relief of Guaniguanico Mountain Range. Also, in Soroa locality (eastern part of this Range) is situated one of the first Cuban seismic station (year 1964). It was constructed here in order to study this fault because the immense majority of specialists assured that was the responsible of the San Cristóbal earthquake (23.01.1880, $M_s = 5.9$). Nevertheless, the great quantitative of industrial explosions do not induce seismic events. Also, any focus of registered earthquake by Soroa is associated to PRF [30, 31, 34, 35, 56]. Then, we consider this fault is a north branch of GF, and quite less active [34, 40].

Cárdenas [18] proposed an original paper where presented some active faults in Cuba. But, he sustained their relation with the outer space influence. More recently, Pérez and Rodríguez [108] exposed the same idea. Our ideas are far away from such papers.

Cotilla et al. [50] discussed the 1992 series of earthquakes in the Moa region (in Eeu) and pointed out that the seismogenic NCF was responsible, as previous stated by Cotilla [34]. But, Rodríguez et al. [119] stated in Moa region that the principal limits of the six delimited blocks are the active faults: Cabaña, Cayo Guam, Los Indios, Miraflores, Moa, and Quesigua. They assured that: (1) the Quesigua fault is responsible of 1992 earthquakes; (2) these six faults are displaced 1.5 km in some sites by Sabana fault. It is a NW-SE strike-slip fault; (3) the youngest system has a N-S strike but that this is not evident in the relief due to its youth. After, Rodríguez et al. [118] confirm that the Quesigua fault was responsible for some earthquakes in 1992. They also claimed that this N-S fault (7.5 km length) is cut by another younger fault, called El Medio (it is not Sabana fault). Finally, Rodríguez and Blanco [117] asserted that El Medio and Cananova active faults cut and displaced each other. Evidently, all these data and conclusions are erroneous because an active fault of such dimensions, and displaced by other similar structures, cannot be responsible for an earthquake.

The result of Zapata et al. [142] for Eastern Cuba shows a set of 17 alignments (N-S and NE strike) (their Fig. 9) obtained from the study of seismic regime for the period 1998–2007. Zapata [141] showed the same result but for the period 1998–2003. These specialists ensure that the alignments correspond to seismically active geological structures and that they are included on the final report of the Comisión ad hoc [25] (Fig. 14). With respect of this figure, the author of the present work belonged to the mentioned Commission and therefore can give arguments which can clarify all. At first, that result: (1) presented unproven seismogenerating zones and do not geologically active faults; (2) is eclectic; (3) was reached by consensus. Second, the author showed in the Commission important and serious errors which had the outline of some areas as: (1) draw the seismic zones following the arrangement of earthquake epicenters; (2) the foci and its depths were not considered; (3) presented a large seismogenerating zone from Santiago de Cuba to Nipe (NE strike) that cut

OF and NCF (such structure do not exist); (4) two parallel and small E-W seismogenerating zones over the mountainous region of the Northeast Cuba (Sagua–Baracoa) where up to now any real fault is located [49]). Then, we can say that the NE and N-S alignments proposed by Zapata et al. [142] are not reflected as new structures in any known publication. However, we see in their Fig. 9 that they are cutting the active NCF and OF. Therefore, if they cut the outer limits of the Cuban megablock then the Zapata's proposal structures would be extremely active. While, if they do not cut OF and NCF then are not actives. It is the key.

Cotilla et al. [56] explained the important errors of Cuevas et al. [58] to determine the existence and activity of faults in the Central Cuba. They considered erroneously that the faults can cut each other without cinematic and dynamic consequences. The cases of Rodríguez et al. [118, 119], Zapata [141] and Zapata et al. [142] are quite similar to the mentioned Cuevas et al. [58].

