Available online at www.sciencedirect.com
ScienceDirect
Russian Geology and Geophysics 51 (2010) 1227–1246
RUSSIAN GEOLOGY AND GEOPHYSICS
www.elsevier.com/locate/rgg

The August 20, 1852 earthquake in Santiago de Cuba

Mario Octavio Cotilla Rodríguez *, Diego Córdoba Barba

Departamento de Física de la Tierra, Astronomía y Astrofísica 1,Facultad de CC Físicas, Universidad Complutense de Madrid, Ciudad Universitaria, s/n 28040 Madrid, Spain

Received 27 April 2009; received in revised form 17 March 2010; accepted 9 April 2010

Abstract

On August 20, 1852, an earthquake caused widespread destruction in the city of Santiago de Cuba and its surroundings. A comprehensive search for contemporary documentation was made. The information gathered was used for a detailed analysis of the damage from and characteristics of the earthquakes. Intensities were evaluated at 45 localities, and an isoseismal scheme has been drawn. Maximum intensity reached 8 degrees (MSK), and 6.4 was the estimated magnitude. Damage to the city of Santiago de Cuba has been studied in detail. The low quality of construction aggravated the damage. The total number of casualties was two dead and approximately 200 injured. The shock was felt within 80,000 km^2. The epicenter was determined as 19.75º N, 75.32º W, h = 30 km. This study shows that contemporary Cuban documents must be studied with care in their historical and cultural background to avoid overestimating earthquake intensities.
© 2010, V.S. Sobolev IGM, Siberian Branch of the RAS. Published by Elsevier B.V. All rights reserved.

Keywords: Cuba; earthquake; historical seismicity; macroseismic evaluation; seismicity

Introduction

To gain more accurate knowledge of historic earthquakes, revision of data in the available catalogues is essential. Good research can be done in source locations such as archives, libraries or newspaper libraries, in all countries, if materials are contemporary to the earthquake and if the documents contain reliable data. The investigative research requires much effort and dedication but is justified by improved results and correct evaluation and cataloguing. (Cotilla, 1993, 1998a,b; Cotilla and Álvarez, 2001) repeatedly examined Cuban catalogues, which allowed them to judge the quality of the sources. (Cotilla, 2003; Cotilla and Córdoba, 2010a,b; Cotilla and Udías, 1999) demonstrate both the viability of historical investigation and the quality of research available from Cuban sources.

The authors showed that contemporary Cuban documents must be studied with care in their historical and cultural context to avoid overestimating earthquake intensities. Here, we discuss the Cuban earthquake that occurred on August 20, 1852 (Poey, 1855a,b). The information on the earthquake comes from contemporary sources such as unpublished consular correspondence, official documents and damage reports, as well as from press reports and the observations of travelers who passed through the epicentral region during and after the earthquakes. An extensive search for documents related to these earthquakes was carried out in libraries and archives.

In 1687, Cuban newspaper publishing started in Santiago de Cuba (SC) and La Habana (LH) (Cotilla, 2003, 2007, 2010; Cotilla and Córdoba, 2007, 2010). Felt earthquakes were reported in the newspapers. Newspaper publishing continued to spread across the Eastern Cuban region with time as the population increased. The real descriptions of the earthquakes were catalogued by (Poey, 1855a,b, 1857) and were later interpreted in terms of shaking intensities, and ultimately earthquake epicentres and magnitude (Álvarez et al., 1985, 1993, 1999). Cotilla and Udías (1999) gives a quality classification of the information on these earthquakes. For example, the quality of the information on the 1852 event is considered Good, rather than Very Good or Excellent, because the authors maintain that the base reports could have been better detailed.

The purpose of this paper is to outline what is known about the above mentioned earthquake and its sequences, locate the epicentral area, and assess the magnitude and the effects on the ground and on man-made structures. Furthermore, the study seeks to provide a critical review of the information available and resolve some ambiguities appearing in previous works. The relationship of the 1852 earthquake with local tectonics is studied, and the associated seismic hazard is evaluated.

* Corresponding author.
E-mail address: macot@fis.icm.es (M.O. Cotilla)

1068-7971/$ - see front matter © 2010, V.S. Sabolev IGM, Siberian Branch of the RAS. Published by Elsevier B.V. All rights reserved.
doi:10.1016/j.rgg.2010.10.008

Some general information about Cuba

Cuba was discovered in 1492 by Christopher Columbus. Permanent Spanish settlements were not established until 1512. To understand the importance of the 1852 earthquake and the information contained in the contemporary documents, one must take into account the historical and demographic situation in Cuba, in particular SC. Table 1 shows the different cities and towns founded in Cuba by Sir Diego Velázquez de Cuellar. Churches were built in all of these cities and towns. In the year 1544, over 40 churches and five hospitals existed on the island (Bayamo (1518), SC (1520), LH (1521), Port-au-Prince (1523), and Sancti Spíritus (1523)). All the hospitals had their barbers, nurses or itinerant quack doctors, but rarely real doctors (Delgado, 2000; Gaceta Médica de México, 1945). Population data are shown in Table 2. All these structures permit assessing the damages produced by the earthquakes and, in consequence, estimating the seismic intensity. Also, on the basis of the (Carta Geográfico-Topográfica de la Isla de Cuba, 1832; Economía de La Habana, 1852) it is possible to numerically demonstrate that the socioeconomic level of SC was inferior to that of LH (Table 3). These data contradict the statements of some authors that the mentioned cities had equivalent levels of development.

Regional tectonics and seismicity

The relative motion between the North American and Caribbean plates determines the tectonic regime of the area at a regional scale (Cotilla, 1993; Cotilla and Córdoba, 2007) (Fig. 1). It has been argued that the eastward motion of the Caribbean plate relative to the North American plate occurs at a rate of 12–40 mm/yr (DeMets et al., 1990; Deng and Sykes, 1995; Dixon et al., 1998; Sykes et al.,1982). DeMets et al. (2000) estimate this rate at 18 ± 3 mm/yr for southeastern Cuba. This eastward motion of the Caribbean plate produces a left-lateral strike-slip deformation along the Bartlett–Caymán (BC) fault zone (Calais et al., 1998; Mann and Burke, 1984) and left-lateral slips along the Walton–Plantain Garden–Enriquillo fault zone (Burke et al., 1980; Pubellier et al., 1991). In the area there are four important local structures affecting the tectonic regime (Fig. 1): (1) the Mid-Cayman rise spreading center (Rosencrantz and Mann, 1991; Rosencrantz et al.,1988); (2) the Cabo Cruz (CC) basin; (3) the Santiago deformed belt (Calais and Mercier de Lépinay, 1991); (4) the Maisí area (Calais and Mercier de Lépinay, 1991; Cotilla et al., 1991b; Pubellier et al., 1991). These structures account for more than 85 % of the seismicity along this part of the plate boundary (Cotilla et al., 1991a).

Cuba is a megablock (or microplate) located in the southern part of the North American plate (Fig. 2) (Cotilla et al., 1991b;

Table 1. First cities and towns with their date of foundation (General Archive of the Indies)

Date	First denomination	Actually	Date	First denomination	Actually
03.10.1512	Nuestra Señora de la Asunción de Baracoa	Baracoa	19.01.1514	Sancti Spíritus	Sancti Spíritus
05.11.1513	San Salvador de Bayamo	Bayamo	31.01.1514	Santa María de Puerto Príncipe	Camagüey
04.12.1513	San Juan de los Remedios	Remedios	06.07.1515	Santiago de Cuba	Santiago de Cuba
04.01.1514	Trinidad	Trinidad	16.09.1519	San Cristóbal de La Habana	La Habana

Table 2. Data of the population census

Year	Data
1608–1616	20,000 Spaniards, natives and slaves on the island: La Habana (2500), Santiago de Cuba (4400), Bayamo (200), and in other localities (12,900)
1774	171,670 Spaniards on the island: Santiago de Cuba (10,734), La Habana (25,800), Puerto Príncipe (13,200)
1792	205,000 Spaniards on the island
1817	Santiago de Cuba people in 26,740 people (9302 whites, 10,032 negroes frees, 7404 negroes slaves)
1827	704,487 people on the island (311,000 whites, 106,000 negroes frees; 286,000 negroes slaves, 1487 mulattos)
1842	1,037,624 people on the island (448,291 whites, 152,838 negroes frees, 436,495 negroes slaves)
1846	896,294 people on the island
1861	1,179,713 people on the island; Santiago de Cuba (36,752 people)

Table 3. Economic data ($ Cuban pesos) on La Habana and Santiago de Cuba cities (Carta Geográfico-Topográfica de la Isla de Cuba, 1824–1831)

Commerce of the ports	Imports	Exports	Total value
La Habana	13,374,343	9,609,858	22,984,201
Santiago de Cuba	1,278,697	1,412,358	2,690,955

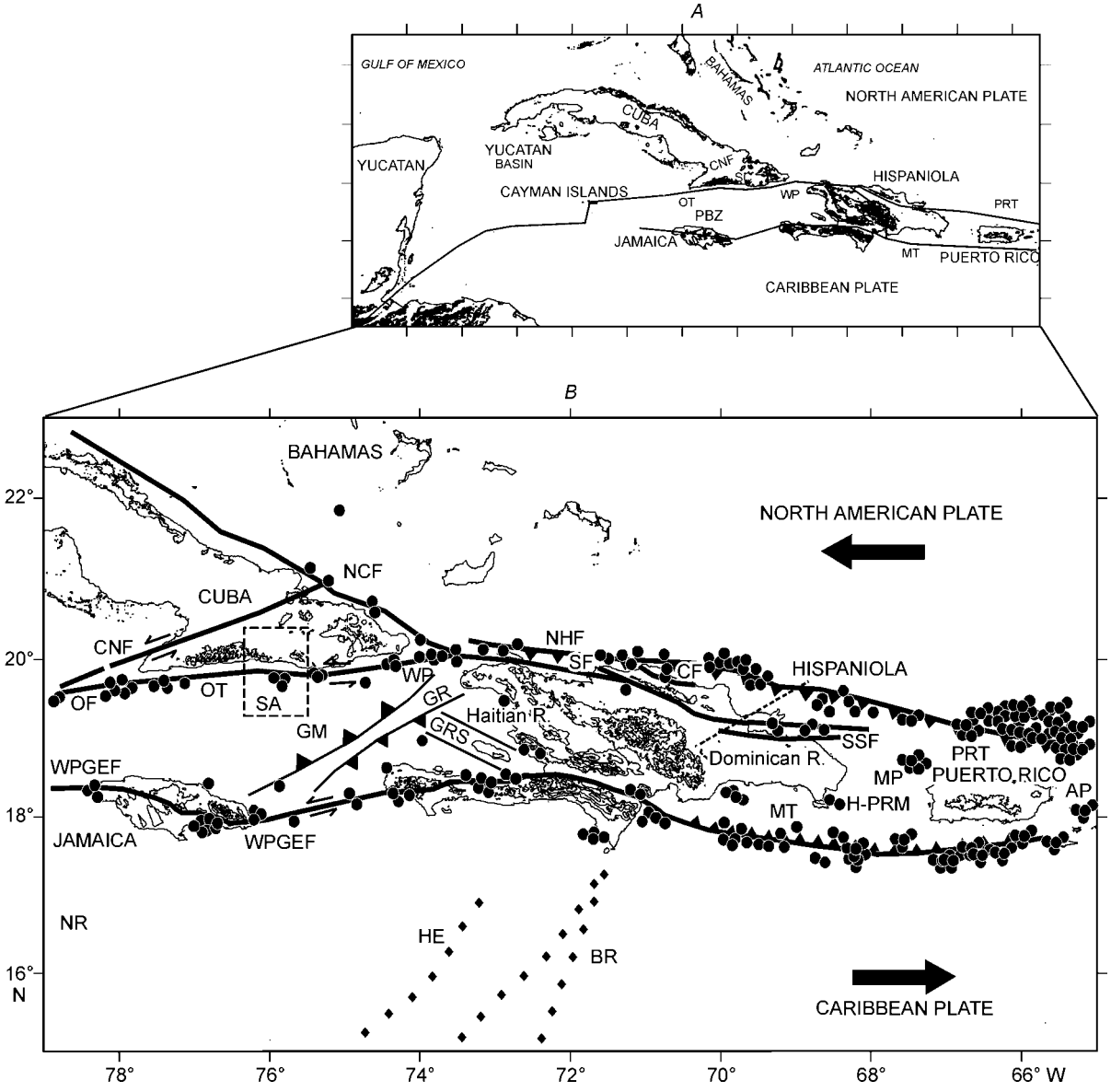

Fig. 1. Simplified tectonic map of the Caribbean. (*A*) Black lines: main fault systems. Other structures (MT: Muertos trough, OT: Oriente trough, PBZ: Plate Boundary Zone, PRT: Puerto Rico Trench, WP: Windward Passage). (*B*) The direction of plate movements (heavy black arrows); epicenters (black circles); the main faults (black lines); CF: Camú, CNF: Cauto-Nipe, NCF: Nortecubana, NHF: North Haiti, OF: Oriente, SF: Septentrional, SSF: South Samaná, WPGEF: Walton–Plantain Garden–Enriquillo; the drawing of the points outlines the structures BR: Beata Ridge and HE: Hess Escarpment; passages (AP: Anegada, MP: Mona, WP: Windward), islands (Cuba, Hispaniola, Jamaica, Puerto Rico); microplates (GM: Gonave, H-PRM: Hispaniola-Puerto Rico); troughs (MT: Muertos, OT: Oriente, PRT: Puerto Rico); other structures (GRS: Gonave Rise, NR: Nicaragua Rise); SA: study area (rectangle with discontinuous lines).

