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The Santiago de Cuba earthquake of 11 June 1766: Some new insights

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RESUMEN

La información del terremoto reportado en Santiago de Cuba el día 11 de junio de 1766 ha sido re-evaluada en detalle. Para ello se han empleado datos del Archivo de Indias, Sevilla, y de otras fuentes bibliográficas. Este terremoto fue perceptible en un área muy extensa que incluyó a La Habana y a Jamaica. Fue posible cartografiar la distribución de los daños producidos en las diferentes poblaciones. El número total de fallecidos se situó entre 34 y 40 personas y en 700 los heridos. No se produjo tsunami. La localización aproximada del epicentro es 19.9ºN, -76.1ºW, dentro de la zona de fallas de Bartlett – Caimán. La profundidad focal se fijó a 25 km, mientras que la intensidad sísmica estimada fue IX (MSK) y la magnitud (Ms) alcanzó el valor de 6.8. Entre los años 1578 y 1842 en este sector marino se reportaron otros terremotos fuertes: cuatro de I=8 (MSK) y seis de I=7 (MSK).

PALABRAS CLAVE: Cuba, sismicidad histórica, evaluación macrosísmica, sismotectónica.

ABSTRACT

Data concerning the Santiago de Cuba earthquake of 11 June 1766 are examined using information collected in the Archivo de Indias, Seville, and other sources in Spain and abroad. The earthquake was felt over a large area including La Habana and Jamaica. A damage distribution with reference to urban settlements is provided. The total number of casualties is estimated at 34 to 40 dead and 700 injured. A tsunami did not occur. The approximate location of the epicentre was 19.9ºN, -76.1ºW, in the Bartlett – Caimán Fault Zone. The focal depth is estimated at 25 km, the epicentral intensity is estimated at IX (MSK) and the magnitude (MS) at 6.8. Between 1578 and 1842 this sector experienced other strong seismic events: four of I=8 (MSK) and six of I=7 (MSK).

KEY WORDS: Cuba, historical seismicity, macroseismic evaluation, seismotectonics.

INTRODUCTION

In Cuba, a potentially rich source of earthquake data can be gathered from 500 years of written records. Earthquake records and descriptions in Cuba began with the arrival of the Spaniards in 1492.

Cuba is located in the southern part of the North American plate. The plate boundary is along the south - east coast (Figure 1) (Álvarez *et al*., 1985). The general pattern of seismicity of the Caribbean region is shown in Figure 2A. Large earthquakes occur along the plate boundary near Hispaniola, Jamaica and Puerto Rico (Figure 2B), but no event since the 18th century has reached a magnitude of 7,0 (Cotilla and Udías, 1999). Low magnitude seismicity (Ms < 4) occurs throughout the western region of the island (Figure 2A) particularly around Santiago de Cuba (Figure 2C). The main seismic activity follows the Bartlett – Caimán Fault Zone. In this segment faulting is mostly left-lateral strike-slip (Cotilla, 1998).

The 11 June 1766 earthquake was felt over a large area, as far away as the city of Havana at 800 km. It was also felt in Jamaica, 140 km to the south. This event was studied by Cotilla and Udías (2000). Other references are listed in Table 1. 20th century references such as Grases (1990), Chuy (1990), Álvarez *et al*. (1999) and Cotilla (1999) were based on Chuy and Pino (1982) and/or Zapata and Chuy (1992). Earlier work was based on Poey (1855a,b, 1857), whose main source was Perrey (1843, 1845, 1856). Cotilla and Udías (1999, 2000) include the bibliographical sources used by Poey and other authors concerning the 1766 earthquake. Among these sources are reports of the earthquake in Gazette de France, Gentleman's Magazine and Journal of History (Cotilla and Udías, 2000), and later in Faro Industrial and Diario de La Habana published in La Habana in 1842 and 1853, respectively.

One of the aims of this study is to provide a critical review of the information available and to resolve some ambiguities appearing in previous works. We use contemporary original documents from the Archivo de Indias (AI) in Seville, Spain. Excerpts from the documents in Spanish can be found in Cotilla and Udías (2000). A perusal of original documents in AI concerning the 1766 earthquake reveals a number of discrepancies with the available Cuban earthquake