We consider that the earthquakes in Cuba are produced in faults and their intersections (or knots) [30, 34, 35, 50, 55, 56]. With these ideas Cotilla and Udías [46] presented for the northern boundary of the Caribbean plate a geodynamic model. It contains 4 tectonic blocks (Swan, Gonave, East Cuba and La Española–Puerto Rico). They depend of the interaction between Caribbean and North American plates that produced a little counter clock displacement. Then, to propose a model of dynamic interaction between Eastern Cuba and Bartlett–Caimán megablocks is essential to consider the active structural elements of larger dimensions as OF, NCF and CNF (Fig. 15a). Using these three faults Cotilla [30] presented a first model to the westernmost part of Cuba (his fig. 8). He drew a model of neotectonic cells which could explain the seismic activity. After, Cotilla and Álvarez [35] showed their fig. 5 with more arguments about seismicity. This model has three seismic interceptions (or knots) (Cabo Cruz (N1), Nipe (N3) and Maisí (N2)). These are morphostructural elements of first regional category. They can be consider as the nodal points on a regional scale and therefore form a set of systems of minor cells (blocks) in the context of the PBZ of the North American and Caribbean plates. Cotilla et al. [53] explained from neotectonic cells the seismic activity in Eastern and Southeastern Cuba. After, González et al. [67] developed the idea and produced two models with more arguments (their figs. 8a, 8b).

When we add the BF to the three systems of faults mentioned before is made the second model (Fig. 15b). With this combination of faults we describe others three active knots (N4 (Baconao), N5 (Cauto), N6 (Puerto Padre)) and four smaller cells: CI, CII, CIII, CIV (Fig. 15b). These knots are active structures. Assinovskaya and Soloviev [7], Cotilla et al. [52], Guelfand et al. [70], Gvishiani et al. [71–73], Hernández et al. [80], Rantsman [112], Schenkova et al. [122],

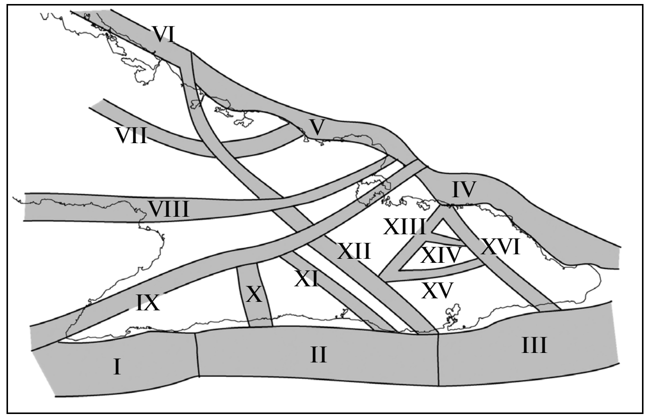


Fig. 14. Seismogenic zones map of Eastern Cuba [25]. Grey rectangle—seismogenetic zones (I–XVI).

Zhidkov [143] and Zhidkov et al. [144] considered these knot of faults as the more probable sites occurrence of strongest earthquakes.

Each one of the neotectonic cells has associated a mountainous group: CI—Sierra Maestra, h_{max} = 1974 m; CII—Nipe–Cristal–Sagua–Baracoa, h_{max} = 1175 m and CIII—Maniabón, h_{max} = 455 m. They are represented in very simplified way at least by three active knots and the main lines of current tectonic weakness that joint them. All of them are articulated structures among themselves since at least the Upper Eocene within a regional transpressive regime.

The energy release (mechanism, depth, frequency and magnitude of earthquakes) at the intersections of the fault systems OF with CNF (N1) and OF with BF (N4) is very different from the occurred at the intersection of NC with CNF (N3) and the NCF with BF (N6) fault systems. This difference means that in the first case the energy release is easier than in the second one where interact different types of earth crust. Also, the ellipses of influence and deformation for the Eeu possess a different relationship between its two main axes (major (a) and minor (b)). This allows distinguishing the sense of rotation of the cells. Such movement is in the counter clock sense. We noted three different relationships between the axes for the cells: (1) CI ($a_1 \gg b_1$), (2) CII ($a_2 > b_2$), and (3) CIII ($a_3 \geq b_3$). This has been interpreted as a different speed of displacement in each one of the cells.