Lewis and Draper, 1990). The active plate boundary is situated along the southeast coast where the main seismic activity follows the BC fault zone (Calais and Mercier de Lèpinay, 1991; Cotilla, 1993; Cotilla and Córdoba, 2007; Mann and Burke, 1984; Mann et al., 1995). In this segment, faulting is mostly left-lateral strike-slip (Cotilla, 1998a). The general pattern of seismicity in the Caribbean region is shown in Fig. 1B. Large earthquakes occur along the plate boundary near Hispaniola, Jamaica and Puerto Rico (Álvarez et al., 1985; Cotilla and Córdoba, 2010a; Pacheco and Sykes, 1992), but no event since the eighteenth century has reached a magnitude of 7.0 (Cotilla, 1998a; Cotilla and Udías, 1999). Low magnitude seismicity ($M_S < 4$) occurs throughout the western region of the island and particularly around Santiago de Cuba. Results in (Cotilla et al., 1991a) suggest that Cuba is a seismotectonic province composed of four units (Western, Central Eastern, Eastern and Southeastern). Figure 2 shows the location of the main units and their limits, the three crust types (wide transitional, fine transitional, and oceanic (Prol et al., 1993)) that compose the region, and a selection of the associated earthquakes. It is known that most of the stress accumulated by the Caribbean–North American plate's motion is released seismically along the northern Cuban margin during relatively infrequent but strong earthquakes (Álvarez et al., 1985). The epicentres of other important earthquakes were located in this region (Cotilla and Córdoba, 2010a).

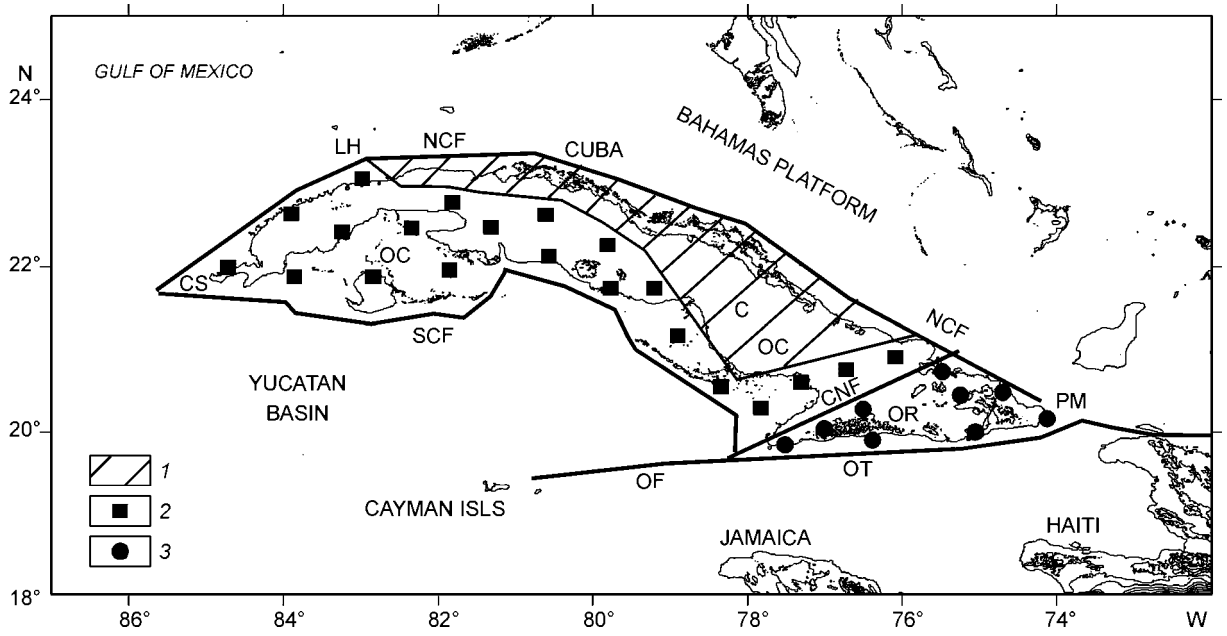

Fig. 2. The Cuban megablock according to Cotilla et al. (1991a). Heavy black line: Faults (CNF: Cauto-Nipe, NCF: Nortecubana, OF: Oriente, SCF: Surcubana); Neotectonic units (OC: Western, OR: Eastern); crust type (1: post-orogenic complex, 2: orogenic complex, 3: volcanic arc complex); localities (C: Camagüey, CS: Cape of San Antonio, LH: La Habana, PM: Punta de Mais).

Eastern Cuba tectonics

According to Makarov (1987), the neotectonic structure of Eastern Cuba (Fig. 3) includes extremely diverse areas, differing in layout, morphology and development history. It developed from the Late Eocene, on a mixed basement and, in general, on crust of various thicknesses and types, ranging from subcontinental to suboceanic. The evolution of this structure was associated with, and considerably influenced by, deep-water troughs like the Yucatan basin to the southwest, the Old Bahamas Channel to the northeast and the Oriente trough to the south (Fig. 1*A*).

The Sierra Maestra Range (Fig. 3*A*) has a simple geologic structure (González et al., 2003). Overall, it is an asymmetric swell, derived from an anticlinorium that formed in the concluding phase of sheet folding in the Late Eocene. Its southern limb is cut off by a series of stepped faults from deep-water trench (Oriente trough) and is shifted eastward. The topography in this area varies up to 10 km, with an average slope dip of up to 16º. On the northern limb, the topography varies about 2 km and the slope 3º–5º. Some geomorphological characteristics (Cotilla et al., 1991b) support the conclusion that the northern limb is also deformed, with sublatitudinal uplift zones successively decreasing in size from south to north can be identified within it.

Santiago de Cuba (~845 km^2) (Fig. 3*A*) is a NE trending tectonic basin in the Sierra Maestra Range, with a transverse asymmetry (Cotilla and Córdoba, 2007; Cotilla et al., 1991b). It is characterized by rocks and stiff and unconsolidated sediments of different age, origin and lithological composition (Academias de Ciencias de Cuba y de Hungría, 1981; González et al., 2003). It is located in the higher northeastern part of the basin, on the limestones of different densities (Upper Miocene to Pliocene). It is bounded on the west and north by the El Cobre Group (Paleocene–Eocene, thickness of ~1000 m) of volcaniclastic rocks of mafic and intermediate composition with intrusions of diorites and granodiorites (Academias de Ciencias de Cuba y de Hungría, 1981). The La Cruz Formation (calcareous conglomerates and sandstones, organic limestones; thickness of ~100 m) overlies the El Cobre Formation. The city of SC is situated in the Santiago Formation consisting of Pliocene stiff clays and sandy clays (thickness of 5–50 m). There are two calcareous formations along the seacoast, Maya (thickness of 50 m) and Jaimanitas (thickness of 1–20 m). According to the classification of Cotilla (1993) for the CC (in the west)–Baconao (in the east) coastline, Santiago de Cuba belongs to Sierra Maestra block 5, which is tilted to the north and uplifted.

The earthquake of August 20, 1852

Among the documents and texts that contain data on this earthquake are the following: (1) CUBA: Press (Diario de La Marina, 1852; El Correo de Trinidad, 1852; El Faro Industral de La Habana, 1852; El Orden, 1852; Fanal de Puerto Príncipe, 1852; Gaceta de La Habana, 1852; Gaceta del Gobierno, 1852; La Ilustración Española y Americana, 1852, 1855; La Prensa, 1852; La Verdad, 1852; Redactor de Cuba, 1853; Revista de La Habana, 1852); Authors (Álvarez et al., 1993; Bacardí, 1925; Bottino, 1878; Castellanos, 1934; Chuy, 1999; Chuy and Pino, 1982; Chuy et al., 1990; Cruz, 1958; de la Torre, 1854; Estorch, 1852, 1853; González et al., 1994; Gutiérrez Lanza, 1914; Lorie, 1852; Martínez-Fortún y Follo,

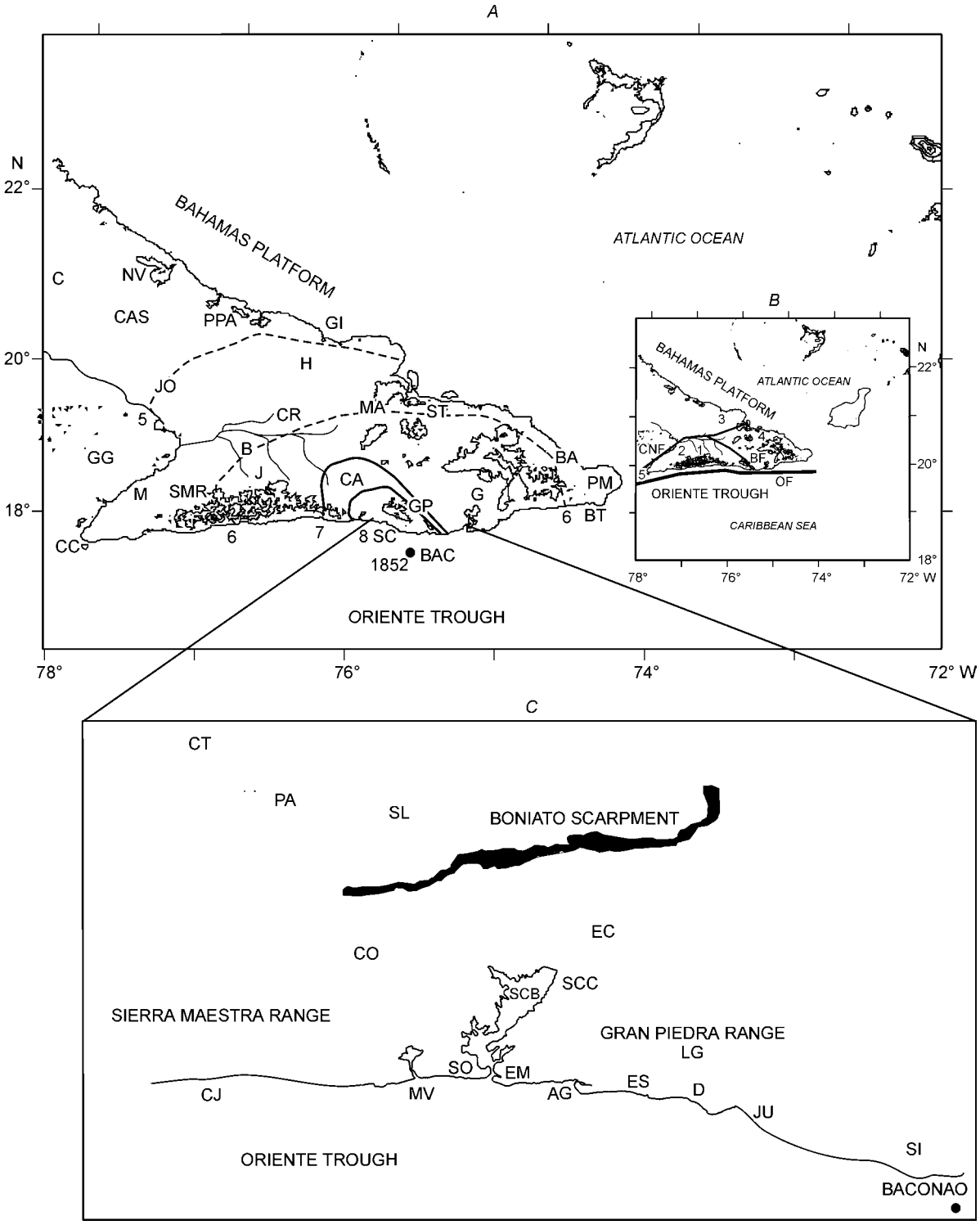

Fig. 3. Eastern Cuba and isoseismals scheme and the epicenter of the August 20, 1852 earthquake. (*A*) Epicenter (black circle); intensity 5–8 degrees (MSK); localities (B: Bayamo, BA: Baracoa, BAC: Baconao, BT: Baitiquirí, C: Camagüey, CA: Caney, CAS: Cascorro, CC: Cabo Cruz, CO: El Cobre, CR: Cauto River, G: Guantánamo, GG: Guacanayabo Gulf, GI: Gibara, GP: Gran Piedra Range, H: Holguín, J: Jiguaní, JO: Jobabo, M: Manzanillo, MA: Mayarí, N: Niquero, NV: Nuevitas, P: Pilón, PPA: Puerto Padre, PM: Punta de Maisí, SC: Santiago de Cuba, SL. San Luis, SMR: Sierra Maestra Range, ST: Sagua de Tánamo). (*B*) Faults (BF: Baconao, CNF: Cauto-Nipe, OF: Oriente); localities (1: Sierra Maestra Range, 2: Cauto basin, 3: NW Mountains, 4: Nipe–Cristal–Baracoa Mountains, 5: Cabo Cruz area). (*C*) Panoramic view of Santiago de Cuba and its surroundings (AG: Aguadores, CJ: Cojímar, CO: El Cobre, CT: Contramaestre, D: Daiquiri, EC: El Caney, EM: El Morro, ES: El Sardinero, JU: Juraguá, LG: Las Guásimas, MV: Mar Verde, PA: Palma Soriano, SCB: Santiago de Cuba Bay, SCC: Santiago de Cuba City, SI: Sigua, SL: San Luis, SO: La Socapa); epicenter of 1852.