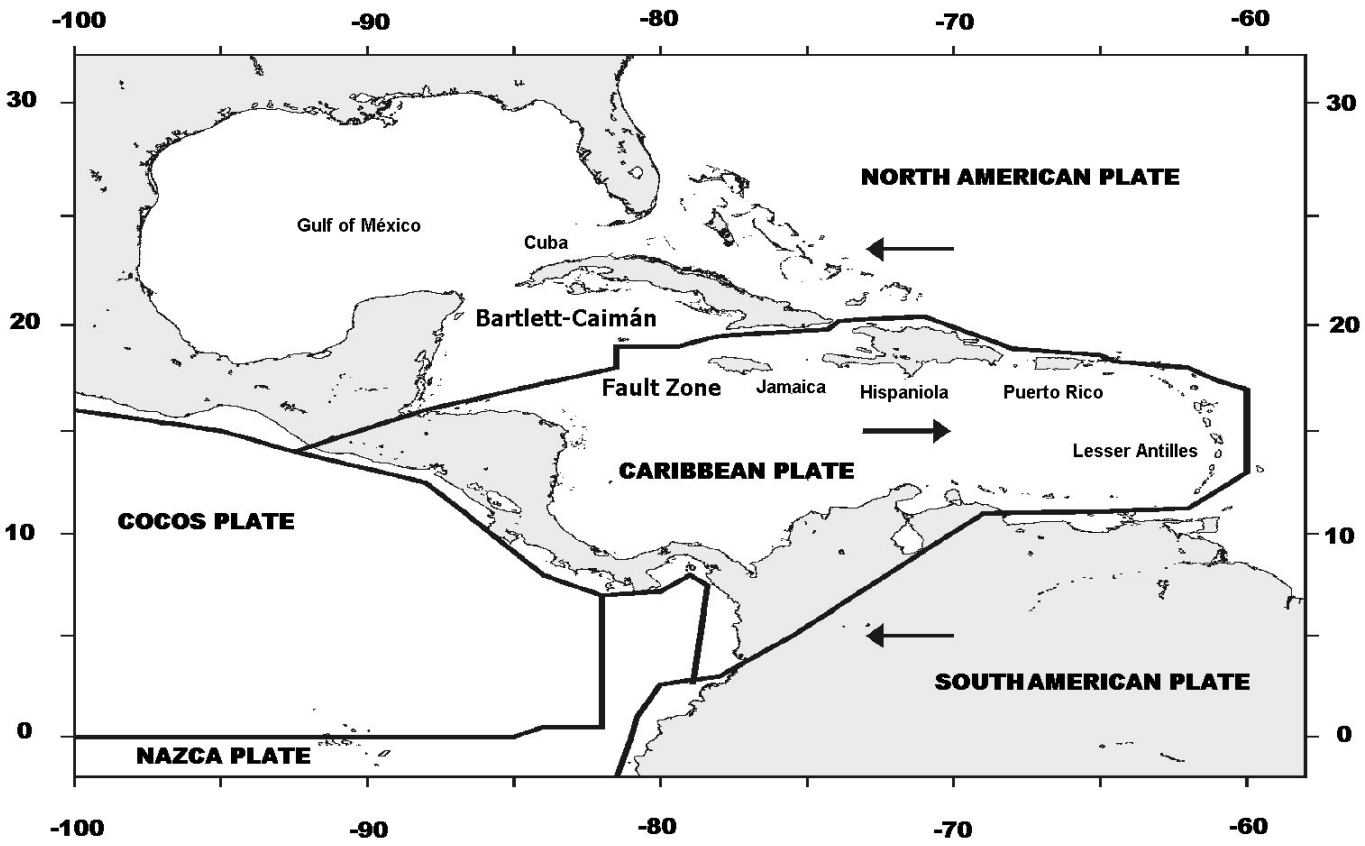

Fig. 1. Location of Cuba in the Caribbean region. Heavy lines indicate the plate boundaries. The arrows indicate the plate motion direction.

catalogue, as well as misinterpretations of reports in catalogue compilations and some transcription errors (Cotilla and Udías, 2000). We find that the 1766 earthquake occurred in the area of greatest seismic activity in Cuba (Cotilla *et al*., 1991). More than 10 strong earthquakes have been documented historically (Álvarez *et al*., 1999), and another three significant events have been recorded instrumentally, in this area (Cotilla, 1998). Chuy *et al*. (1999) studied the Santiago de Cuba earthquake of 20.08.1852 and found it to be the second strongest historical earthquake in Cuba. They placed the epicenter at 19.75°N, 75.32°W and estimated a macroseimic magnitude of 7.3 (I=9 MSK) and h=30 km.

EVALUATION AND DISCUSSION OF NEWLY RETRIEVED DOCUMENTS

The 1766 Cuban earthquake is significant because of its seismotectonic characteristics, and its implications for earthquake hazard assessment. In a new and wider bibliographical review of historical earthquakes in the American colonies, we found that two strong Colombian earthquakes had been reported in 1766. These earthquakes are in the catalogue of Ramírez (1975). They are: 1) 1766.07.09, 16:00 hours, 3.7ºN, -76.3ºW; 2) 1766.10.21, 16:30 hours, 6.5ºN, -67.4ºW. The King of Spain, Carlos III, responded to the catastrophe and gave important economic support to Cuba: 10.000 pieces of gold. He also ordered an accurate cartographic field study done on the whole island. In the Hemeroteca de Madrid and the Biblioteca Nacional of Spain we found the Cuban reports, the Faro Industrial and the Diario de La Habana, mentioned by Poey.

Cotilla (1999) provided information on the most important seismological events for 1492 1996. He claimed that in Cuba there are no original sources on earthquakes occurring from the arrival of the Spaniards to the beginning of the 20th century. Cotilla and Udías (1999) discussed the characteristics of the strongest earthquakes in the Santiago of Cuba region; the epicentre location of the 1551 earthquake; and the earthquake catalogues of Andrés Poey and their use by other authors. Finally, Cotilla and Udías (2000) carried out an initial study of the 11.06.1766 earthquake with data from the Archivo de Indias. We also provided some isoseismals, and two different estimates of the magnitude.

The collected information about this destructive earthquake revealed that a significant number of persons in different cities of Cuba wrote, between 1766-1771, at least a short report about it. They sent their reports to the Governor Fernando de Cagigal y García, Marquis of Casa Cagigal, to

the Captain General Antonio María Bucareli y Ursua in La Habana, and in some cases to the King of Spain.

A total of 32 documents have been located in the Archivo de Indias as follows: Cuba – 1051, 1052, 1053, 1071, 1084, 1085, 1086, 1097, 1111, 1118, 1120, 1124, 1136B. These are official or private letters written from 21 June 1766 to 24 September 1771. The documents can be classed as follows:

- Letters by the Governor of Santiago de Cuba, Marquis of Casa Cagigal and by the Captain General of Cuba
- Letters from several persons in Cuba addressed to Bucareli
- Correspondence between Bucareli and the Minister of the Indies, Julián de Arriaga
- Reports of Casa Cagigal to the King of Spain, Carlos III
- A letter of Carlos III to Casa Cagigal.

The most complete information is found in the following seven documents to be referred by number.

1. Letter of Casa Cagigal to Bucareli: 14 June 1766 (Cuba 1051)
2. Report of Beltrán Beaumont and Pedro Beaumont, engineers appointed by Casa Cagigal: 15 June 1766 (Cuba 1051)
3. Letter from Luis Unzaga to Bucareli: 16 – 17 June 1766 (Cuba 1084)
4. Letter from Bucareli to Arriaga: 6 July 1766 (Cuba 1124)
5. Letter from Casa Cagigal to Bucareli: 18 July 1766 (Cuba 1051)
6. Letter from Casa Cagigal to King Carlos III: 31 July 1766 (Cuba 1124)
7. Letter of Bucareli to Arriaga: 24 September 1767 (Cuba 1136B).

Here is an example of translated excerpts from a letter of Casa Cagigal to Bucareli:

CUBA 1051 (document 1): Cuba, 14th June of 1766

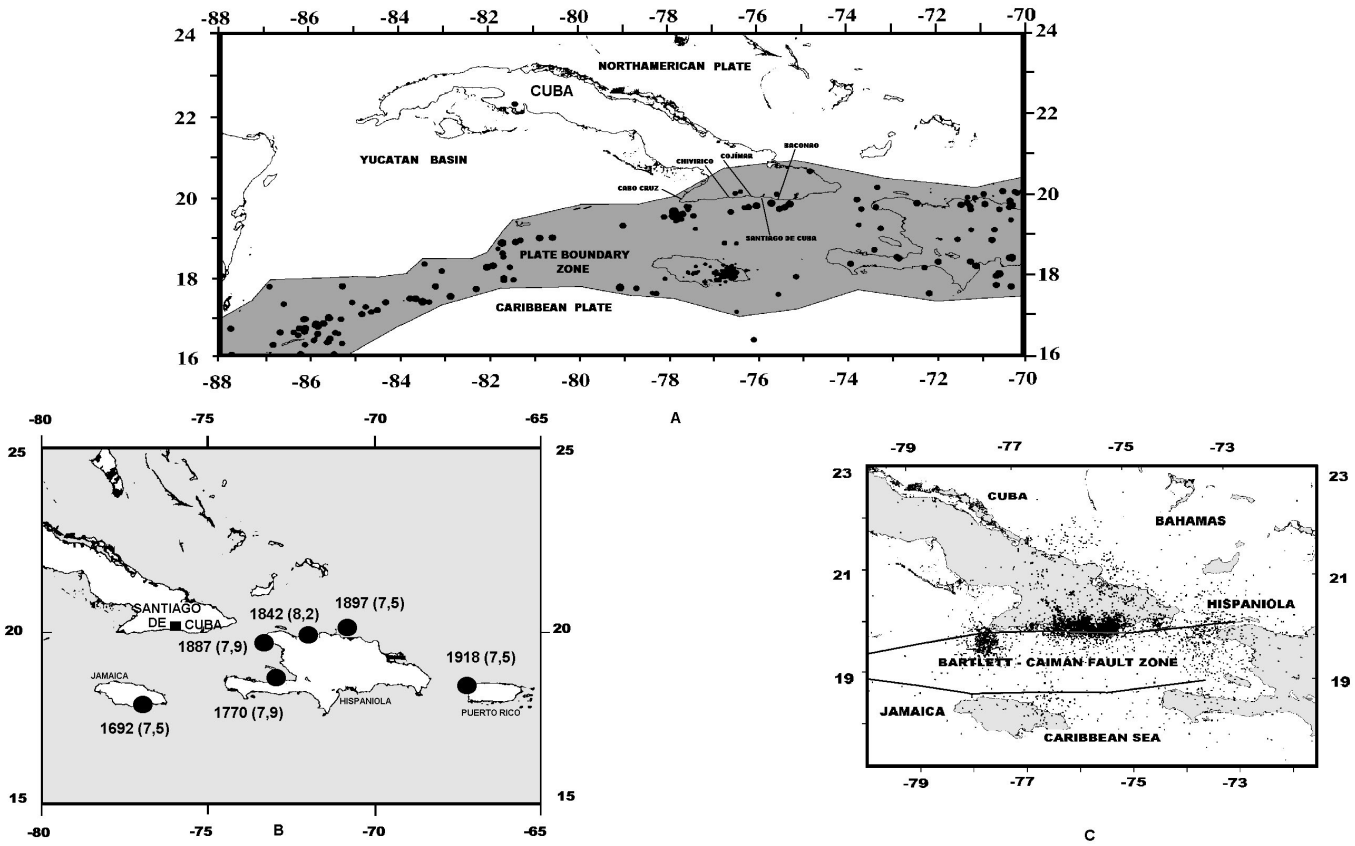

Fig. 2. Sketch of the seismicity in the tectonic framework of Cuba. (A) Epicentres in the North Plate Boundary Zone (1970-1995, Ms > 4, h < 30 km). (B) Largest historical seismic events (Ms >5) (Álvarez *et al.,* 1985). (C) Seismicity of Eastern Cuba based on the catalogue compiled from the Cuban network (1979-1991, Ms < 4, h < 30 km).

Table 1

Selection of previous studies and information about the earthquake of 11 June 1766

Author	Date	Local Time	Notes
Pichardo, 1854	11.06.1766	-	Horrendous
Poey, 1855 a,b,1857	11.06.1766	midnight	Strong shocks for seven minutes. Destroyed many buildings. Aftershocks up to 1st August
Pezuela, 1863	11-12.06.1766	midnight	A lot of injured. Destruction of Santiago de Cuba and Bayamo cities
Salteraín & Legarra, 1884	11.06.1766	11 _ night	Horrendous. Around 30 earthquakes
Morales & Pedroso, 1933	11.06.1766	midnight	Used Poey's information. The epicentre is located in the knot of faults Kingston with Bartlett – Caimán (19.75ºN, -76.65ºW)
Chuy & Pino, 1982	11.06.1766	23:45	I=IX (MSK), 120 dead and more than 600 injured. Many aftershocks
Grases, 1990	11.06.1766	23:45	I=IX (MSK)
Zapata & Chuy, 1992	12.06.1766	00:14	Ms=7.5, Io=IX (MSK), h=30 km, 19.90ºN, 76.10ºW. 120 dead and more than 600 injured
Chuy, 1999	12.06.1766	00:14	Ms=7.6, I=IX (MSK), h=35 km, 19.80ºN, -76.10ºW. 120 dead and more than 600 wounded
Álvarez et al., 1999			As Chuy, 1999
Cotilla, 1999			As Zapata and Chuy, 1992
Cotilla & Udías, 1999	11.06.1766	00:00	Ms=6.8, I= IX (MSK), h=20 km, 19.92ºN, 76.00ºW. No tsunami. 34-40 dead and 700 injured (only in S. of Cuba). Aftershocks for 66 days
Cotilla & Udías, 2000	11.06.1766	00:00	Ms=6.8, I= IX (MSK), h=25 km, 19.9ºN, -76.1ºW. No tsunami. 34-40 dead and 700 injured (only in S. de Cuba). Aftershocks during 66 days

Letter from the Marquis of Casa Cagigal to the General Captain
"The 11th day of the current month at 12 o'clock at night, when most of the inhabitants of this city were lying asleep in their houses, God lifted the arm of his justice with an earthquake so huge that after a quarter of an hour there were not any buildings left in good condition….Everybody would have died if not for the special providence of His Mercy…"
…"Up until now, as far as it has been possible to determine, there are not more than 40 dead; many have been injured…."
…"The land has not ceased shaking…"
…"Shocks are repeated daily, some not very small but distant from the impetus and rigor of the first one…"

Effects of past earthquakes need to be referred to the degree of urban development, building types, vulnerability factors and soil conditions, all of which might have undergone significant changes over long periods of time. Also, it is important to consider the total population. The 1774 census cites a population of 171 620 (Table 2), the majority in Western Cuba. Table 3 shows a summary of the 1817 census for Santiago de Cuba. At the time of the earthquake Santiago de Cuba and Bayamo had about 5200 inhabitants each. If 120 persons had been killed in Santiago de Cuba, the economic effects and the number of injured would have been ten times greater than we have found. Captain Diego Velázquez founded Bayamo and Santiago de Cuba in 1513 and 1515, respectively. Their economic and urban development remained far below that of other cities in Western and Central Cuba, such as La Habana, Trinidad and Camagüey (Figure 3A). No sugar mills existed in Santiago de Cuba between 1760-1868, in contrast with 143 in the Cauto valley