The six knots are characterized by the declining level of the energy release (or the maximum magnitude): N1 ($M_s < 8.0$) > N4 ($M_s < 7.5$) > N2 ($M_s > 7.0$) > N3 ($M_s < 6.5$) > N6 ($M_s < 6.0$) > N5 ($M_s < 5.5$). We have interpreted this result from the knowledge of the different levels of articulation between the crust types, tectonic style, dynamics, types and categories of faults, the distance to the main seismogenetic structure in the region and the time of energy accumulation–release. Then, there is a marked magnitude gradation (in descending order) in the east-west

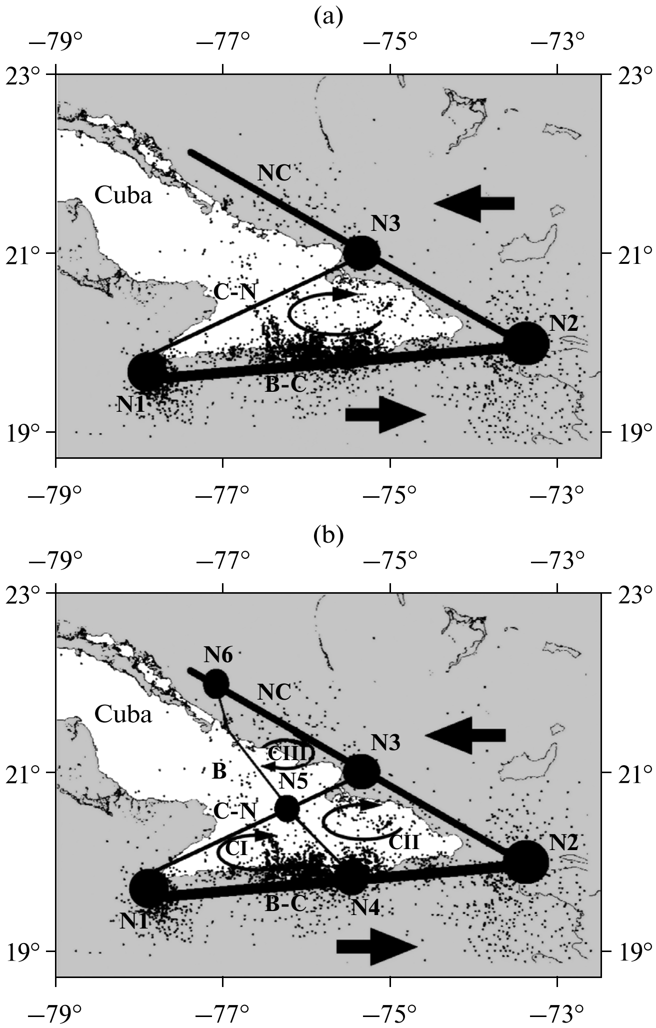


Fig. 15. Geodynamic cells of Eastern Cuba: (a) Model 1, (b) Model 2.

(a) Heavy black arrow—sense of the plate movement. Black line—fault: BC—Bartlett–Caimán (Oriente), C-N—Cauto–Nipe, NC—Nortecubana. Large black circle—knot of faults: N1—Cabo Cruz, N2—Punta de Maisí, N3—Nipe. Curve black arrow—block movement. Black point—epicenter.

(b) Heavy black arrow—sense of the plate movement. Black line—fault: B—Batabanó. Black circle—knot of faults: N4—Baconao, N5—Cauto–Nipe, N6—Puerto Padre. Curve black arrow—block movement. Cell: CI—Sierra Maestra, CII—Nipe–Cristal–Baracoa, CIII—Maniabón. Black point—epicenter. Other symbols see in Fig. 15a.

(knots: N1, N4, N2) and in the south-north (knots: N1, N5, N3) directions.

The N1 shows historic seismic activity in the vicinity of Cabo Cruz (18.10.1551) [40]. Also, there are contemporary strong earthquakes 26.08.1990, 25.05.1992 and 04.02.2007. We believe that this knot has an important meaning for the reconstruction of the structural map of Cuba, and particularly Eastern Cuba. It is associated with intense displacement occurred in the NE direction and supposed to this condition and its relationship with the interisland CNF where exist a pull-apart basin. Other important knot is N2. It also has associated seismicity and from the geodynamic point of view is a place of great interest, because from it changes the nature of the PBZ in the North of the Caribbean. Important differences in morphological characteristics of the NCF system are detected in the N3 (of lower category than the previous two).