1948; Montelieu, 1933, 1968; Morales y Pedroso, 1931, 1933; Orbera et al., 1990; Pezuela, 1863, 1866; Pichardo, 1854; Poey, 1855a,b, 1857; Rodríguez Ferrer, 1876; Salteraín y Legarra, 1884; Somohano, 1969; Valiente, 1853); (2) BELGIUM: Press (L'Émancipation Belge, 1852; L'Indépendence Belge, 1852, 1853; Moniteur Belge, 1852); (3) FRANCE (Perrey, 1853, 1856; Vilanova, 1853); (4) JAMAICA (Tomblin and Robson, 1977); (5) USA: Press (Boston Traveller, 1852; Daily National Intelligence, 1855; New York Herald, 1852; Wells, 1852); (6) VENEZUELA (Grases, 1990). A selection of 19 works with the data contributed by several authors and the press is given below, the most significant in our opinion, with some comments by the authors of this paper in brackets:

[W1] Estorch (1852, 1853): ...*the dawn of August 20 was for Santiago de Cuba's inhabitants and its surroundings one of the most beautiful that the tropics present; the churning NE was not blowing, and the land breeze was clean; the atmosphere, far from being muggy, was clear; the sun shone as never before, without its rays being oppressive; nor was there any sign to suggest variations in the atmosphere*... [only poetry] ...*we have a dead person, ruin and deterioration of buildingsthe Executive Mansion, Temples and Churches, all the quarters and 100 houses totally destroyed... Some 500 houses are damaged*... [We will see later on that these notes by Estorch are erroneous and imprecise.] ...*this earthquake has brought more misfortunes on the economy of the city, they withdraw capitals and with them capitalist, so useful and necessary* [These data are very important and explain that the city of Santiago de Cuba continued to be far behind Havana in terms of economy, in spite of having been one of the first villages founded. We will refer to this later.]

[W2] The daily newspaper El Orden (1852), of SC city, wrote on August 20, 1852: ...*at some points of the city* [SC] *we see a cloud of dust, which announces the fall of some buildings... speak right now of several misfortunes; but we abstain for the moment from informing about anyone, for in the first moments always there are exaggerations*... [it reports a strong earthquake on August 20, 1852] ...August 22: ...*the only victims of the earthquakes were a little boy, upon whom a wall fell, and an old woman, Doña María de los Ángeles Reyes, killed by a fall*... [two fatalities] *the damage was calculated in town in excess of two million of pesos; there were principal flaws or ones of less importance in 672 private buildings*... September 2: ...*Several laborers arrived from Havana, and a convicts' gang* (Gaceta del Gobierno, 1852), *and $ 50,000* [Cuban pesos] *in gold were sent by the Captain General of Cuba* [Sir Joaquin Martínez de Medinilla] *to repair the damages caused by the earthquake*... This newspaper (Gaceta del Gobierno, 1852) writes abour fatalities, the aftershocks of the earthquake, damages and destruction in the city, the help received, the estimated economic damage, the people's exaggerations, and that the Governor's house was not destroyed, whereas the Town Council (the building adjacent to the Government House) was. Some of the buildings damaged (according to this source) are listed in Table 4.

[W3] La Ilustración Española y Americana (1852) says that Queen Isabel II of Spain donated one million strong pesos. Also, it says that the oldest church in the city, San Francisco

Table 4. Buildings damaged by the 20 August 1852 earthquake according to El Orden (1852)

No.	Building (time of construction)	Damages
1	Cathedral	The aisles and domes were ruined; the clock tower and the third and fourth modules collapsed; the belfry cracked
2	Nuestra Señora de los Dolores Church (1723)	The clock tower and the front wall of the sacristy were ruined
3	Trinidad Church (late 17th century)	A wall of the church and the sacristy collapsed, as well as the front of the shrine
4	San Francisco Church (1592)	The church cracked and the tower was ruined
5	Nuestra Senora del Carmen Church (1719)	Arches and walls were ruined. The tower cracked and collapsed
6	Santa Lucía Church (late 17th century)	The southern part was ruined; under threat of collapse
7	Santa Ana Church	Roof and towers completely in ruins
8	Belén, Belencito and del Cristo Church	Total ruin. The rooftops were sustained by wooden posts
9	Santo Tomás Apóstol Church (1726)	Little affected
10	San Juan de Dios Church (1739)	Not affected
11	Government House	Total ruin
12	Archbishop's House	Walls cracked
13	Seminary	The interior walls were ruined, and the rest cracked
14	Intendance	Ruin
15	Customs	Total ruin
16	Hospital	Completely destroyed (Hospital of the Army)
17	Theater	The main walls cracked

(1592), and Nuestra Señora de los Dolores Church (1723), both made of stone with a framework of solid tree trunks were seriously damaged.

[W3A] Similarly, La Ilustración Española y Americana (1855) recounted: *...north of this plaza* [Central Plaza, today Carlos Manuel de Céspedes Park] *the Government House and the Town Council are located, and to the south the Cathedral... the Cathedral has suffered very much from earthquakes, and it had to be rebuilt several times, last in the year 1819...* [Table 4 presents information on the churches of SC] *the most ancient church is San Francisco, the one belonging to Nuestra Señora de los Dolores is from 1723... it has two towers and three aisles* [the cathedral], *one of which shows signs of the repeated earthquakes of 1852...*

[W4] Redactor de Cuba (1853): *...here in Santiago de Cuba on August 20* [1852] *the pain and the lament gather themselves one more time with another earthquake... the population is very affected... once again the Cathedral suffers great damage...*

[W5] Colección Legislativa de España (1852) is an original document of the Council of Ministers of Queen Isabel II that reports on the economic contribution of the Spanish Crown to Santiago de Cuba. *Presidencia del Consejo de Ministros October 3, 1852. Royal Decree, Granting to the Secretary of the Treasury* [Sir Juan Bravo Murillo] *an extraordinary credit of 2000.00 reales* [~$ 1,000,000.00 Cuban pesos], *the Treasury of the Peninsula is more than enough to help the poor families who suffered in the earthquakes of Santiago de Cuba...*

[W6] Pichardo (1854): *...I have read a poetical description* [referring to Mr. Estorch], *that if the poet does not exceed himself in his hyperbolic licenses, it should have been stronger in all senses... a frightening earthquake happened in Santiago de Cuba, August 20, 1852, repeated November 26... the people were terrified and shouted, "Mercy!"*

[W7] Pezuela (1863): *...reinforcing this building* [the cathedral] *with such arts which can defend it from the fury of the shakings and supply precautions to it, without which it might not stand completely against the one that broke into pieces a great part of the town on the twentieth and last days of August of 1852. Cracking then its border masonry and the four arches that supported the dome. The main wall of West cracked along almost all its length above 6 feet above the ground; and a part of the clock tower collapsed. They remedied all these damages promptly... Nuestra Señora de los Dolores Church founded in 1723 only indicates effect in 1852... San Juan de Dios Church is a building of simple architecture and not much elevation, with only one aisle, founded in 1739 was not damaged... Santa Lucía Church founded at the end of the eighteenth century, affected... Santísima Trinidad Church founded at the end of the seventeenth century, affected... Santo Tomás Apóstol Church declared auxiliary parish church of the one belonging to the Tabernacle of the Cathedral in 1726, only a little affected... its simple and solid architecture has withstood the frequent shakings of the building site that it occupies, and better than any other temple for edification of the population, the terrible earthquakes of August of 1852...*

The works W2, W3, W3A, W4, W5, W6 and W7 confirm that: (1) there was an earthquake on August 20, 1852 in SC; (2) the intensity of the main seismic event was high; (3) there were aftershocks; (4) the people panicked; (5) many buildings were damaged (~700), especially religious ones.

[W8] Poey (1855a): *1852.– Août, à Cuba* [SC], *secousse qui s'est fair sentir dans une grande partie de l' île. Le 20, 8 h 1/2 du matin, à Santiago de Cuba, secousse extrêmement violente, suivie de deux autres non moins intenses ; on signale ensuite, parmi les nombreuses secousses de ce jour, celles de 3 h 1/2, 5 h 20 m et 9 h du soir. Le 21, 3 h et 5 h du matin, deux nouvelles secousses très violentes...les secousses ont continué plus ou moins fortes, plus ou moins désastreuses; mais celle 3 h 35 m du matin a été d'une violence incroyable, et s'est renouvelée deux minutes après, mais avec moins de force...on peut dire que depuis lors jusqu'au du 22 la terre est restée continuellement en mouvement, et que les secousses se sont renouvelées réguliérement (?) de demi-heure en demi-heure;on évalue les désastres à deux million de piastres...*

[W8A] Poey (1855b): *Le 28 août à Santiago de Cuba et à Saint–Domingue. Le 6 novembre, une secousse à Santiago de Cuba pendant la nuit.*

[W8B] Poey (1857): *20 août, 8 h 30 m, 5 h 20 m et 9 s.– Santiago de Cuba (cinq secousses: la première à 8 h 40 m, matin; elle persista pendant trois jours), Saltadora, Falmouth, Montego-Bay, Kingston (trois secousses à Falmouth et Montego Bay; la prèmiere à 8 h 38 m, matin et la troisième à 9 h, matin. A Kingston, forte secousses entre 8 et 9 h du matin du N au S. Saltadora, Falmouth, Montego-Bay, Kingston (Jamaïque).* It is appreciated from Poey's French notes that: (1) the earthquake occurred on August 20, 1852; (2) it was a strong earthquake; (3) the seism had some aftershocks; (4) it was noticeable in Jamaica and Santo Domingo; (5) the damage was estimated at 2,000,000.00 pesos. The aforementioned works do not report damage to El Morro Castle.

Table 5 lists the aftershocks (13) of the earthquake (El Orden, 1852), and Table 6 describes the foreshock, the main seismic event, and the aftershocks (>50), according to (Poey, 1855a,b, 1857). According to Álvarez et al. (1999) there were 60 aftershocks in the period 1852–1857. This all happened at 19.75º–20.02º N, 75.32º–75.84º W. Also, we pointed out that this earthquake was preceded by another one of bigger magnitude with an epicentre in the Cayman Islands (to the west of SC), and felt on the entire island of Cuba (Poey, 1855a,b, 1857). According to Álvarez et al. (1999) the data are: July 7, 1852, 12:25, 19.70º N, 79.70º W, 30 km, M_S = 7.5.

[W9] Perrey (1856): *Le 20* [August 1852], *8 h 38 m du matin, à Falmouth et Montego-Bay (Jamaïque), première secousse; une troisième à 9 h du matin; 8 à 9 du matin, à Kingston, une violente secousse du N. au S.* Surprisingly this author, cited by Poey (1855a,b) say nothing about the

Table 5. Aftershocks of the 20 August 1852 earthquake (El Orden, 1852)

No.	Date	Time	Observation
1	20, Friday	08:36	Shock
2		08:45	Shock
3		09:10	Vibration
4		09:18	Vibration
5		13:00	Vibration
6		14:00	Vibration
7	21, Saturday	03:00	Shock
8		06:00	Vibration
9		12:00	Vibration
10		21:00	Vibration
11	22, Sunday	05:00	Vibration
12	28, Saturday	02:00	Vibration
13	29, Sunday	12:44	Shock

earthquake on August 20 in Santiago de Cuba. However, he says that on that day a strong shock from N to S was reported in Jamaica, explained by an earthquake in the Oriente trough, near SC.

[W10] Gutiérrez Lanza (1914): *...because to give numbers of personal misfortunes on earthquakes experienced in Santiago de Cuba they are almost always void or insignificant. One of the most notable, which happened on the August 20, 1852, is described in vivid colors by the Licentiate Estorch. However, in spite of terrifying expressions used and damage appraised at $ 2,000,000.00* [Cuban pesos] *only one little boy died and a few had various contusions...*

Works W6 and W10 agree that Mr. Estorch exaggerates (author of Work W1 used by other authors in order to evaluate this earthquake).

[W11] Bacardí (1925): *(August 20) At 8:30 in the morning a strong earthquake terrifies the population* [SC]*; the peoples go out into the street, and only the shout "Mercy!" is heard. Nine shocks follow after the first three from that hour to the two very strong ones during the early morning, altogether twelve moderate earthquakes. From day 25* [August] *followed moderate earthquakes of minor intensity to the day 31, when a strong one like the first one made itself felt* [aftershocks], *following heavy showers and hurricane winds. The townspeople go to the fields or to the ships anchored at the bay* [no tsunami] *...the Office of Treasurer sets up in the Resguardo's pigeonhole, extracting the books from among the ruins... the Hospital of the Army is established in the Tinglado.. .there were only two dead persons.* [These data match those in El Orden (1852) (Table 4).