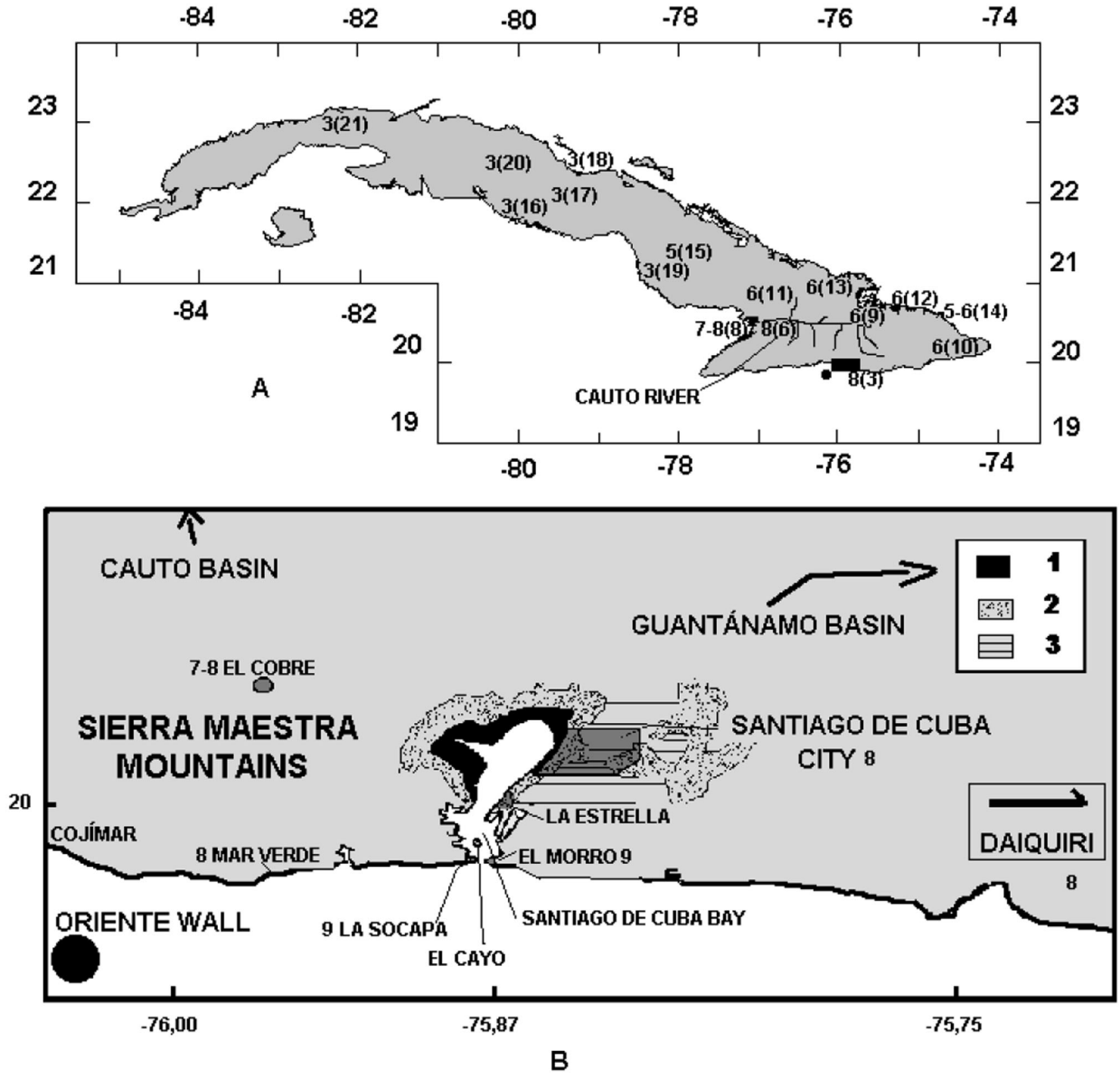

Fig. 3. Sketch of the 11.06.1766 earthquake perceptibility. (A) Localities of Cuba where the earthquake of 1766 was felt, according to the new historical documents. Numbers 5(15) refer to the associated intensity value (and locality) found in Table 2. A solid circle indicates the epicentre. Santiago de Cuba area is represented by a solid rectangle.) (B) Site conditions in the surroundings of Santiago de Cuba (terrain: 1- marine and river sediments; 2- slope sediments; 3- hills and important relief-slopes; 4- localities are accompanied by the associated intensity value (8); 5- epicentre = solid circle).

(~6% of the total in Cuba). Also, document 4 (Bucareli to Arriaga) made a tacit reference to the fact that the economy of Santiago de Cuba was not affected by the earthquake of 1766:

> "*…I must inform you that though the severity of the earthquake was great, it should not be considered excessive with respect to damage caused, as a preliminary examination of the situation of Santiago de Cuba villages reveals, since all the destruction is limited to the material ruin of some buildings and to the loss of others in the town centre, but without importance or damage to the coffee plantations and farms as I verified after this event....*"

Santiago de Cuba is in a NE trending tectonic basin in the Sierra Maestra Mountains, with a transverse asymmetry (Cotilla *et al*., 1991) (Figure 3B). It is located in the higher, northeastern part of the basin, on limestones of different densities (Upper Miocene to Pliocene). It is bounded on the west and north by the El Cobre Group (Palaeocene – Eocene) of volcano – clastic rocks of basic and intermediate composi-

Table 2

Data of the Cuba Census

Year	Population
1774	171.620[1]
1827	704.487[1]
1862	1.179.713[1] 1.409.238[2]

Note: [1] Sagra (1869, 1872)
[2] Boletín de la Sociedad Mexicana de Geografía y Estadística

Table 3

Data of Santiago de Cuba Census (1817)

Citizens			
White	Free	Slave	TOTAL
9.302	10.032	7.404	26.740

tion (Academias de Ciencias de Cuba y de Hungría, 1981). According to the classification of Cotilla (1998) for the Cabo Cruz (W) - Baconao (E) coastline (Table 5), Santiago de Cuba belongs to Sierra Maestra Block 5, which is tilting to the north and uplifting (Figure 4A).

At 00-h local time on June 11, 1766 an earthquake heavily damaged the cities of Santiago de Cuba and Bayamo. The people in these towns reported some aftershocks during the next 66 days. Some aftershocks were accompanied by underground noises. There is no basis for Chuy and Pino's (1982) claim that the earthquake occurred at 23h 45m local time. Álvarez *et al*. (1999) used this erroneous time in the latest Cuban catalogue.

