

The Bayamo Earthquake (Cuba) of the 18 October 1551

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Abstract

Using contemporary and original documents from the Archivo General de Indias it has been possible to complete the data for the 18 October 1551 earthquake in Cuba. The seism took place at midday, approximately. It had foreshocks and aftershocks. In Bayamo, 7 inhabitants were injured, and the town was severely affected. Maximum seismic intensity was IX degrees on the MSK scale, and the area of perceptibility is estimated at 40,000 km². Liquefaction processes and soil type in Bayamo contributed to the damage. This locality is in the Eastern region of the island, and continues to suffer the most and the strongest seismic events. The epicenter was in the southern marine area of the western segment of Oriente trough (19.6 N 77.8 W, h = 15 km, Ms = 6.6), where there is a crossing of faults, and neotectonics and focal mechanisms are affected by transtension, although the Bartlett-Cayman region's tendency to left-lateral strike-slip movement is maintained, in the Caribbean and North American plate boundary zone.

Keywords: Bayamo, Cuba, Earthquake, Historical Seismicity

1. Introduction

In previous papers we have shown that relatively large and destructive earthquakes have occurred frequently in the past along the Oriente fault system [1,2]. We have also shown that American contemporary documents must be studied with care, in their historical and cultural context, in order to avoid overrating when evaluating intensity [3]. In this paper, we will discuss an historic Cuban earthquake, which occurred in the year 1551. The information for this seismic event comes from contemporary sources, such as unpublished consular correspondence, official documents and damage claims, as well as from the observations of travelers who passed through the epicentral region during and after the earthquake. An extensive literature search for documents relative to this earthquake was carried out in libraries and archives of Belgium, Cuba, Dominican Republic, England, France, Jamaica, Mexico, Spain, and United States of America.

Cuba's written history is fairly extensive. It began in 1492 with the diaries of the first Spanish explorers [4,5]. The Spanish colonizers and priests established Catholic churches throughout the island, in all the villages founded from 1512 onwards. Many of these documents are available in the Archivo General de Indias (AI), Spain. Consultation at the AI enabled access to the original sources

of information, for the first time, revealing that information on many XVIth century earthquakes has been compiled. Cotilla [3] and Cotilla and Córdoba [2] have already shown the usefulness of the AI, in the studies of four earthquakes in Santiago de Cuba.

In 1687, Cuban newspapers were published for the first time, initially issued in Santiago de Cuba and La Habana [5,6]. They mentioned perceptible earthquakes, continued to spread across the Eastern Cuban region as the population increased. Descriptions of the Cuban earthquakes were catalogued by Poey [7-9], and were later interpreted in terms of shaking intensity, and later, earthquake epicenters and magnitude [10-12]. Cotilla and Udías [5] classify the earthquake information quality of the works by Andrés Poey y Aguirre, concluding that the information given for the event of 1551 in Bayamo is unsatisfactory.

The aim of this paper is to detail what is known about the 1551 Cuban earthquake (Bayamo) including its sequences, the location of the epicentral areas, assessment of magnitude, and its effects both on the ground and on man-made structures. A further aim is to provide a critical review of the information available and to resolve some ambiguities appearing in previous works. Attempts are made to associate these events with local tectonics or to evaluate the associated seismic hazard.

2. Short Notes on Tectonics and Seismicity

The relative motion between the North American and Caribbean plates is decisive for the area's tectonic regime on a regional scale [13-20] (**Figures 1(a), 1(b)**). Cuba is a megablock (or microplate) located in the southern part of the North American plate (**Figure 2**) [21-23]. The active plate boundary is situated along the southeast coast where the main seismic activity follows the eastern segment of Bartlett-Cayman fault zone (Oriente fault) [14,24,25]. In this segment, faulting is mostly sinistral strike-slip (**Figure 1(d)**) [1,14].

The general pattern of seismicity in the Caribbean region is shown in **Figure 1(b)**. Large earthquakes occur along the plate boundary near Hispaniola, Jamaica and Puerto Rico [12,26], but no event since the XVIIIth century has reached a magnitude of 7.0 [1,5]. **Table 1** presents the most significant earthquakes in Southeastern Cuba [2-4]. Low magnitude seismicity ($M_s < 4$) occurs throughout the Western region of the island and particularly around Santiago de Cuba [14]. The seismicity determined with the Eastern Cuban network appears in **Figure 1(c)**. These low-energy events have been regis-

tered by 3 or more stations in the period 1979-1994 [1]. It shows two important earthquake clusters, namely, in Cabo Cruz and Pílon-Baconao. The second cluster is the largest and it corresponds to most important seismogenic segment of Oriente fault [22] where the strongest earthquakes are observed there. The cluster of Cabo Cruz has an important epicentral error and the accuracy in azimuth is about 15-30%. Using the mentioned Cuban seismic data, Cotilla [1] presented the **Figures 1(e)** and **1(f)** where appear the predominant depth range of earthquake occurrence.