From this model of four systems of faults (OF, NCF, CNF and BF) and their corresponding intersections, considering also the results of Prol et al. [111] relating to the existence of three types of crust in Cuba (oceanic, transitional and thin) and also the very different values of the gravimetric fields in Cuba [57, 111], and in particular between the two main neotectonic regions, including within the Eastern region, is possible to sustain that the cinematic model of four cells (CI, CII, CIII, CIV) and six knots (N1, N4, N2, N5, N3, N6). It can explain the differential contemporary tectonic situation of the region and its seismic activity. Then, each cell is an active morphostructure directly connected with the adjacent submarine morphostructures. The most relevant of this proposal is the possibility of considering the CNF, NCF and OF segmentation and consequently assumed that the future seismic events must not be higher than those that occurred (and registered) magnitude until the present time.

Hernández et al. [79] identified from a geomorphological research for the Southeastern Cuba (area of Cauto–Nipe to Cabo Cruz–Baconao, which corresponds to our CI) six seismoactive morphostructural knots. Two of these knots comprising OF with CNF and OF with BF fully coincide with our proposals, while the rest of knots are structures of lower category.

González et al. [67] delimited to the Western region various morphostructures. They are Guaniguanico Mountain Range, some hills (Habana–Matanzas blocks) and plains (south Pinar del Río and south Habana–Matanzas). All they are associated to a set of faults (CHF, GF, HF, HCF, PRF, NCF and SCF). Cotilla [30] argues that the faults are active and have associated earthquakes (GF = 21, CHF = 21, HF = 14, HCF = 31, NCF = 4). In the fault intersections are delimited eight knots. They are (N1—Bahía–Cienfuegos (3 event3, Imax = 4.5 MSK), N2—Torriente–Jagüey Grande (3 events, Mmax = 5.0), N3—Güines (1 event, Imax = 5 MSK), N4—San José de las Lajas (3 events, Mmax = 2.5), N5—Bahía de La Habana (13 events, Imax = 5), N6—Bahía de Matanzas (2 events, Imax = 5), N7—Hicacos, N8—Bahía de Cochinos (5 events, Imax = 4)) (Fig. 16). The most active knot is N5. Cotilla and Álvarez [35] associated to these knots some earthquakes and considered as the preferential area for the earthquake occurrences (see Fig. 16). Cotilla [34] considered that the foreshock and the aftershocks of the T-JG earthquake are located in N2.

We can say that Western Cuba also has a structure of faulting blocks and uneven, various in mobility and tendency of the vertical displacement, but interrelated (under a law not yet studied) in a regional context predominantly of left-lateral strike slip [48]. Blocks show a mix vertical movement, rotation and tilting. In this region there are eight cells: CI—Matanzas Este, CII—Matanzas Centro, CIII—Habana–Matanzas, CIV—La Habana, CV—Habana Oeste, CVI—Habana Sur, CVII—Zapata–Cochinos and CVIII—Cienfuegos (see Fig. 12). These cells are configured with the following faults: CHF, GF, HF, HCF, NCF and SCF [30].

Cotilla et al. [49] identified a regional stress tensor toward NE-SW strike. This allows considering the existence of normal and left-lateral strike slip faults, with the configuration of small pull-apart basins. They determined different segments in the Cuban faults (see Table 3).

Díaz and Lilienberg [61] have been identified for Weu (Cabo San Antonio–Cienfuegos segment) an important increment in the intensity of the recent vertical tectonic movements from W to E. They have also supported a tilting to the north and a very important contrast between the morphostructures. Cotilla and Álvarez [35] (see their Fig. 7) suggest that GF and HCF are the boundaries of the areas where major changes of intensity of these movements occur. Díaz and Lilienberg [61] also demonstrated the existence of three types of seismogenerating mechanisms for Western Cuba. They are in order of decreasing importance: (1) morphoestructural knots, (2) seismogenerating lineal elements, (3) disruptive knots. In this respect they give to La Habana Bay as the morphostructural knot of upmost importance and it is configured with NCF and PRF. While the earthquake of 16.12.1982 in Torriente–Jagüey Grande is associated to a disruptive knot. They coincide with our proposals N5 and N2, respectively.