Maximum damage and intensities were associated with the proximity to the epicentral zone in Santiago de Cuba, and with sites on thick alluvial deposits and high relief-slopes. Bayamo (~100 km from Santiago de Cuba) and its surroundings (Figure 3A) are situated in the alluvial plain of the Cauto River, where the earthquake was strongly felt. At this location, a degree VIII (MSK) event was reported in 1551 (Poey, 1855a). Table 4 lists some localities by name with the year corresponding to their foundation.

According to document 1, Santiago de Cuba suffered 34 to 40 dead and about 700 injured, but there were no deaths reported in Bayamo. The number of victims (documents 1 and 7) is relatively low (not 120 dead as supposed by Chuy and Pino (1982)). In both cities the shock caused considerable damage and panic (documents 3 and 4). Most houses were severely damaged and no longer inhabitable; however some solidly-built houses, like the home of Diego Velázquez, a former Captain General, in Santiago de Cuba, were not severely damaged (document 5). Other well-built houses, like that of Juan de Mata Texada, suffered no damage in this earthquake, or in those of 11.02.1678 and 20.08.1852 (Pichardo, 1854).

In Santiago de Cuba the following damage was observed (documents 2, 3 and 6): (a) Destroyed buildings: El Morro Castle, La Socapa Fort guarding the entrance to the

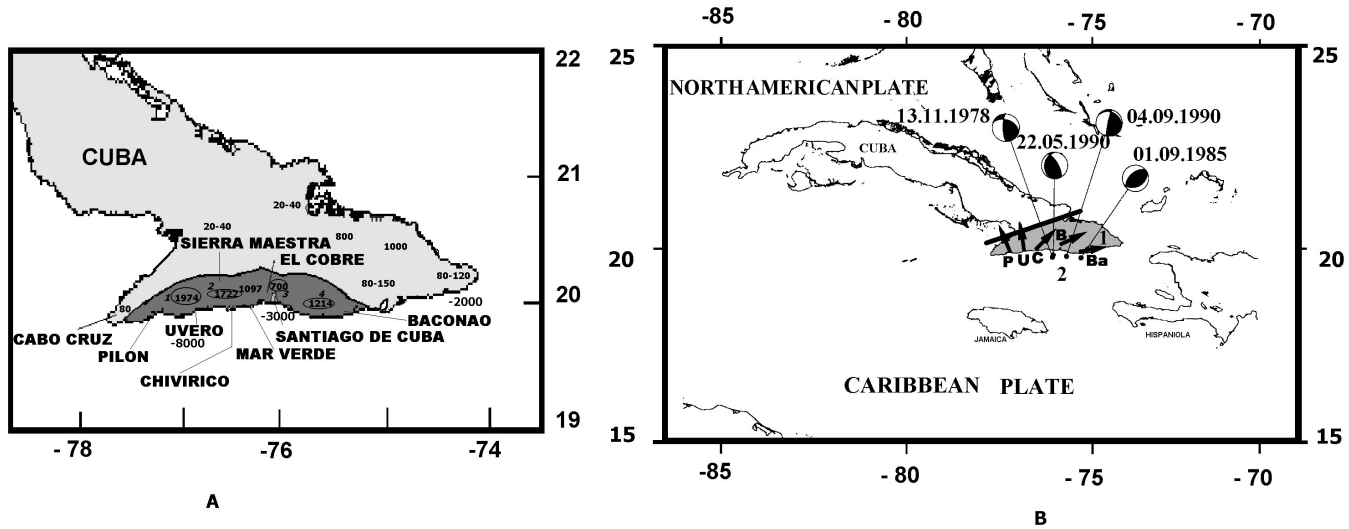

Fig. 4. Neotectonic scheme of Eastern Cuba. (A) Sketch of Sierra Maestra Mountains {(1974= altitude (m); -8000= depth (m)). Closed neotectonic isolines = uplifting (1- 600 m; 2- 300 m; 3- 180 m; 4- 300 m)}. (B) Four focal mechanisms (from CMT) in the southern of Santiago de Cuba (see Table 8). Numbers represent Cuban Seismotectonic Unit: 1- Eastern; 2- Southeastern. Heavy line is the western boundary of the Eastern Seismotectonic Unit. Arrows represent maximum horizontal stress (σ_{max}) (B: Boniato; Ba: Baconao; C: Cojímar; P:Pilón; U: Uvero).

Table 4

Former names and dates of foundation of some Cuban localities

Sites	Founded
Nuestra Señora de la Asunción de Baracoa	1511
San Salvador de Bayamo	1513
Sancti Spíritus	1514
La Santísima Trinidad	1514
San Cristóbal de La Habana	1519
Santa María de Puerto Principe	1528
Baitiquirí	1539
San Juan de los Remedios	1545
Gloriosa Santa Clara	1689
Sagua de Tanámo	1750
San Isidro de Holguín	1751
Tunas de Bayamo	1752

bay of Santiago of Cuba, the Castle of San Francisco, the Hospital, the House of the Governor and the Accountancy (all in the downtown area); b) damaged: the Cathedral in the downtown area; c) collapsed: an unkown number of small homes, stores, and the dock. From Pezuela (1863), Salteraín y Legarra (1884) and the Archivo de Indias, we summarise in Table 6 the degree of damage to religious buildings in Santiago de Cuba. This is important since churches were generally stone buildings. This table illustrates the significant differences between the descrptions in the AI and given by other authors. Salteraín y Legarra (1884) reports damage to Santa Lucía and Nuestra Señora del Carmen churches: according to the AI they were undamaged. The AI shows that Nuestro Padre San Francisco church was not in the city of Santiago, as Salteraín and Legarra reported. These inaccuracies and mistakes were repeated in later works (i.e. Chuy and Pino, 1982)).