[W12] Morales y Pedroso (1931): *...20 August 1852: 8:30. It was felt on the entire island* [imprecise, it was perceptible

Table 6. Foreshocks, main seismic event, and aftershocks of the August 20, 1852 earthquake according to Poey (1855a,b, 1857)

No.	Date	Time / Comments	No.	Date	Time / Comments
1	20.08	01:00 / strong shock	20	26.11	17:15 / very strong shock
2		08:30 / main event and two light shakes	21		20:15
3		15:30	22	27.11	05:00–08:30 / shocks
4		17:20	23	28.11	Series of shocks. The strongest at 04:20
5		21:00	24	28–29.11	Weak earthquake
6	21.08	03:00 / strong shock	25	29.11	03:00 / some shocks
7		05:00 / strong shock	26	14.12	Series of shocks
8		12:25 / strong shock	27	29.12.1853	01:00
9		16:50 / strong shock	28	30.12	06:00 with noises
10		21:15 / strong shock	29	16.03.1854	01:00 / earthquake
11	22.08	Two weak shocks	30		05:45
12	28.08	Strong earthquake with underground noises	31	–.09	Shocks
13	20.09	Some earthquakes in the month	32	26.09	Weak shock in the morning
14	–.10	The earthquakes continue	33	27.09	05:20
15	26.11	03:15–03:30 / a series of noticeable shocks in El Cobre, the Sierra Maestra (Gran Piedra), Manzanillo, Bayamo, Holguin, Nuevitas, and Santa Cruz	34	–01.1855	Weak shock in Santiago de Cuba
16		04:00 / earthquake	35	20.02	07:00 / strong earthquake and two weak vibrations
17		08:15 / strong earthquake in the Sierra Maestra Range accompanied by a series of shocks	36	11.05	10:30
18	26.11	14:23 / series of three shocks	37	11.08	03:10 / strong shock
19		14:30			

up to the central-eastern part, approximately Ciego de Ávila]. *The first shake of extreme violence was followed by others, less intense. Another violent shake at 15:30, 17:20, and at night.* [aftershocks] *...the shakes continued through the early morning of the 21st, at 3 a.m. and 5 a.m. There were two very violent shakes, taking place in a deep darkness after which there followed a windy and rainy time* [there was a hurricane] *the shakes continued until the morning of the 22nd, lasting over half an hour. At 25 minutes before noon on the 22nd one strong shake was felt on the entire island* [it was felt as far away as Camagüey], *other ones at 16:50 and 21:45. The losses were estimated at two million pesos. The Sierra Maestra Range to the ENE of the city suffered such shakes that solids and the farmstead's low barracks "La Merced"* [located in the Gran Piedra Mountains, where there are several coffee areas to the ESE of SC] *collapsed and fell. The motion's direction was from SW to NE...* (cited after Poey (1855a,b, 1857)).

[W13] Monteulieu (1933) held that: *...the descriptions that we told of Santiago de Cuba's destructive seisms before 1852 are not as detailed as the memories of February 11, 1678* [19.90º N, 76.00º W, $h = 30$ km, $M_S = 6.75$, $I = 8$ MSK], *known as "The Strong Shaking". The claims of Mr. Miguel Storch* [Estorch] *and of Mr. Prisciliano Manzano, however impressive, because they contain the most expressive epithets of the terror that seized the inhabitants of that city in 1852, once examined, led us to the conclusion that the earthquake was no intenser than the 1932 one* [3rd February, in SC, 19.75º N, 75.58º W, $h = 35$ km, $M_S = 6.75$, $I = 8$ MSK; according to Álvarez et al. (1999)] *if the victims and effects in each one of them are considered...*

We conclude that there is a coincidence between six works (W6, W7, W10, W11, W12, W13). The first three authors are contemporaries of the earthquake of 1852, while the other three authors cite them and some other sources.

[W14] Morales y Pedroso (1931) said: *...witnessing the earthquakes in Santiago and considering eyewithess accounts: the panic felt by the people; the resulting exaggeration of the descriptions; the inferior construction of the buildings in Santiago on the date the ruinous earthquake 1852 happened (almost everything is made of masonry with mailbag mixes and inappropriate mortar, with the interior made of wooden or light partitions, not tied to the structure, such construction was unsuitable for earthquakes, as demonstrated by experience); and if also consider the phrase "put out of plumb" used frequently, we have the true sense of the oldest chronicles we can consult, and that it signifies therefore leaning, but not falling down, for in those cases we see that the ancient chroniclers use the word "collapsing." So we can see that Santiago's earthquakes do not seem to have exceeded, in the historical period, an intensity of level VI (Rossi-Forel scale), which is an acceleration not larger than 500 mm/s^2...* The similar opinion in (Bacardí, 1925; El Orden, 1852; Morales y Pedroso, 1931; Pichardo, 1854) on the behavior of the SC population durinng strong earthquakes and the chroniclers' distortion of information indicates that the historical events are exaggerated. Also, Work W14 contains information from a specialist on the architecture of SC.

Morales y Pedroso (1931) said: *...at the alluviums of the Cauto valley, in the sugarcane factories Palma and América, regardless of there being a greater distance from the epicentre and the north of the Range, in its seismic shade, the earthquake had greater intensity than that observed on the firm ground of the Santiago valley* [local effect of amplifying seismic waves] *...in Santiago City, in the marls that form its ground, the earthquake had a variable intensity according to the consolidation of these own marls... the earthquake has not much intensity in the new aqueduct's tanks, regardless of its emplacement at 90 m above sea level at the Lomas de las Cuabas above the city; without a doubt to be settled on compact marls dismounted to 7 m under the original ground surface... in the heart of the city there was in like manner, the intensity was weak at the Cuban Telephone Company's building, constructed with a basement and a consequent deep foundation. Instead it was felt weakly where the torrential erosion was left on the surface, previously deep and marls were stronger. In the meantime only two blocks of houses* [200 m] *distant from the anticus building, the Venus Hotel, the Provincial Palace, and Cathedrals' towers, located on the hills formed by the loose marls of the original surface of the alluvial ground, are shaken so strongly that they are left pregnant ruinous...* This extract shows the importance of the damage iteration and the engineer-geological conditions of the soil in estimating the seismic intensity of earthquakes with trial elements. In this sense, the notes of this author agree with the results of González et al. (1989) and Heredia et al. (1982).

[W15] Chuy and Pino (1982) reproduced almost all that had been written by the above-mentioned authors (works W1–W14), including the destruction of the Governor's House, but added that the 1852 earthquake was felt in Baracoa, Gibara, Holguín and Bayamo; and that in Camagüey there were weak shakes. Later on, Chuy et al. (1990) drew an isoseismals map that placed the focus at 19.75º N, 75.32º W and a depth of 35 km. These isoseismals have many discontinuous zones and very scarce checkpoints (Cotilla, 1993). There is general agreement between several authors that on August 20, 1852 a strong earthquake occurred near SC (Fig. 4A) that produced shakes all the way to Central-Eastern Cuba (Poey, 1855a,b, 1857). According to Álvarez et al. (1999) the main event occurred at 14:05:00 UT, and the magnitude and coordinates of the epicentre are the same as the proposals by Chuy and Pino (1982). However, they place the focus at a depth of 30 km and add that there were 60 aftershocks.

[W16] Grases (1990) included in his catalog the August 20, 1852 earthquake. He used the results of Estorch (1852) and noted the local time at 08:36. This agrees with the data of Chuy et al. (1984) that refer intensities of 9 and 4 degrees (MSK), to Santiago de Cuba and Camagüey, respectively.

[W17] Cotilla and Udías (1999): *...there exist serious structural problems with Santiago de Cuba's constructions, as*

pointed out by several persons like (Morales y Pedroso, 1931; Poey, 1857) *and Boytel (Personal communication, 1982). However, the excellently constructed houses of Captain General Diego Velásquez de Cuellar* [constructed in 1522]*, Sir Juan de Mata Texada, and Sir Fernando Boytel withstand seisms without difficulty. The first is only 25 m from the Cathedral, so damaged in all the strong earthquakes. And the third house is located in the aristocratic settlement of Vista Alegre. They were intact after the earthquake of February 3, 1932.*

We consider that three colonial buildings located in or near SC showed seismic resistance: (1) the House of the Governor Sir Diego Velázquez de Cuellar; (2) the present El Morro Castle of the bay of SC; (3) Isabelica Farm. The first was already commented on. While the present El Morro was easily withstood three strong earthquakes: August 20, 1852, February 3, 1932 and August 7, 1947, the previous El Morro Castle was destroyed almost completely in the earthquake of June 11, 1766 (Cotilla, 2003; Cotilla and Udías, 1999). We will refer to this later. The Isabelica Farm, designed by French colonists who had fled Haiti (an active seismic zone), was under constructing from the late 18th to the early 19th centuries. The building is located in the coffee growing area of the Gran Piedra Range, in the eastern part of the Sierra Maestra Range, between the bays of SC and Guantánamo. It showed excellent resistance to the seismic shakes. The structure is made of stone and wood, and its design withstands horizontal movements very well. However, it deteriorated greatly in the decade of 1990s due to a confluence of adverse factors such as: its old construction, the burdens of the tropical meteorology (high humidity, great daily temperature variations, etc.), the action of the insects, vermin and unscrupulousness persons, and, above all, neglect. Many years ago a plan for its rehabilitation was proposed but the authors do not know if it was implemented. Another earthquakeproof structure, from the twentieth century, in the Eastern Cuban region is the aqueduct of SC. The aqueduct was not damaged by the strong earthquakes of February 3, 1932 and August 7, 1947 (Monteulieu, 1933; Morales y Pedroso, 1931, 1933).

Earthquake damages to the religious buildings of SC was analyzed from six sources in Tables 4, 7 and 8. The Cathedral was historically the religious building most affected by earthquakes. There are three possible causes: (1) the design is deficient; (2) there are structural and construction-type deficiencies; (3) that the type of soil it sits on favors seismic oscillations. However, according to works W14 and W16, and due to the location of the Cathedral on loose soils, the damage and destruction at first glance seems to be caused by the factors mentioned in works W2 and W3. We cannot come to a conclusion about the first cause, since there is no commentary in the inspected documents. We will refer to this later.

One must also consider that the authors of some of the accounts were governors, contractors, and merchants. Thus, it is customary in the located documents to find that the accounts of suffered damages came from the local authorities, who exaggerated the losses to obtain greater economic help from superior levels of their hierarchy. In situ verification and the reports submitted by specialists who investigated the claims to evaluate the reliability of the data received previously at the higher level of the administrative hierarchy facilitate the task of the seismologist when evaluating intensity. We see that in the document from the General Archive of the Indies (AI) dated July 6, 1766 (CUBA 1124 (–AI denomination–)) from the Captain General Antonio María Bucareli y Ursúa to Sir Julián de Arriaga: ...*I should inform you, that although the intensity of the earthquake* [June 11, 1766] *was big, it should not be considered excessive in terms of the caused damages, as you alleged initially in the declaration of the villages* [SC and Bayamo]. *This is because all the damage reduced to destruction of some buildings and to the sorrow of people at the population's enclosure marked off by definite limits, but one can go to the works, plantations and farms... as I checked after this event, neither did the neighborhood decrease* [34–40 dead], *nor did its luster decline.*

The distortion of the information in the newspaper accounts has been verified. Monteulieu (1933) assured: ...*The Febru-*

Table 7. Dates of the construction and reconstruction of the Cathedral of Santiago de Cuba (the General Archive of the Indies)

Cathedral	Period of construction	Supervisor	Observations
1	1528–1555	Fray Miguel Ramírez de Salamanca	Value 50,000 ducats (1 ducat = 7–5.5 g of gold)
	1653	Don Juan Álvarez Salgado	Reconstruction of the Greater Chapel
2	1663–1674		Reconstruction with materials and goods from Jamaica
	February 11, 1678		Earthquake destruction of the Greater Chapel and grave structural damages
	1679		Total devastation by a hurricane
3	1686–1690	Bishop Diego Aselino de Compostela	Reconstruction
	1719		Reconstruction and important restoration
	June 11, 1766		Total devastation by the earthquake
4	1810–1818		Construction of five aisles (2115 m^2)
	1852		Reconstruction and repair of the damages caused by the earthquake to the aisles, domes, towers, and bells

Table 8. Damages to the religious buildings of Santiago de Cuba in the 1766 and 1852 earthquakes according to six sources

Building	P		S	B	AI		IEA	MP	EO
	1766	1852	1766	1852	1766	1852	1852	1852	1852
Cathedral	X	X	X	X	X	X	X	X	X
Nuestra Señora de los Dolores Church (1723)		X	X	X	X		X	X	X
San Juan de Dios Church (1739)						X			X
Santa Lucía Church (late 17th century)		X	X	X				X	
Santisima Trinidad Church (late 17th century)		X		X		X		X	X
Santo Tomas Apostol Church (1726)		X				X			X
Nuestra Senora del Carmen Church			X	X				X	X
Nuestro Padre San Francisco Church			X	X			X	X	X
Santa Ana Church		X		X		X		X	X

Note. P: Pezuela (1863), S: Salteraín y Legarra (1884), B: Bacardí (1925), AI: The General Archive of the Indies, IEA: La Ilustración Espanola y Americana (1852), MP: Morales y Pedroso (1933), EO: El Orden (1852), X: affected.

ary 3, 1932's Eastern megaseism was not accompanied by the production of cracks, failures or appreciable fissures in the national territory... the day's national press published a strange remark about big cracks in the Pico Turquino and in several places near Santiago such as Caney, Aguadores, etc. However, none of these accidents, which we investigated and studied for all the effects of the seism, was checked... seismic cracks of little account were observed only in Santiago de Cuba City. In the segments of the Avenida Michaelsen and the Nuevo Malecón north of the Bay, they observed cracks produced by the slide of the filling, which were no wider than 10 cm...

Estorch (1852) reported that in the August 20, 1852 earthquake: *...in Guaninicum de Rizo* [Sierra Maestra Range, to the west of Santiago de Cuba] *...an extraordinary crack formed, about 300 varas* [1 Castillian vara = 0.8359 m (~250 m)] *long and half a foot wide in some parts, at some points unfathomable...* (Cotilla and Córdoba, 2007; Cotilla et al., 1991a) did not find any sign on the ground of that earthquake.