We must say that it was impossible to determine a clear cell's model to the region Matanzas—Las Tunas in Weu. The reasons are the very low level of knowledge about active faults and seismicity.

Finally, Western Cuba has been affected at least by induced two seismic events (09–11.06.1981). They were perceptible in the localities of San Juan y Martínez–Alonso de Rojas (Pinar del Río). They were produced by geophysical explorations. Similar events can be reproduced as a consequence of the new oil exploration in the northern Cuba.

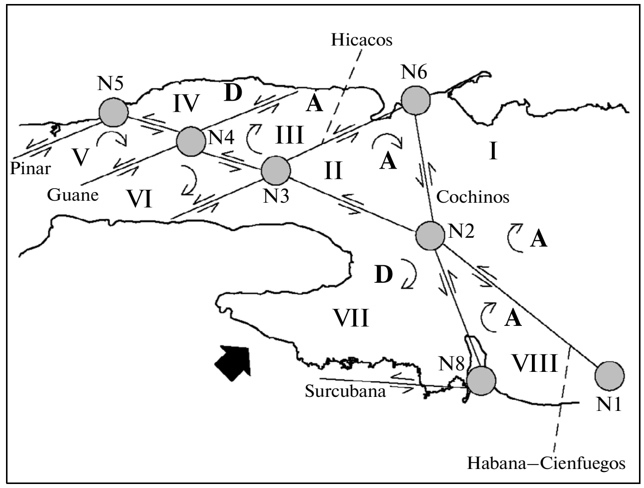


Fig. 16. Geodynamic cells of Western Cuba.
Black line—fault: Guane, Habana–Cienfuegos, Cochinos, Hicacos, Nortecubana, Pinar, Surcubana. Grey circle—knot of faults: N1—Cienfuegos, N2—Torriente–Jagüey Grande, N3—Güines, N4—San José de las Lajas, N5—Habana, N6—Bahía de Matanzas, N7—Hicacos, N8—Bahía de Cochinos. Curve black arrow—block movement. Symbol: I–VIII—cell, A—uplift area, D—downtown area. Heavy black arrow—main stress (ρ_1).

FINAL REMARKS AND CONCLUSIONS

The seismotectonic complexity of the Cuba region is remarkable, due to the fact that the region corresponds to part of the contact between the plates of North America and Caribbean. Then Cuba is differently affected by the SW-NE transpressive stress, resulting from the interaction of the Caribbean and North American plates. These influences are mainly reflected in the Southeastern and Eastern areas. The active faults are segmented and in their intersections accommodate the regional displacement. In the rest of Cuba there are also some small and moderate intraplate seismic events. They are throughout the country and seem to be associated to the pre-existing zones of crustal weakness.

We consider that the earthquakes in Cuba are produced in faults and their intersections (or knots). On this base an alternative explanation to the seismoactivity of Cuban faults is presented. The model is consequence of the interaction between Caribbean and North American plates. It is made with 12 geodynamic cells form by a set of 13 active faults and their 14 areas of intersection. These cells are recognized morphostructural blocks.

The final Cuban geodynamic model is split in two regions of different size and seismic activity: (1) Eastern, and (2) Western (the largest). The Eastern region is the most active and included four cells: CI—Sierra Maestra, CII—Nipe–Cristal–Sagua–Baracoa, CIII—Maniabón, CIV—Cauto–San Germán–Las Tunas. While, the Western region has eight cells of minor size: CI—Matanzas Este, CII—Matanzas Centro, CIII—Habana–Matanzas, CIV—La Habana, CV—Habana Oeste, CVI—Habana Sur, CVII—Zapata–Cochinos and CVIII—Cienfuegos.

In the Eastern region there are six seismic knots: nA—Cabo Cruz, nB—Baconao, NC—Cauto, nD—Puerto Padre, nE—Nipe and nF—Maisí. Western region have more active knots (8): N1—Bahía–Cien-

fuegos, N2—Torriente–Jagüey Grande, N3—Güines, N4—San José de las Lajas, N5—Bahía de La Habana, N6—Bahía de Matanzas, N7—Hicacos, N8—Bahía de Cochinos.

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Reviewer V.G. Trifonov