El Morro Castle was and still is built of solid and heavy blocks of limestone, abundant in this region (Academias de

Table 5

Data of the neotectonic segment Cabo Cruz – Baconao (Sierra Maestra Mountains)

Sector	Maxime altitude (m)	Morphotectonic's block	Characteristics
Cabo Cruz	300	Cabo Cruz Plain	Monoclinal coast. Well developed carbonate marine terraces. Predominant E-W and NE fractures. Two significant earthquakes: 26.08.1990 (Ms=5.9) and 25.05.1992 (Ms=6.9)
Pilón-La Plata	1000	Sierra Maestra 1	Horst and graben system. Some E-W small pull apart basins. Marine terraces in magmatic and volcano-sedimentary rocks. Predominant E-W and NW fractures. Relief-slope value of 430 km/km. An important earthquake in 19.02.1976 (Ms=5.7)
La Plata-Uvero	1974	Sierra Maestra 2	The highest block and relief-slope (650 km/km). Monoclinal horst and graben system. End and very high marine terraces in magmatic and volcano-sedimentary rocks. Predominant N-S and NNW fractures
Uvero-Cojímar	1500	Sierra Maestra 3	Tilt marine terraces with few small pull-apart basins. Terraces in magmatic and volcano-sedimentary rocks. Predominant NW and NNW fractures. Relief-slope value of 480 km/km
Cojímar-Mar Verde	1200	Sierra Maestra 4	Tilt marine terraces with very small bays. Predominant NW, NNW and NE fractures. Relief-slope value of 380 km/km. Some important earthquakes are assigned (I=IX: 11.06.1766; I=VIII: -.08.1578, 11.02.1678, 11.07.1760; I=VII: .-.1580, 11.02.1675, -.-.1682, -.-.1762, 11.02.1775, 18.09.1826, 07.07.1842, 28.01.1848)
Mar Verde-Siboney	700	Sierra Maestra 5	Santiago de Cuba basin here. Predominant NE fractures. The East Side of the bay is higher than the west. Broad and well preserved carbonate marine terraces. Relief-slope value of 200 km/km
Siboney-Baconao	1200	Sierra Maestra 6	Horst and graben system. Predominant NW fractures. Relief-slope value of 460 km/km. End-tilt carbonate marine terraces. Some important earthquakes (20.08.1852, Ms=7.3; 03.02.1932, Ms=6.7; 07.08.1947, Ms=6.7)

Ciencias de Cuba y de Hungría, 1981), on the eastern side of the entrance to Santiago de Cuba Bay 30 m above the western side (La Socapa Fort). West and north of Morro Castle local soil conditions and relief enhance the ground motion. We found an anonymous, rough hand drawing from 1755 representing the entrance of Santiago de Cuba Bay (Libros de Registro del Gobierno de Cuba, ULTRAMAR: legajo 4765 de febrero 1757), showing the location of the fortress (Figure 5).

The city of Bayamo was severely affected in a similar way to Santiago de Cuba (document 7), but without victims. The following buildings were destroyed: the Parish Church, the Convent of the Seraphic Father San Francisco, the churches of Santo Domingo, Parish of San Juan, Santo Cristo del Buen Viaje, Nuestra Señora de la Luz, Nuestra Señora de Regla, Nuestra Señora de la Luz y Santa Ana, the hospital of San Roque, 263 stone and brick houses, 487 houses of adobe and brick walls and 71 straw and wood houses.

Besides Santiago de Cuba and Bayamo, the earthquake: (a) produced light damage in Baitiquirí Fort, Mayarí Town, Sagua de Tánamo Town, Tunas de Bayamo Town and Holguín City (documents 1, 3, 4, 5 and 6); b) was felt strongly in Puerto Principe City (today Camagüey; document 4) and Baracoa City (document number 4); c) felt in Remedios Town, Sancti Spíritus City, Trinidad City and Santa Clara Town (document 4); d) felt slightly in La Habana City (~ 800 km of distance westward; document 4) (Figure 3A), and in Port Royal, Jamaica (Perrey, 1843)).

Table 6

Effects on religious buildings of Santiago de Cuba according to three sources [an X indicates reports of buildings affected.]

Building (constructed)	Pezuela (1863)	Salteraín y Legarra (1884)	Archivo de Indias (AI)	Conclusion [according with the documents located in "AI" (Cuba signature)]
Cathedral (1700)	X	X	X	Affected (1085, 1120, 1124)
Nuestra Señora de los Dolores Church (1723)	-	X	X	Affected (1085, 1124)
San Juan de Dios Church (1739)	-	-	X	Little affected. Architecture simple and not so tall (1136-B)
Santa Lucía Church (end of XVII century)	-	X	-	Unaffected
Santísima Trinidad Church (end of XVII century)	-	-	-	Unaffected
Santo Tomás Apóstol Church (1726)	-	-	X	Little affected. Architecture simple but heavy (1124)
Nuestra Señora del Carmen Church (1719)	-	X	-	Unaffected
Nuestro Padre San Francisco Church (1727)	-	X	-	This is a mistake (1124, 1136-B)

Fig. 5. Sketch of the entrance of Santiago de Cuba Bay. (Anonymous, 1755.) (Fortress: A- La Estrella, B- La Socapa, C- El Morro Castle.)

The epicentre was offshore (document 3). It is unclear whether the epicentre was southeast or southwest of Santiago de Cuba Bay, but we may discard a location to the south of the Sierra Maestra Mountains between the meridian of Santiago de Cuba and Bayamo as proposed by Morales y Pedroso (1933). The main event was not associated with a tsunami. No abnormal fluctuations of the sea level during or after the earthquake were reported. There were changes of level in wells, springs or rivers, landslides, liquefaction and surface cracks.

The damage reports from Cuba and from Port Royal, Jamaica (Perrey, 1843) suggest seismic intensities on the MSK scale as in Table 7. The intensity values for Cuba is shown on Figure 3A. Given the small number of observations, it is not possible to draw the isolines with much accuracy, as Cotilla and Udías (2000) have shown. However, in general, the intensities suggest that the epicentre was to the southwest of Santiago de Cuba Bay (Figure 3A). The maximum intensity of the main shock reached degree IX at El Morro and La Socapa and degree VIII in parts of the towns of Santiago de Cuba and Bayamo and in the villages of Mar Verde and Baiquirí (the present Daiquirí) (Figure 3B). There is some information indicating that the earthquake was felt strongly (intensity V) in Camagüey and without specifications, in Trinidad, Sancti Spíritus, Remedios, Santa Clara and La Habana (intensity III) (Figure 3A). Thus when stress is released in major earthquakes, the effects may be transmitted from Santiago de Cuba as far as La Habana.

The 11.06.1766 isoseismal map made by Chuy (1999) lacks scientific credibility, because it was performed on the basis of seven reports. An intensity value of 6 (MSK) was assigned by this author, which is higher than our interpretation based on AI data. Chuy (1999) gave a hypocentre location of 19.80ºN, -76.10ºW, h=35 km which differs from Chuy and Zapata (1992) (19.90ºN, -76.10ºW, h=30 km) and Álvarez *et al*. (1999). Cases of overestimating earthquakes have been discussed by some authors (Udías and Muñoz, 1979; Vogt, 1991). Gutiérrez-Lanza (1914) and Montoulieu (1933) found large technical and scientific inconsistencies in the writings of different authors in relation to the Cuban earthquakes of 20.08.1852 and 03.02.1932.