[W18] Monteulieu (1933) argued that, on the basis of the damages, the kind of motion causing faults in the February 3, 1932 earthquake: *...one of the most convincing demonstrations of the motions of the fault escarpments that form Santiago de Cuba's coast is offered by the breaking of the submarine wires... the Western Union's ocean-going cables and the All American and as far as we know the French cable, they were cut a minute after the seism and at a short distance from the shore... the breaking points were: 1) 19º57′ N and 75º53′ W; 2) 19º54′25″ N and 75º58′54″ W...* [This maritime zone corresponds to the area with a high neotectonic gradient (Cotilla et al., 1991b), that (Calais et al., 1998) called the Santiago Deformed Belt, which the authors assume to correspond to the epicentral area of the main earthquake.] The same author is also certain that animal behavior gives an idea of the intensity of the seism: *...notable excitement in the horse and cattle herds, observed during the most violent moments of the earthquake, as they stopped their headlong running and spread their legs to stabilize themselves and avoid falling down from the force of the shaking... the crabs abandoned their caves... the doves flew away* [account of engineer Emilio P. Guerra, Member of the Cuban Scientific Commission that studied the earthquake] *after the shaking at 4:30 in the afternoon on February 2, the doves left the dovecote and did not return until the day after the earthquake on February 3... the peasants noticed that the majority of the poultry jumped from their roosts, remaining lying-down on the floor during the loud shakes...*

[W19] Chuy (1999) repeated fundamentally the same as Chuy and Pino (1982): *...August 20, 1852 at 14:05 UT with* I_{max} *= 9.0 in Santiago de Cuba. Very strong earthquake. It produced the ruin of numerous important buildings like the Customs, Intendance, Government House and seriously damaged over a thousand houses. It caused 2 deaths.* The housing code agrees with Work W12. Similarly, Cotilla (2003) examined authentic documents from the AI reporting on the dead and injured, as well as the damages caused by the earthquake of June 11, 1766 in SC. However, they have been employed in recent results such as González and Pérez (2005).

In the present study, new documentation with additional information on the damages caused by this earthquake has been found in the AI: (1) Manuscript documents; (2) topographic maps and drawings, and graphic representations of some buildings.

PAPERS from CUBA: Documents directed to the Governor General of the Island of Cuba, Sir Joaquin Martínez de Medinilla from the Governor of the Villa de Santiago de Cuba, Sir Valentín Cañedo Miranda. [Document 1.–] SANTIAGO-CUBA 3023 (–AI denomination–) (21th August 1852) *...at dawn we were away, in the streets, courts and squares the alert came in the form of several shakings of the ground* [foreshocks] *the biggest earthquake happened unexpectedly, too early...* [in the morning] *a lot of subterranean noise from the southeast collapses, dust, smoke and shouts... there are still no reports of deaths... a lot of severe flaws in the*

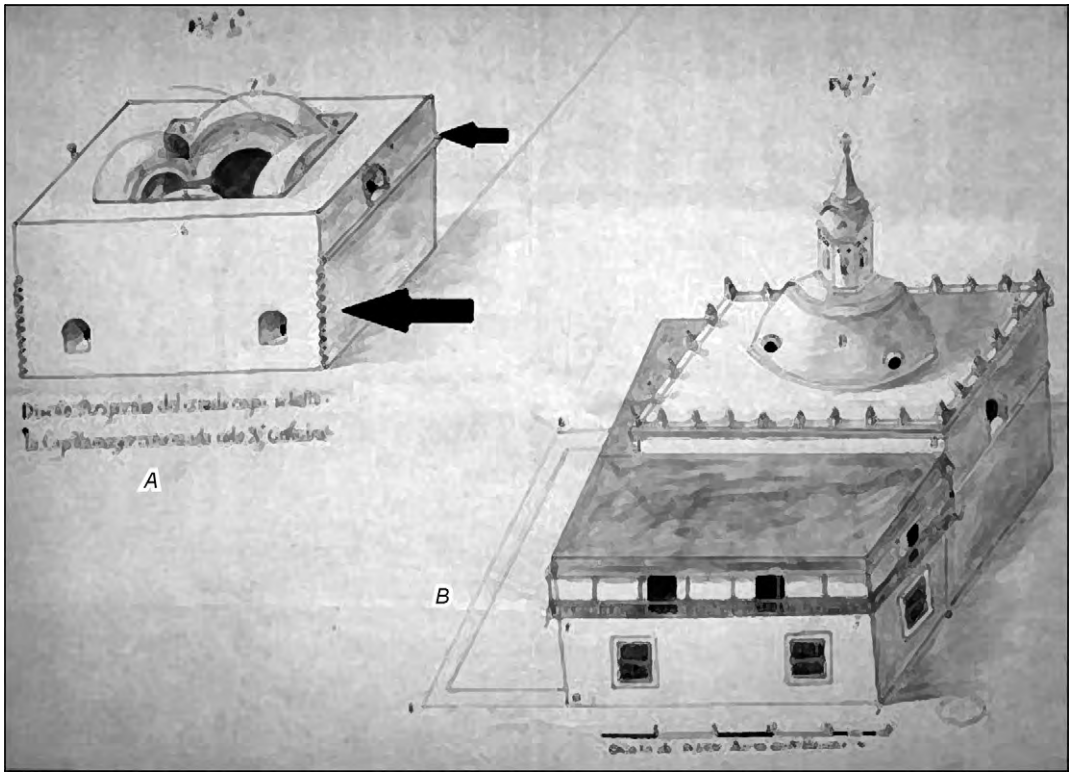

Fig. 4. Cathedral of Santiago de Cuba (SANTO DOMINGO 166 (–AI denomination–)). (*A*) Sketch of the design and of the structure of the Cathedral of the year 1686. Two heavy black arrows indicate the junctions of the supporting walls and the black fine arrow shows the thick wood beam support of the upper structure. (*B*) Built Cathedral, with its main middle and front outer modules.

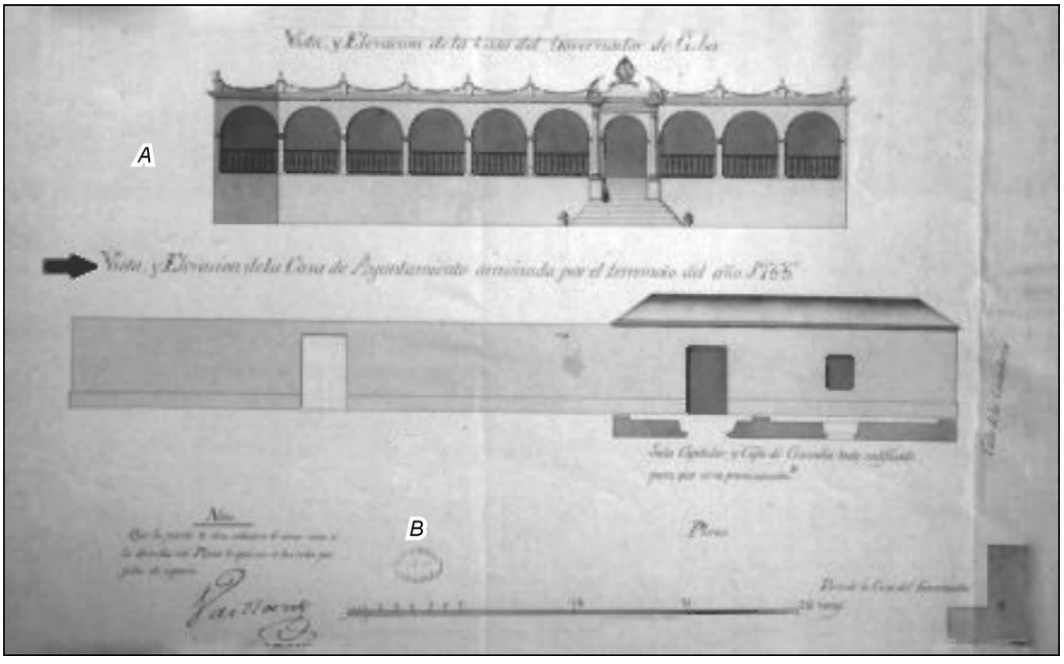

Fig. 5. Government House and Town Council of Santiago de Cuba (SANTO DOMINGO 560 (–AI denomination–)). (*A*) Government House. (*B*) Town Council. Black arrow indicates what is written for the author of the plan regarding the destruction of the Town Council by the earthquake of 1766.

Fig. 6. Santiago de Cuba City (SANTO DOMINGO 643 (–AI denomination–)). 1: Dock, 2: Cathedral, 3: Government House, 4: Nuestra Señora del Carmen Church, 5: Hospital of the Army, 6: Convent of San Francisco, 7: Santo Tomás Church, 8: Seminary, 9: Santísima Trinidad Church, 10: Nuestra Señora de los Dolores Church, 11: Santa Lucía Church, 12: Mars Square, 13: Customs, 14: Intendance, SC Bay: Santiago de Cuba Bay, SCC: Santiago de Cuba City.

buildings... uncontrollable panic among the population... the land does not stop trembling... the defense of the bay is insured with the El Morro Castle, the Battery of La Plataforma, the Battery of La Estrella, La Avanzada Fort, and La Socapa [this is a defense system at the entrance of the bay], *which were not damaged... the ships in the bay are without damage and serve as a refuge for the population...* [it is inferred that there was no tsunami]. El Morro Castle (originally San Pedro de la Roca) was and still is built of solid and heavy blocks of limestone, abundant in this region (Academias de Ciencias de Cuba y de Hungría, 1981), on the eastern side of the entrance to SC bay 30 m above the western side (La Socapa Fort). We found a drawing from 1755, in an anonymous, rough hand, representing the entrance to SC bay (Libros del Registro del Gobierno de Cuba, ULTRAMAR: ledger 4765 of February 1757**)**, showing the location of the fortress. This castle was built by Juan Bautista Antonelli, an Italian arquitect, in 1638, but destroyed on 11 June 1766. Then it was rebuilt and up to now has remained without any damage (Cotilla, 2003).

...news of the farms and plantations [El Caney, San Luis, Maya, Palma, etc.] *do not give victims and again they were refuge for the families... the copper mines operate without difficulty...* [approximately to 19 km northwest of SC's city is the village of Santiago del Prado (today El Cobre) is located. It is founded in the sixteenth century, and the copper mines have existed ever since. In contrast with June 11, 1766 earthquake which affected some of galleries (Cotilla, 2003), the damage on August 20, 1852 is not important.] *...the fishermen's villages in the eastern part of the city* [Aguadores, El Sardinero, Juraguá, Duarte, Sigua, etc. (Fig. 3*C*)] were

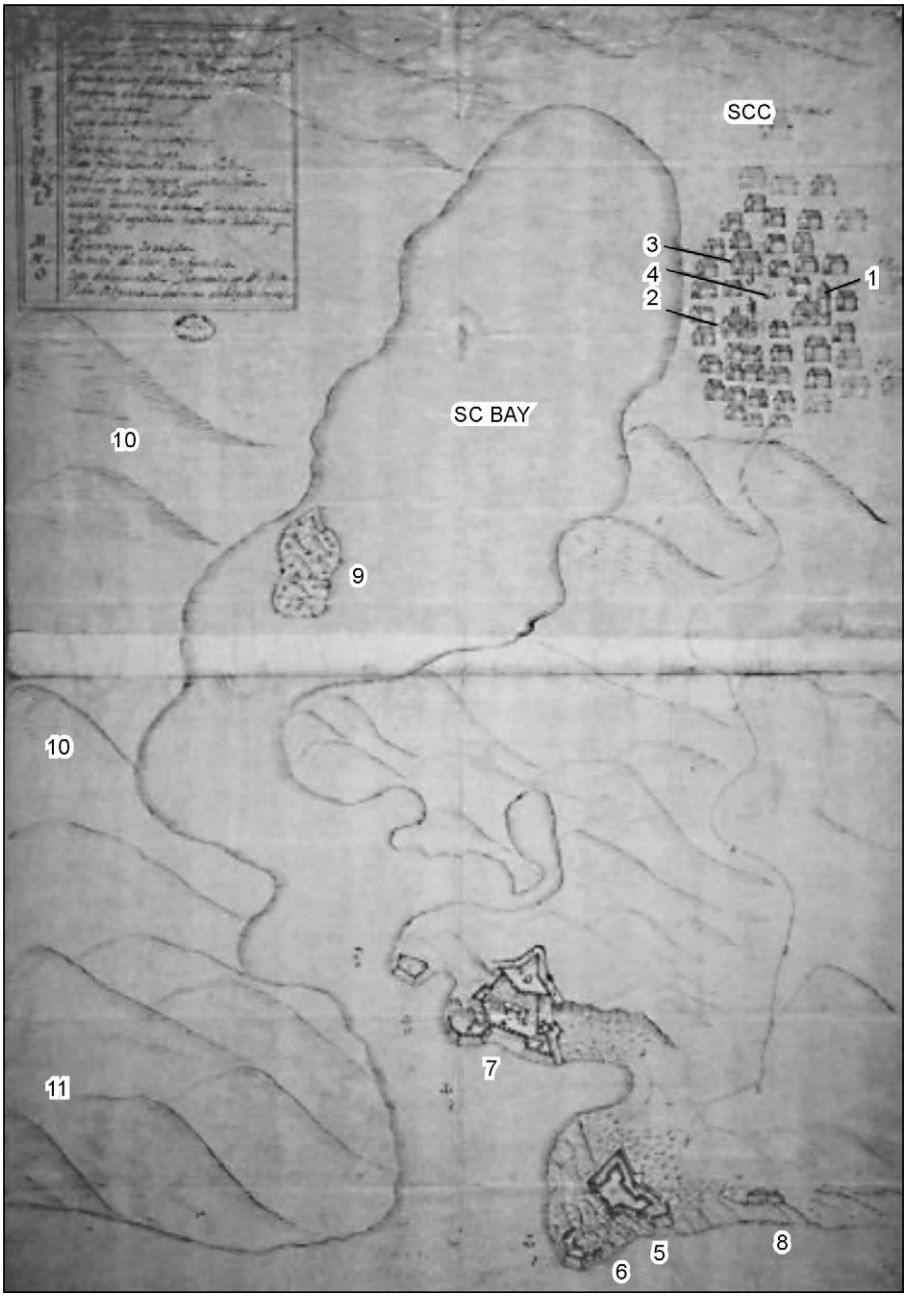

Fig. 7. Santiago de Cuba area (SANTO DOMINGO 066 (–AI denomination–)). 1: Cathedral, 2: Nuestra Señora del Carmen Church, 3: Convent of San Francisco, 4: Mayor, 5: El Morro Castle, 6: Batteries of the La Plataforma and La Punta, 7: Battery of La Estrella, 8: Aguadores Fort, 9: coastal segment of the bay, 10: Sierra Maestra Range, 11: Mar Verde Fort, SC Bay: Santiago de Cuba Bay, SCC: Santiago de Cuba City.

destroyed. The entire seashore correlates with a mountain range, of h ~1100 m, the Gran Piedra Range. The rivers of mountain run south with abrupt slopes, up to 60%. The systems of fluvial terraces and soils are very thin or absent in many sectors (Cotilla et al., 1991b; González et al., 2003) *they are destroyed* [very rustic wooden constructions] *...the inhabitants say that a great movement of rocks was felt underground... the Guasimas's quarters were flattened by a large rock... many ships were damaged by rocks and structures put out of plumb...* [thus, the damage was concentrated mainly in the south–southeast of SC (toward Baconao)].