The Cotilla *et al.* [22] results suggest that Cuba is a seismotectonic province, composed of four units (Western, Central-Eastern, Eastern, and Southeastern). **Figure 2** shows the location of the two main units and their limits, and the three crust types (wide transitional, fine transitional and oceanic) [27] in the region. According to Makarov [28], the neotectonic structure of Eastern Cuba (**Figures 3(a), 3(b)**) includes extremely diverse areas, differing in layout, morphology and historical development. Development began in the Late Eocene, on a mixed basement and, in general, on crusts of various thicknesses and types, ranging from sub continental to sub oceanic, as

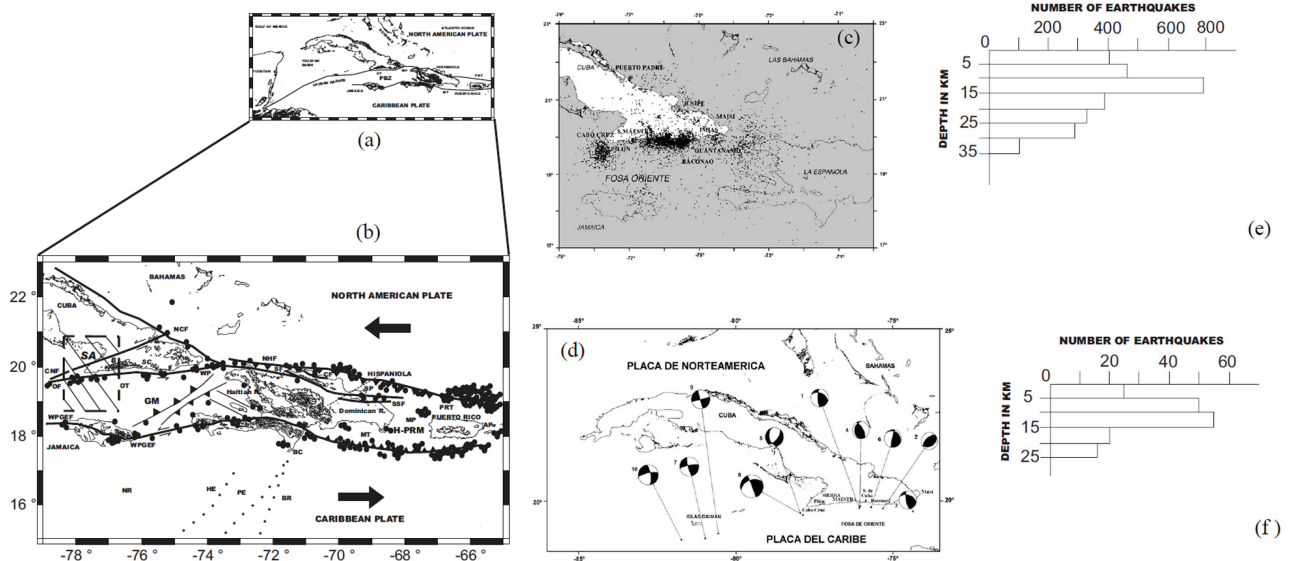


Figure 1. a) Simplified tectonic map of the Caribbean. General view (Heavy black lines=main fault systems: MT = Muertos trough, OT = Oriente trough; PBZ = Plate Boundary Zone; PRT = Puerto Rico trench, WP = Winward Passage); **b)** Main structures in the Caribbean [Eastern Cuba–Puerto Rico]. (Heavy black arrows= sense of plate movements; black circles= epicenters [1]; black lines = the main faults: CF = Camú, CNF = Cauto-Nipe, NCF = Nortecubana, NHF = North Haitian, OF = Oriente, SF = Septentrional, SSF = South Samaná, WPGEF = Walton-Platain 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, HPRM = Hispaniola-Puerto Rico; troughs: MT = Muertos, OT = Oriente, PRT = Puerto Rico; other structures: NR = Nicaragua Rise, PE = Pedro Escarpment; open rectangle (SA) = study area); **c)** Eastern Cuba seismicity determined with a National network in 1979-1994 [1]; **d)** Selection of ten focal mechanism solutions in Oriente fault zone. (1: 13.11.1978 [$M_s = 5.1$], 2: 01.09.1985 [$M_s = 5.1$], 3: 12.02.1989 [$M_s = 5.2$], 4: 22.05.1990 [$M_s = 5.1$], 5: 26.08.1990 [$M_s = 5.9$], 6: 04.09.1990 [$M_s = 5.2$], 7: 26.08.1991 [$M_s = 5.2$], 8: 25.05.1992 [$M_s = 6.9$], 9: 27.06.1992 [$M_s = 5.3$], 10: 27.06.1995 [$M_s = 5.6$] [1]; **e)** Frequency distribution of hypocenters of Southeastern Cuba in 1979-1994; **f)** Frequency distribution of hypocenters in Cabo Cruz in 1979-1994.