Considering the structure and oceanic type of the crust (Prol *et al*., 1993) and the geodynamic conditions of the plate boundary (Cotilla *et al*., 1991), it does not seem likely that the earthquake was a deep one. The observed mean earth-

Table 7

Intensity evaluation by sites (See Figure 3)

Nº	Site	Intensity (MSK)	Document located in: "AI" – (Cuba signature) and Perrey (1843)
1	El Morro Castle	IX	(1051, 1053, 1084)
2	La Socapa Fort	IX	(1051, 1053, 1084, 1124)
3	Santiago de Cuba City	VIII	(1051, 1086, 1124)
4	West Fort (current Mar Verde Fort)	VIII	(1053, 1084, 1124)
5	East Fort (current Daiquirí Town)	VIII	(1053, 1084, 1124)
6	Bayamo City	VIII	(1085, 1086, 1124, 1136B)
7	El Cobre Town	VII-VIII	(1086)
8	Manzanillo Town	VII-VIII	(1124)
9	Mayarí Town	VI	(1085, 1118)
10	Baitiquirí Fort	VI	(1085, 1118)
11	Tunas de Bayamo Town	VI	(1085, 1118)
12	Sagua de Tánamo Town	VI	(1085, 1118)
13	Holguín City	VI	(1085, 1118)
14	Baracoa City	V-VI	(1085, 1118)
15	Camagüey City	V	(1085, 1086, 1124)
16	Trinidad City	III	(1124)
17	Sancti Spíritus City	III	(1124)
18	Remedios Town	III	(1124)
19	Vertientes Town	III	(1124)
20	Santa Clara Town	III	(1124)
21	La Habana City	III	(1086, 1124)
22	Jamaica Island	V	Perrey (1843)

quake depth in the region is 10-15 km for recent earthquakes (Cotilla, 1998). The energy released by recent events is low, and, thus, our depth estimates should be used with care. Furthermore, the lack of tsunamis corresponds well with the prevailing strike-slip focal mechanism in the Cabo Cruz – Santiago de Cuba segment (Cotilla, 1998). On the other hand, the focal mechanisms of four earthquakes to the south of Santiago de Cuba Bay indicate a fault plane oriented to the NW-SE and a pressure axis to the NE (Figure 4B, Table 8). This is in agreement with the neotectonic results of Cotilla *et al*. (1991), for the maximum horizontal stress direction ($\sigma_{máx}$) in the Sierra Maestra (Figure 4B). The stress indicators of geological faults in Boniato (6 faults), Baconao (8 faults), Cojímar (4 faults), Pilón (5 faults) and Uvero (5 faults) were taken into consideration. From this data it is possible to conclude that southern Cuba (Pilón - Baconao segment) is undergoing a NE-SW oriented compression in the context of strike-slip plate motion (Northamerican – Caribbean), which has remained almost constant since the Miocene.

The approximate epicentral location, using the central point of the area of greatest damage as the starting point for a line extending offshore to the south, can be estimated as: 19.9ºN, 76.1ºW, which is on the Bartlett – Caimán fault zone. This location agrees with Chuy and Zapata (1992) (19.90ºN, -76.10ºW), but a second decimal figure is not justified by the available data. From the maximum intensity of IX at Morro Castle and using the Sponheuer (1960) relation (MS= 0,66 I_0 + 1,7 logh – 1,4), assuming a depth of 25 km (Cotilla *et al*., 1991), we obtain a magnitude (M_S) of 6,8 (see also Cotilla and Udías, 2000).

The epicentre of the earthquake of 1766 is located in the region with the densest cluster of low magnitude earthquakes in the Cuban seismic network, to the south of Santiago de Cuba (Figure 2C). The highest values of the epicentre density and seismic activity maps (Cotilla *et al*., 1991) describe an elongated W-E band from Uvero to Baconao. This zone is the most active segment of the Bartlett – Caimán fault. The epicentre is approximately 10 km from the small, new village of Cojímar in the Sierra Maestra Mountains, where a high relief-slope (480 km/km) exists from the coast line into the sea (Cotilla *et al*., 1991) (Figure 3B). The distance from the village to El Morro Castle is around 20 km. Here the Bartlett-Caimán Trough (or "Oriente Deep" of Calais and Mercier de Lepinay (1991)) shows an important change of relief. Calais and Mercier de Lepinay (1991) distinguished a morphologic feature from -76.17ºW to -78.00ºW called "Oriente Wall", which is interrupted by the "Santiago Promontory" at -76.00ºW. Here the W-E trending isobaths change abruptly to a N-S trend. Within the "Oriente Wall" a small rectangular morphologic domain called Chivirico Basin was identified. The latitude range of this structure is approximately 19.80ºN to 19.95ºN, which corresponds to the epicentre area proposed here.

Álvarez (1983) discussed the seismic regime in southeastern Cuba using international catalogues and data for Río Carpintero (RCC), a Cuban seismic station, from 10/1968 to 06/1982. He showed that 85% of epicentres located by RCC belong to zone 1 (-75.2ºW/76.2ºW) which is the most seismically active area in Cuba. All the earthquakes listed in table 9 lie within the southern parts of Sierra Maestra Blocks 4, 5 and 6 (Table 5). They are in the Gonave microplate (Mann *et al*., 1995), the Santiago Deformed Belt (Calais and Mercier, 1991), and the boundary of the Eastern and Southeastern Seismotectonic Units of Cuba (Cotilla *et al*., 1991) (Figure 4B). The Eastern Seismotectonic Unit (emerged part) adjacent to the Southeastern Unit (Gonave microplate) has significantly differentiated relief (Figure 4A, Table 5) and is related to the oceanic unit by NW transverse faults such as the Cojímar and Baconao (Cotilla *et al*., 1991). The intersections (called faults' knots by Rantsman, 1979) of such transverse faults with the Bartlett - Caimán fault may be favourable areas to produce strong earthquakes (Cotilla, 1998).

Álvarez *et al*. (1999) placed the 20.08.1852 earthquake at 19.75N, -75.32W (near Baconao). This is to the east (~80 km) of the 1766 event, but also in the most active sector of the Bartlett - Caimán fault. The earthquakes of 03.02.1932

Table 8

Data of focal mechanisms (from CMT) (See Figure 4B)

Date	Location	Ms	Comment
13.11.1978	19.84N, -76.05W	5.1	~ 1766 (to southeast 10 km)
01.09.1985	19.78N, -75.28W	5.1	~ 1852 (to northeast 5 km)
22.05.1990	19.74N, -76.02W	5.1	~ 1766 (to southeast 20 km)
04.09.1990	19.80N, -75.69W	5.2	Located between the approaches of Mocquet (1984) and Álvarez *et al*. (1999) to 1932's earthquake, but 10 km to the second proposal

and 07.08.1947 are located in approximately the same area. The 07.08.1852 and 03.02.1932 earthquakes were felt in La Habana and Jamaica, supporting the hypothesis of transmission of seismic energy to the NW.