[Document 2.–] SANTIAGO-CUBA 3036 (–AI denomination–) (28th August 1852)...*I send this mail of upmost urgency to procure your help... the land continues trembling... the people sleep in plazas and parks in spite of the rain and the cold... we prayed very much... there are only two dead and 200 injured, but the material losses are abundant... the bay's sea* [SC] *was and keeps dead calm* [no tsunami], *but damages and the destruction in the port facilities are great... the road to the Gran Piedra and to the Laguna Baconao is still blocked in some sectors by very large blocks* [gravitational process]... *some roofings of houses in Guantánamo are damaged... the*

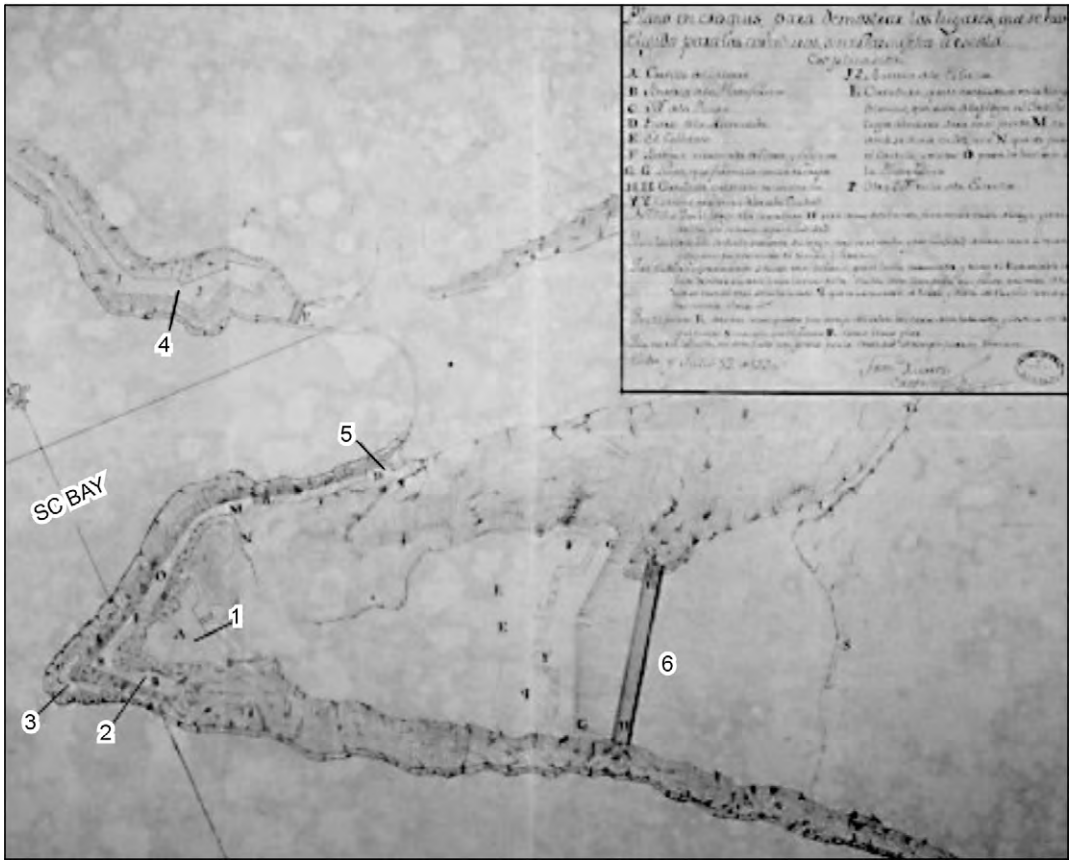

Fig. 8. El Morro Castle and fieldwork (SANTO DOMINGO 555). 1: El Morro Castle, 2: Battery of La Plataforma, 3: Battery of La Punta, 4: Battery of La Estrella, 5: Castle of the La Avanzada, 6: fragment of La Defensa.

quarters are arranged... [It can be understood that the perceptibility of the earthquake differs significantly in the south and southeast of SC.] ...*now a strong storm hits us accompanied by continued winds and rain*... [tropical cyclone] *several infectious diseases appear... the doctors and soldiers are of uppermost value and inspire confidence... the priests and nuns console and support, but people here are given to panic*...

A drawing from the year 1686 of the Cathedral of SC (SANTO DOMINGO 166 (–AI denomination–)) (Fig. 4) shows in two figures the geometry and the dimensions of its dome and of the walls that sustain it, as well as a very good idea of its outside walls and the load-bearing walls segmented in height. This design indicates that the structural elements are adapted to sustain horizontal efforts. However, the cathedral collapsed with the earthquake of 1766. This responds to the possibility suggested in previous paragraphs. Therefore, the negative influence must have come from the material used for the construction and the type of soil. The soil, according to the results of (González et al., 1989, 2003; Heredia et al., 1982) it is loose marl [low quality]. It is assumed that the damage was due mainly to the type of soil.

The drawing from the year 1855 [SANTO DOMINGO 560 (–AI denomination–)] (Fig. 5) presents in two figures the facades of the Government House and the Town Council, in SC. In it is written: *Picture of the Town Hall ruined by the earthquake of the year 1766* [11th June 1766]. Thus, it is confirmed that the Government House was not affected, although the Town Council was. This refutes the reports by Estorch (1852) (Work W1) concerning the destruction of the Government House, when actually the building destroyed was the Town Council.

The topographic plan of the city of SC (SANTO DOMINGO 643 (–AI denomination–)) (Fig. 6) from the year 1840 traces the streets, the location of the principal buildings (The Cathedral, Government House, Dock, Hospital of the Army, Convent of San Francisco, Santo Tomás Church, Nuestra Señora de los Dolores Church, etc.). They are all located in loose soil areas, and in particular the Dock and the Santo Tomás Church are in zones with a phreatic level practically at the surface, according to Fernández et al. (2000). These same areas were damaged and destroyed in the earthquake of 1766 (Cotilla, 2003).

Another topographical drawing, from the year 1650, shows the Bay of SC (SANTO DOMINGO 066 (–AI denomination–)) (Fig. 7) the city, El Morro Castle, and la Plataforma and la Estrella Batteries. The drawing is similar to the cartography of Callejas (1795) and de Aragón (1863).

The third topographic plan is actually a sketch (SANTO DOMINGO 555 (–AI denomination–)) (Fig. 8) from July 12,

Table 9. Intensity of the 1766, 1852, and 1932 earthquakes

No.	Locality	Intensity (MSK)		
		1766	1852	1932
1	El Morro	9	8	8
2	La Socapa	9	8	8
3	Centrer of S. de Cuba	8–9	8	8
4	Mar Verde	8–9	8	8
5	Daiquiri	8–9	8	7–8
6	Bayamo	8	6	6–7
7	El Cobre	7–8	7	7–8
8	Manzanillo	7–8	5–6	5–6
9	Mayarí	6	5–6	5–6
10	Baitiquirí	6	5	5
11	Tunas de Bayamo	6	5	5–6
12	Sagua de Tánamo	6	5	5–6
13	Holguín	6	4–5	5–6
14	Baracoa	5–6	5	5
15	Camagüey	5	4	5
16	Trinidad	3	–	3–4
17	Sancti Spíritus	3	–	3–4
18	Remedios	3	3	3
19	Vertientes	3	3	3–4
20	Santa Clara	3	–	–
21	Matanzas	3	–	–
22	Guantánamo	3	5–6	6–7
23	La Habana	3	3	–
24	Jamaica Island	5	5	5
25	Hispaniola Island	–	3	3

1780, which bears the signature of the Engineer Sir Francisco Suárez Carrasco. It shows the improvement of fieldworks for El Morro Castle and its surrounding lines. Evidently, this document is posterior to the destruction of the castle by the seism of 1766.

A map of Cuba from 1600 (SANTO DOMINGO 574 (–AI denomination–)) shows that the island housed a total of 44 towns, but we concentrate on only 20. A map of the Eastern District of Cuba (Santo Domingo 608 (–AI denomination–)) from the year 1640 shows the position of 21 urban localities and a great knowledge of the territory. The comparison between these maps demonstrates a significant population increase, outlined in the data in Table 2.

According to the information found in the mentioned documents, the damages caused by this earthquake can be summarized as follows. A total of 34 points of perceptibility of the earthquake of 1852 have been entered in Tables 8 and 9. Other points the earthquake was felt are: Aguadores, Duarte, Juraguá, Las Guásimas, El Sardinero, Sigua and Baconao (7–8 degrees, MSK), El Caney and Gran Piedra (6–7 degrees, MSK), and Gibara (4–5 degrees, MSK) (Fig. 3*C*). Using some information, [18] drew a map of qualitatively similar perceptibilities. The central point in the map, the epicentre of the 1852 earthquake, is located at coordinates: 19.75º N, 75.32º W (Fig. 3*A*).

The epicentre of the earthquake has been proposed previously by other authors, cited above. In Álvarez et al. (1993) the data are: 19.9º N, 75.9º W, $h = 30$ km, $I = 9$ degrees (MSK). Chuy (1999) proposes 19.77º N, 75.35º W, $h = 30$ km, $M_s = 7.3$, $I = 9$ degrees (MSK). The authors of the present article defer to the coordinates noted by Álvarez et al. (1999) 19.75º N, 75.32º W. The experience of the first author of the present work reveals many discrepancies concerning the reliability of the macroseismic information in Cuba (Cotilla, 1993, 2007, 2010; Cotilla and Córdoba, 2010a,b; Cotilla and Udías, 1999). We assumed as valid the data of Álvarez et al. (1999), who places the August 20, 1852 earthquake in the immediate area of Baconao. This position is also advocated by the observation, already cited, of Morales y Pedroso (1931) in Work 12. Furthermore, the epicentre of the earthquake of February 3, 1932 (19.75º N, 75.58º W, $h = 35$ km) is also placed in Baconao, but slightly to the west with respect to that of 1852. This can be justified on the basis of the damage produced in the coastal segment of the Bay of SC. Morales y Pedroso (1933) determined that during the earthquake of February 3, 1932 the majority of walls fell westward (W1/4–E1/4S), and that objects were launched in the same direction. This coincides with the NW strike of the isoseismals made by Monteulieu (1933) and the observations on the Gran Piedra by (Morales y Pedroso, 1931) in Work W12. Also, it is the same direction that (23) was assumed to be the main axis of perceptibility of the earthquake of August 20, 1852. Thus, it is possible to conclude that the focuses of the earthquakes of 1932 and 1852 are in the same area, Baconao. To estimate the magnitude we used the relation $M_s = 1 + (2/3)I_0$ (See: Kárník, 1969) and the Sponheuer (1960) relation ($M_s = 0.66I_0 + 1.7\log h - 1.4$). At $I_0 = 8$ degrees (MSK) and $h = 30$ km (Cotilla, 1993; Cotilla and Córdoba, 2010a,b), the magnitude results were: 6.3 and 6.4, respectively. Also, using the relations of Shebalin (1968) ($I_0 = bM - s \log h + c$; $I_0 - I_i = s \log (\Delta_C^2 + h^2)^{1/2}$) we obtained $M = 6.5$ and $h = 31$ km. This last value (h) is quite similar to our estimation.

The occurrence of earthquakes in SC region is associated with the plate boundary zone Caribbean–North American. The distribution of historical shocks with maximum intensities equal to or larger than 8 degrees (MSK) shows an important concentration of large earthquakes along the southeastern coast (Cotilla, 1993; Cotilla and Córdoba, 2010a,b). A brief comparison of the characteristics of three strong earthquakes (1766, 1852, 1932) in SC (Tables 9 and 10) permits us to obtain some ideas on the real scale of these phenomena. The first is that the earthquake of 1852 was overestimated by other authors and that the magnitude must be lower than 7.3, which is the estimate in (Álvarez et al., 1999). Hence, the value of the forfeitures is proportionaly much greater in the earthquake of 1766 that for those of 1852 and 1932. However, the value of the forfeitures is greater in the earthquake of 1932 than in the earthquake of 1852. In this regard, we will point out only

Table 10. Characteristics of the 1766, 1852 and 1932 earthquakes

No.	Characteristic	Earthquake (year)		
		1766	1852	1932
1	Foreshock	Yes	Yes	Yes
2	Aftershocks	Yes–50 (66 days later)	Yes–60 (3 years later)	Yes–122 (1 year later)
3	Time duration of the main shock, s	–	~ 4	~ 4
4	Time of occurrence	00:00	14:05	12:35
5	Seismic intensity (MSK)	9	8	8
6	Perceptibility area, 10^3 km^2	~110	~80	~90
7	Tsunami	No	No	No
8	Epicentre at the sea	Yes	Yes	Yes
9	Seismic vibration	E–W	SE–NW	E–W
10	Residents	5149	41,230	500,000
11	Dead	34–40	2	14
12	Injured	700	200	300
13	% dead, 10^{-3}	8	0.05	0.07
14	% injured	0.1	0.005	0.002
15	Estimated losses, $\$10^6$	10	2	20
16	Destruction of Morro Castle	Yes	No	No
17	Damages to Morro Castle	Yes	No	No
18	Religious buildings affected	Yes	Yes	Yes
19	Civilian buildings affected	90%	85%	80%
20	Perceptibility in La Habana	Yes	No	No
21	Perceptibility in Jamaica	Yes	Yes	Yes
22	Perceptibility in Haití	Yes	Yes	Yes
23	Magnitude	6.8	6.4	6.75
24	Coordinates	19.9º N, 76.1º W	19.75º N, 75.32º W	19.75º N, 75.58º W
25	Depth, km	30	30	35–40

some of the facts that support this position: (1) the population of SC grew from 1766 to 1852 (86 years) by some eight times, while from 1852 to 1932 (80 years) it grew by 12 times; (2) the increase in housing was considerable in the second time interval, but the quality of housing deteriorated, as is confirmed in Work W13; (3) the number of streets, highways, industries, public facilities, etc. also increased (they were less damaged, given the good construction quality, according to Works W14 and W17). For this reason, we consider that the earthquake of August 20, 1852 had at most a magnitude close to that of the events of 1766 and 1932. However, the fact that the earthquake of 1766 was felt all the way to LH and destroyed El Morro Castle, while those of 1852 and 1932 were not felt in LH, and did not affect El Morro, suggests a similarity between the two last earthquakes. Therefore, our estimation of the magnitude and the above discussion indicates that the earthquake of August 20, 1852, had $M_S = 6.4$.

Figures 7 and 8 of Moreno et al. (2002) show 34 earthquake focal mechanism solutions to the Oriente fault (CC–Guantánamo). These solutions are consistent with the known left-lateral strike-slip motion along this major structure (Oriente fault) as well as with the stress regime of the two local structures (CC basin and Santiago deformed belt (Calais and Mercier de Lèpinay, 1991)). Álvarez (1983) inferred from the records of the permanent seismic station of three components in Rio Carpintero (RCC) that the number of seismic events was noticeably greater in the north edge of the BC fault than in the rest of it. Later, Cotilla (1993) demostrated, with data from a network of ten seismic stations of three components, that approximately 80 % of the seismic energy of the Cuban megablock is freed in the CC–Baconao segment. In particular, the Pilón–Baconao segment has one of the highest amounts of seismic activity and shows the highest neotectonic gradient, although there are one or two other significant epicentral groups in CC and Punta de Maisí. For this Pilón–Baconao coastaline segment, Cotilla (1993) and Cotilla and Córdoba (2010) considered the earthquake depth to be mainly 30 km. This value agrees with that of other authors for the 1852 earthquake.

Conclusions

The analysis of historical sources has shown that documents must be judged very critically, establishing which ones provide first hand information and which are the generally accepted

literature in each case. Also, knowledge of the socioecomic situation, demographic conditions, characteristics of buildings, etc., is necessary for a correct assessment of damage. Lack of these knowledge will lead to gross errors in intensity estimations with consequent effects on the evaluation of seismic risk.

Eastern Cuba suffered the strong earthquake of the August 20 at 14:05 hours. Aset of published documents and those from the AI permitted specifying data and enriching the knowledge of the seismicity in this territory. It has been verified that the data were not contrasted and, in consequence, they were historically overestimated. Therefore, the most reliable information on it is as follows: (1) the main event had its epicentre at 19.75º N, 75.32º W, h = 30 km, near Baconao, in the Santiago deformed belt of the Oriente trough and in the Caribbean–North American PBZ; (2) the estimated magnitude was 6.4; (3) there were foreshocks and over 60 aftershocks during 3 years; (4) the damages did not exceed the value of $2,000,000.00 Cuban pesos; (5) it produced only two deaths and approximately 200 people were injured; (6) the area of perceptibility (with 43 points) in Cuba reached only up to the surroundings of Ciego de Ávila (~80,000 km^2) with I_{max} = 8 degrees (MSK) in SC; (7) the religious structures affected, in particular the Cathedral, were also damaged, before and after this event, by other strong earthquakes; (8) 85% of the civilian buildings was affected (all of low-quality construction and all located on the loose soils of the SC city); (9) the damage to the buildings depended on the types of soil and the phreatic mantle level (the Custom, the Dock, Santo Tomás Church, Nuestra Señora de los Dolores Church, the Hospital of the Army, the Convent of San Francisco, etc.).

Acknowledgments. The authors wish to thank the General Archive of the Indies for providing important information and data. Also we thank: (1) Belgium: Biblioteque Centrale; (2) Cuba: Biblioteca Nacional “José Martí”, Biblioteca del Museo de Ciencias; (3) Dominican Republic: Instituto Sismológico Universitario. Universidad Autonóma de Santo Domingo; Dirección General de Minería; (4) France: Institut de Physique du Globe (Paris and Strasbourg); l’Academie de Sciencias, Arts et Belles-Letres de Dijon; Biblioteque Nationale de Paris; (5) Jamaica: University of the West Indies-Jamaica (UWIJ); (6) México: Biblioteca Nacional Autónoma; (7) Spain: Observatoire de L’Ebre (to Doña Arantza Ugalde); Archivo del Ejército; Archivo Histórico Nacional; Biblioteca del Museo de Ciencias Naturales; Biblioteca Nacional; Biblioteca del Instituto Geológico y Minero; Centro de Información y Documentación; Consejo Superior de Investigaciones Científicas (Biblioteca Central, Instituto de Economía y Geografía); Hemeroteca Municipal de Madrid; Museo Naval; Instituto de Ciencia de la Construcción “E. Torroja”; Real Academia de Historia; Real Academia de Ciencias Exactas, Físicas y Naturales; and Universidad Complutense de Madrid (Bibliotecas de las Facultades de Ciencias Geológicas, y de Geografía e Historia); (8) United Kingdom: Civil Engineering Department, Imperial College; (9) United States of America: the Library of Congress. This work has in part by the financially supported by REN2003-08520-C02-02, REN2002-12494E/RIES and CGL2005-25012-E. We are grateful to two anonymous reviewers, who helped to improve the work.

References

Academias de Ciencias de Cuba y de Hungría, 1981. Levantamiento geológico de las provincias orientales, escala 1:250,000 [in Spanish]. Inst. de Geología y Paleontología.

Álvarez, L., 1983. Estimación de la peligrosidad sísmica para la ciudad de Santiago de Cuba [in Spanish]. Investigaciones Sismológicas en Cuba, 4, 87–123.

Álvarez, L., Rubio, M., Chuy, T., Cotilla, M., 1985. Estudio de la sismicidad de la región del Caribe y estimación preliminar de la peligrosidad sísmica en Cuba [in Spanish]. Informe final del tema 310.01. Inst. de Geofísica y Astronomía, Academia de Ciencias de Cuba.

Álvarez, L., Mijailova, R.S., Chuy, T., 1993. Catálogo de los terremotos fuertes de la región 16°/24ºN y –78°/–86ºO, desde el siglo XVI hasta 1988 [in Spanish]. Informe científico-técnico, Inst. de Geofísica y Astronomía, Academia de Ciencias de Cuba.

Álvarez, L., Chuy, T., Garcia, J., Moreno, B., Álvarez, H., Blanco, M., Expósito, O., González, O., Fernández, A.I., 1999. An earthquake catalogue of Cuba and neighbouring areas. The Abdus Salam International Centre for Theoretical Physics, Miramare–Trieste. Internal Report IC/IR/99/1.

Bacardí, E., 1925. Crónicas de Santiago de Cuba [in Spanish]. Tomos 1–5. Barcelona–España. Tipografía de Carbonell y Esteva.

Boston Traveller, 21 November, 1852.

Bottino, L.C., 1878. Calendario histórico de Santiago de Cuba. Establecimiento tipográfico de B. Mestre, Santiago de Cuba, Cuba.

Burke, K., Grippi, J., Sengör, A.M.C., 1980. Neogene structures in Jamaica and the tectonic style of the Northern Caribbean Boundary Zone. J. Geophys. Res. 88 (4), 375–386.

Calais, E., Mercier de Lépinay, B., 1991. From transtension to transpression along the southern Caribbean plate boundary off Cuba: Implications for the recent motion of the Caribbean plate. Tectonophysics 186, 329–350.

Calais, E., Perrot, J., Mercier de Lépinay, B., 1998. Strike-slip tectonics and seismicity along the northern Caribbean plate boundary from Cuba to Hispaniola, in: Dolan, J.F., Mann, P. (Eds.), Active Strike-Slip and Collisional Tectonics of the Northern Caribbean Plate Boundary Zone. Geol. Soc. Am. Special Papers 326, pp. 125–169.

Callejas, J.M., 1795. Plano del puerto de Cuba situado en la costa meridional de la Ysla de este nombre Santiago de Cuba.

Carta Geográfico-Topográfica de la Isla de Cuba (1824–1831) [in Spanish], 1832. Ministerio de Gobierno, Madrid.

Castellanos, G., 1934. Panorama histórico, ensayo de una cronología cubana desde 1492 hasta 1933 [in Spanish]. La Habana.

Chuy, T., 1999. Macrosísmica de Cuba y su aplicación en los estimados de peligrosidad y microzonación sísmica [in Spanish]. Fondos de la Fundación “García Siñériz”, España.

Chuy, T., Pino, O., 1982. Datos macrosísmicos de los terremotos en la provincia de Santiago de Cuba [in Spanish]. Investigaciones Sismológicas en Cuba 2, 46–136.

Chuy, T., González, B., Vorobiova, E., 1984. Sismicidad de las provincias de Camagüey y Ciego de Avila, Cuba [in Spanish]. Investigaciones Sismológicas en Cuba 5, 61–94.

Chuy, T., Zapata, J.A., Rubio, M., 1990. Isosistas del terremoto del 20 de agosto de 1852. In Atlas de la provincia de Santiago de Cuba, Academia de Ciencias de Cuba.

Colección Legislativa de España. Continuación de la Colección de Decretos. Tercer Cuatrimestre de 1852 [in Spanish], 1853. Imprenta Nacional, Madrid, Tomo LVII.

Cotilla, M.O., 1993. Una caracterización sismotectónica de Cuba. Tesis en opción al grado de Doctor en Ciencias Geográficas (especialidad geofísica) [in Spanish]. Inst. de Geofísica y Astronomía, Academia de Ciencias de Cuba.

Cotilla, M.O., 1998a. An overview on the seismicity of Cuba. J. Seismology 2, 323–335.

Cotilla, M.O., 1998b. Terremotos de Cuba [in Spanish]. GEOS 18 (3), 180–188.

Cotilla, M.O., 2003. The Santiago de Cuba earthquake of 11 June 1766: Some new insights. Geofísica Internacional 42 (4), 589–602.

Cotilla, M.O., 2007. Un recorrido por la Sismología de Cuba [in Spanish]. Editorial Complutense, Madrid. ISBN 97-8-47-491827-4.

Cotilla, M.O., 2010. Cuban Seismology. Historia de América 140.

Cotilla, M.O., Álvarez, J.L., 2001. Regularidades sismogenéticas de la unidad neotectónica Occidental de Cuba [in Spanish]. Revista Geológica de Chile 28 (1), 3–24.

Cotilla, M., Córdoba, D., 2007. Seismicity and seismoactive faults of Cuba. Russian Geology and Geophysics 48 (6), 505–522.

Cotilla, M.O., Córdoba, D., 2010a. Notes on three earthquakes in Santiago de Cuba (14.10.1800, 18.09.1826, 07.07.1842). Russian Geology and Geophysics 51 (2), 228–236.

Cotilla, M.O., Córdoba, D., 2010b. The Bayamo earthquake (Cuba) of the 18 October 1551. International Journal of Geosciences 1, 1–50.

Cotilla, M., Udías, A., 1999. La ciencia sismológica en Cuba (II). Algunos terremotos históricos [in Spanish]. Historia de América 125, 45–90.

Cotilla, M., Bankwitz, P., Franzke, H.J., Álvarez, L., González, E., Díaz, J.L., Grünthal, G., Pilarski, J., Arteaga, F., 1991a. Mapa sismotectónico de Cuba, escala 1:1,000,000 [in Spanish]. Comunicaciones Científicas sobre Geofísica y Astronomía 23, 35 p.