Santiago de Cuba has suffered the effects of other strong earthquakes located in the Bartlett-Caimán Fault Zone, mainly in 07.08.1852 (I_0= IX), in 1578, on 11.02.1678, and 03.02.1932 [I_0= VIII]. All are more or less well documented (Cotilla and Udías, 1999). On this basis, the mean occurrence rate in this region may be one strong earthquake roughly every century. Table 9 shows data from twenty strong earthquakes located south of Santiago de Cuba Bay (Álvarez *et al*., 1999). The right hand column indicates the quality of the determination according to the Accuracy Index (Cotilla and Udías, 1999). This index considers the completeness of the following three parameters: 1) date; 2) time; 3) source of the report; and 4) existence of an isoseismal map. Agreement of intensity estimations is better for the strongest events, and the recurrence period averages 83 years.

Lander *et al*. (2002) presented a catalogue of tsunamis in the Caribbean. These authors cite Grases (1971) and Mallet (1854) to the effect that in *"1766, June 12 [4:45 UT]: An earthquake lasting one and a half to seven minutes hit Santiago de Cuba, and Bayamo, Cuba, and was felt strongly on Jamaica. Ships reported to be 7.2 km from the coast of Jamaica rolled so much that their gunwales were immersed in the water. A tsunami would not greatly affect ships in deep water. Either the ships were in shallow water or the effect was due to a seaquake."* They classified the report as V2, namely: *"A tsunami may or may not have occurred; data are insufficient to ascertain occurrence."* The degree of confidence of the data is very low, as the authors recognised; Perrey (1843) had not mentioned a tsunami; according to Rubio (1982) the earthquake did not produced a tsunami; Grases (1990) does not include the report of a tsunami; and in the Archivo de Indias (document 5 - Cuba 1051) *"…the movement of the sea waves was not larger than 20 baras, as is customary here, either because of the situation of the bay, or due to the direction*

Table 9

List of important earthquakes in the south of Santiago de Cuba

						Intensity value (MSK)				
				Coordinates		≤ VII		≤ VIII		
Nº	**Date**	**Time**	**I (MSK)**	**N**	**W**	**Years**	**Years (by ai)**	**Years**	**Years (by ai)**	**Accuracy Index (ai)**
1	1578/08/-	-	8	19.9	-76.0	-	-	-	-	Poor
2	1580/-/-	-	7	19.9	-76.0	2	-	-	-	Not considered
3	1675/02/11	-	7	19.9	-76.0	95	-	-	-	Good
4	1678/02/11	14:59	8	19.9	-76.0	3	3	100	-	Good
5	1682/-/-	-	7	19.9	-76.0	4	-	-	-	Poor
6	1760/07/11	-	8	19.9	-76.0	78	82	82	82	Good
7	1762/-/-	-	7	19.9	-76.0	2	-	-	-	Poor
8	1766/06/12	00:00	9	19.9	-76.1	4	6	6	6	Very Good
9	1775/02/11	-	7	19.9	-76.0	9	-	-	-	Not considered
10	1826/09/18	09:29	7	19.9	-76.0	51	60	-	-	Good
11	1842/05/07	-	7	19.9	-75.8	16	16	-	-	Good
12	1842/07/07	-	7	19.9	-76.0	0.17	0.17	-	-	Good
13	1852/08/20	14:05	9	19.75	-75.32	10	10	86	86	Very Good
14	1858/01/28	10:14	7	19.9	-76.0	6	6	-	-	Good
15	1887/09/23	11:55	7	19.4	-73.4	35	35	-	-	Good
16	1903/09/19	07:59	7	19.9	-75.8	16	16	-	-	Good
17	1914/08/28	05:19	7	21.3	-76.2	11	11	-	-	Good
18	1930/01/17	12:00	7	19.9	-75.8	16	16	-	-	Good
19	1932/02/03	06:15:55	8	19.75	-75.58	2	2	80	80	Very Good
20	1947/08/07	00:40:20	7	19.9	-75.30	15	15	-	-	Very Good

Note: *Accuracy Index (ai) (Cotilla and Udías, 1999).*

of the ground movements, or by that of the sea currents…”. In conclusion, no tsunami occurred.

CONCLUSIONS

The attention given to the Santiago de Cuba earthquake of 11 June 1766 in historical works reflects the importance and size of the event. A reevaluation of this earthquake from documents in the Archivo de Indias, Seville, and other sources in Spain and abroad allows the following conclusions:

1- At 00-h local time on June 11, 1766 an earthquake took place affecting a large area of Cuba. This event caused 34 – 40 deaths and 700 injured in Santiago de Cuba. Bayamo was also strongly affected but suffered no casualties. The greatest part of the damage was due to a combination of local soil conditions and poor quality building materials in structures of the affected areas.

2- There is evidence of a correlation between damage and site specific effects due to unconsolidated soils and strong relief-slopes in the vicinity of the epicentral region (Figure 3B). These effects are especially visible near El Morro Castle and in Santiago de Cuba, heavily damaged by MSK intensity IX and VIII, respectively (Table 7).

3- The approximate macroseismic epicentre coordinates were 19,9ºN, -76,1ºW, focal depth was estimated at 25 km and maximum intensity IX (MSK) corresponded to a magnitude Ms=6,8. The shock originated in the Bartlett – Caimán fault zone, the principal seismogenic source in the region (Figure 3B).

4- This earthquake was followed by a series of aftershocks felt over 66 days.

5- The epicentre area of 11.06.1766 was affected by other strong earthquakes (I=8 (MSK) in 11.02.1678, 11.07.1760, 13.11.1762, 18.09.1826; I=7 (MSK): 1578, 1580, 11.02.1675, 1682, 01.11.1775, 05.07.1842, 28.01.1848). This area also features a dense cluster of low magnitude seismic events. There was no tsunami associated with the 1766 earthquake.

6- Southern Cuba is near the Bartlett – Caimán Fault Zone (Caribbean – North American plate boundary) in a tectonic setting responsible for significant neotectonic and seismic activities. Santiago de Cuba belongs to the so-called Eastern Cuban Seismotectonic Unit, where the maximum horizontal stress direction (σ_{max}) has an approximately NE-SW trend. In general, this is consistent with the focal mechanism solutions.

7- The mean occurrence rate in this region is of one strong earthquake roughly every century.

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