Cotilla, M., González, E., Franzke, H.J., Díaz, J.L., Oro, J., Arteaga, F., Alvarez, L., 1991b. Mapa neotectónico de Cuba, escala 1:1,000,000 [in Spanish]. Comunicaciones Científicas sobre Geofísica y Astronomía, 22, 37 p.

Cruz, C., 1958. Temblores y terremotos. Santiago de Cuba [in Spanish].

Daily National Intelligence, 1855. E. Meriam. Washington, 28 November.

de Aragón, R., 1863. Plano del puerto de Santiago de Cuba. Comisión Hidrográfica de España, Madrid.

Delgado, G., 2000. Homenaje al Dr. José a. Martínez-Fortún y Foyo. Cuaderno de Historia de la Salud Pública [in Spanish]. Ministerio de Salud Pública, Cuba.

de la Torre, J.Mª, 1854. Geografía de la isla de Cuba [in Spanish]. La Habana.

DeMets, C., Gordon, R.G., Argus, D.F., Stein, S., 1990. Current plate motions. Geophysics J. Intern. 101, 425–438.

DeMets C., Jansma, P.E., Mattioli, G.S., Dixon, T.H., Farina, F., Bilham, R., Calais, E., Mann, P., 2000. GPS geodetic contraints on Caribbean–North American Plate motion. Geophys. Res. Letters 27 (3), 437–440.

Deng, J., Sykes, L.R., 1995. Determination of Euler pole for contemporary relative motion of Caribbean and North American plates using slip vectors of intraplate earthquakes. Tectonics, 14, 39–53.

Diario de La Marina [in Spanish], 1852.

Dixon, T.H., Farina, F., DeMets, C., Jansma, P, Mann, P., Calais, E., 1998. Relative motion between the Caribbean and North American plates and related boundary zone deformation from a decade of GPS observations. J. Geophys. Res., Ser. B 103 (7), 15,157–15,182.

Economía de La Habana [in Spanish], 1852. t. XIV, p. 370.

El Correo de Trinidad [in Spanish], 1852.

El Faro Industrial de La Habana [in Spanish], 1852.

El Orden [in Spanish], 1852.

Estorch, M., 1852. Apuntes para la historia sobre el terremoto que tuvo lugar en Santiago de Cuba y otros puntos el 20 de Agosto de 1852 y temblores subsiguientes [in Spanish]. Imprenta de D. Loreto Espinal, Santiago de Cuba.

Estorch, M., 1853. Segunda parte de los apuntes para la historia sobre los sucesos que tuvieron lugar en Santiago de Cuba desde mediados de Setiembre de 1852 hasta el 31 de Diciembre del mismo año [in Spanish]. Cuba.

Fanal de Puerto Príncipe, 20.11.1852 [in Spanish].

Fernández, B., Rivera, Z., Reyes, C., Zapata, J., 2000. Los fenómenos físico-geológicos secundarios en la ciudad de Santiago de Cuba [in Spanish]. Revista Minería y Geología 17 (2), 11–13.

Gaceta Médica de México [in Spanish], 1945. Cronología Médica Mexicana. Curadores de heridas y boticarios, 31 de Diciembre de 1945.

Gaceta de La Habana [in Spanish], 1852.

Gaceta del Gobierno [in Spanish], 1852.

González, B.E., Pérez, L.D., 2005. Los sismos de gran intensidad y las construcciones con valor patrimonial en Cuba. En: Resúmenes del V Congreso de Geología y Minería, Cuba. Sección de Ingeniería Geológica e Hidrogeología.

González, B.E., Mirzoev, K.M., Chuy, T., Golubiatnikov, V.L., Lyskov, L.M., Zapata, A., Alvarez, H., 1989. Microzonificación sísmica de la ciudad de Santiago de Cuba [in Spanish]. Comunicaciones Científicas sobre Geofísica y Astronomía 15, 24 p.

González, B.E., Chuy, T., Álvarez, L., Rubio, M., et al., 1994. Estudio sismológico regional complejo de Cuba Centro Oriental para el emplazamiento de objetivos nucleares [in Spanish]. Informe científico-técnico del Centro Nacional de Investigaciones Sismológicas, Ministerio de Ciencia, Tecnología y Medio Ambiente de Cuba, 90 p.

González, E.C., Cotilla, M.O., Cañete, C.C., Díaz, J.L., Carral, R. Arteaga, F., 2003. Estudio morfoestructural de Cuba. Geogr. Fis. Dinam. Quat. 26 (1), 49–69.

Grases, J., 1990. Terremotos destructores del Caribe 1502–1990 [in Spanish]. UNESCO-RELACIS, Montevideo, Uruguay.

Gutiérrez Lanza, M., 1914. Conferencias de sismología pronunciadas en la Real Academia de Ciencias de La Habana [in Spanish]. Ed. Imprenta y Librería de Lloredo y Cía., La Habana, 178 p.

Heredia, N., Seisdedos, G., Oliva, R., 1982. Regionalización ingeniero-geológica de la cuenca de Santiago de Cuba a escala 1:25,000. Informe del ISPJAM [in Spanish]. Ministerio de Educación Superior, Santiago de Cuba, Cuba.

Kárník, V., 1969. Seismicity of the European area. Reidel, Dordrecht, Part 1, pp. 64–82.

La Ilustración Española y Americana [in Spanish], 1852, agosto.

La Ilustración Española y Americana [in Spanish], 1855, XVII, 35. Carlos L. de Cuenca.

La Prensa [in Spanish], 1852.

La Verdad [in Spanish], 1852.

Lewis, J., Draper, G., Bourdon, C., Bowin, C., Mattson, P.O., Maurrasse, F., Nagle, F., Pardo, G., 1990. Geology and tectonic evolution of the northern Caribbean margin, in: Dengo, G., Case, J.E. (Eds.), The Geology of North America, Vol. H: The Caribbean Region. Geol. Soc. Amer., Boilder, pp. 77–140.

L' Emancipation Belge, 24 Septembre, 1852.

L' Indépendence Belge, 30 Octobre, 1852.

L' Indépendence Belge (Supplément), 15 Janvier, 1853.

Lorie, A. Terremoto de Santiago de Cuba. Descripción en verso de los terremotos sufridos en dicha ciudad en los días 20 y 21 de Agosto de 1852, por un testigo ocular [in Spanish], 1852. Madrid.

Makarov, V.I., 1987. Recent tectonics of eastern Cuba. Part 2. The Sierra Maestra-Baracoa orogenic system. General conclusions. Geotectonics 21 (2), 169–174.

Mann, P., Burke, K., 1984. Neotectonics of the Caribbean. Review of Geophysics and Space Physics 22 (4), 309–362.

Mann, P., Taylor, F.W., Lawrence Edwards, R., Ku, T.-L., 1995. Actively evolving microplate formation by oblique collision and sideways motion along strike-slip faults: An example from the northeastern Caribbean plate margin. Tectonophysics 246 (1–3), 1–69.

Martínez-Fortún y Follo, J.A., 1948. Meteorología histórica cubana [in Spanish]. Caibarién.

Moniteur Belge [in French], 1852. 21 Novembre.

Monteulieu, E., 1933. Informe de la comisión nombrada para el estudio del terremoto de Santiago de Cuba de Febrero de 1932 [in Spanish]. Revista de la Sociedad Cubana de Ingenieros 25 (1), 1–79.

Monteulieu, E., 1968. Notas y apuntes acerca de terremotos ocurridos en Cuba [in Spanish]. (Inédito) Archivo del Inst. de Geofísica y Astronomía, Academia de Ciencias de Cuba.

Morales y Pedroso, L., 1931. Los terremotos de Cuba [in Spanish]. Revista de la Sociedad Cubana de Ingenieros 23 (5), 264–308.

Morales y Pedroso, L., 1933. El terremoto de Santiago de Cuba de 3 de febrero de 1932 [in Spanish]. Revista de la Sociedad Cubana de Ingenieros 25 (2), 123–166. La Habana.

Moreno, B., M. Grandison, M., Atakan, K., 2002. Crustal velocity model along the southern Cuban margin: implications for the tectonic regime at an active plate boundary. Geophys. J. Int. 151 (2), 632–645.

New York's Herald, 1852. 18 September.

Orbera, L., González, B., Chuy, T. Oro, J., 1990. Investigación sísmica en la región de emplazamiento del Centro de Investigaciones Nucleares, Vol. 1: Secretaría Ejecutiva para Asuntos Nucleares [in Spanish]. Cuba.

Pacheco, J.F., Sykes, L.R., 1992. Seismic moment catalog of large shallow earthquakes, 1900 to 1989. Bull. Seism. Soc. Am. 82 (3), 1306–1349.

Perrey, M.A., 1852–1853. Note sur les tremblements de terre en 1852, avec suppléments pour les années antérieures [in French]. Mémoires de l'Acad. des Sc., Arts et Belles-Lettres de Dijon, t. II, p. 108.

Perrey, M.A., 1856. Note sur les tremblements de terre en 1855, avec suppléments pour les années antérieures [in French]. Bull. Acad. Royale des Sciences des Lettres et des Beaux-Arts de Belgique 23 (2), 23–77.

Pezuela, J., 1863. Diccionario Geográfico, Estadístico e Histórico de la Isla de Cuba [in Spanish]. 3 Tomos. Ed. Imprenta del Establecimiento de Mellado, Madrid.

Pezuela, J., 1866. Diccionario Geográfico, Estadístico e Histórico de la Isla de Cuba [in Spanish]. 4º Tomo. Ed. Imprenta del Banco Industrial y Mercantil, Madrid.

Pichardo, E., 1854. Geografía de la Isla de Cuba [in Spanish]. 3 partes. Ed. Establecimiento Tipográfico de Don M. Soler, La Habana.

Poey, A., 1855a. Tableau chronologique des tremblements de terre resentís a l' ile de Cuba de 1551 à 1855 [in French]. Annales des Voyages, 6ª serie, 11, 301 p., Malte-Brun, Paris.

Poey, A., 1855b. Supplément au tableau chronologique des tremblements de terre ressentis à l'île de Cuba de 1530 à 1855 [in French]. Annales des Voyages 4, Malte-Brun, Paris.

Poey, A., 1857. Catalogue chronologique des tremblements de terre ressentis dans les Indes Occidentales de 1530 à 1857. Accompagnè d' une revue bibliographique contenant tous les travaux relatifs aux tremblements de terre des Antilles [in French]. Annuarie de la Societé Météorologique de France 5, 75–227, Paris.

Prol, J., Ariaza, G., Otero, R., 1993. Sobre la confección de los mapas de profundidad del basamento y espesor de la corteza terrestre en el territorio cubano [in Spanish]. Informe científico-técnico de la Empresa Nacional de Geofísica, Ministerio de la Industria Básica de Cuba.

Pubellier, M., Vila, J.-M., Boisson, D., 1991. North Caribbean neotectonic events: The Trans-Haitian fault system. Tertiary record of an oblique transcurrent shear zone uplifted in Hispaniola. Tectonophysics 194, 217–236.

Redactor de Cuba [in Spanish], 1853. 26 de Mayo.

Revista de La Habana [in Spanish], 1852, pp. 27–29.

Rodríguez Ferrer, M., 1876. Naturaleza y civilización de la Isla de Cuba [in Spanish].

Rosencrantz, E., Mann, P., 1991. Sea MARC II mapping of transform faults in the Cayman Trough, Caribbean Sea. Geology 19 (7), 690–693.

Rosencrantz, E., Ross., M.I., Sclater, J.G., 1988. Age and spreading history of the Cayman trough as determined from depth, heat flow and magnetic anomalies. J. Geophys. Res., Ser. B 93, 2141–2157.

Salteraín y Legarra, P., 1884. Ligera reseña de los temblores de tierra ocurridos en la Isla de Cuba [in Spanish]. Anales de la Academia de Ciencias Médicas, Físicas y Naturales de La Habana 21, 203–218.

Shebalin, N.V., 1968. Methods of using engineering-seismology data in seismic zoning, in: Medvedev, S.F. (Ed.), Seismic Zoning of the USSR. Nauka, Moscow, pp. 101–121.

Somohano, A., 1969. A catalogue of earthquakes felt at Cuba. Thesis of Diploma of Imperial College, London.

Sponheuer, W., 1960. Methoden zur Herdtiefenbestimmung der Makroseismik [in German]. Freiberg Forschungsh., C88, Akademie Verlag, Berlin.

Sykes, L.R., McCann, W.R., Kafka, A.L., 1982. Motion of the Caribbean plate during the last 7 million years implications for earlier Cenozoic movements. J. Geophys. Res., Ser. B 87 (13), 10,656–10,676.

Tomblin, J., Robson, G.R., 1977. A catalogue of Felt Earthquakes for Jamaica with References to Others Islands in the Greater Antilles, 1564–1971. Ministry of Mining and Natural Resources, Mines and Geology Division, Spec. Publ. 2, Hope Gardens, Kingston, Jamaica.

Valiente, G., 1853. Tabla cronológica de los sucesos ocurridos en Santiago de Cuba [in Spanish]. New York.

Vilanova, B., 1853. Tremblements de terre des Antilles [in French]. Bull. de la Soc. géol. de France, série 2ª, t. XI, p. 108.

Wells, D.A., 1852. Annual of Scientific Discovery: or, Year-Book of Facts in Science and Art.

Editorial responsibility: V.S. Seleznev