Table 1. The most significant earthquakes in southeastern Cuba.

Date/ Locality	Coordinates/ Depth (km)	Magnitude/ Intensity (MSK)	Fatalities/ Injured
11.06.1766/S.Cuba	19.9N,-76.1W/25	6.8/IX	34/700
20.08.1852/S. Cuba	19.75N,-75.32W/30	6.4/VIII	2/200
03.02.1932/S. Cuba	19.75N,-75.58W/35-40	6.75/VIII	14/300

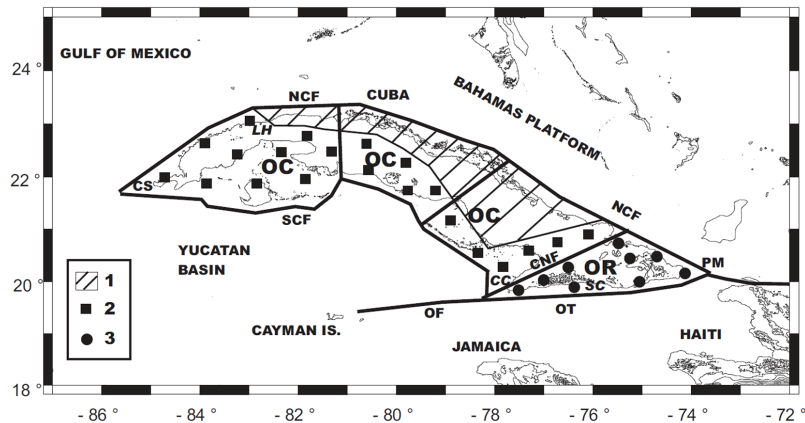


Figure 2. Cuban megablock according with Cotilla *et al.* [22]. (Heavy black line = faults: CNF = Cauto-Nipe, NCF = Nortecubana, OF = Oriente, SCF = Surcubana; Neotectonic Unit: OC = Western, OR = Eastern; crust type: 1 = post-orogenic complex, 2 = orogenic complex, 3 = volcanic arc complex; localities: CC = Cabo Cruz, CS = Cabo de San Antonio, LH = La Habana, PM = Punta de Maisí, SC = Santiago de Cuba).

established by Prol *et al.* [27]. The evolution of this structure was associated with, and considerably influenced by, deep-water troughs such as the Yucatan basin in the southwest, the Old Bahamas Channel in the northeast, and the Oriente trough in the south (**Figure 1(a)**).

Sierra Maestra Range ($h = 1,974$ m) (**Figures 3(a), 3(b)**) has a simple structure [21,29]. Overall, it is an asymmetric swell, derived from an anticlinorium which was 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 a deep-water trench (the Oriente trough) and is shifted eastward (**Figure 3(b)**). The relief in this area has a range of up to 10 km, with an average slope dip of up to 16°. On the northern limb the relief varies by about 2 km and the slope, by 3°-5°. Some geomorphologic characteristics [30] indicate that the northern limb is also deformed, and sub latitudinal uplift zones successively decreasing in size from south to north can be identified within it.

The largest newly generated neotectonic element in the structure of Eastern Cuba is the Cauto-Nipe synclinal system. It developed in association with the Sierra Maestra Range, but is not a piedmont downward in the strict sense of the term [21,30]. According to Mann and Burke [25], the Cauto area constitutes a pull-apart basin, and the city of Bayamo is located within it (**Figures 3(a), 4(a)**). The zone where it is located is characterized by significant layers of sediments from the Cauto-

Nipe basin [21,30,31] (**Figure 4(b)**), something which evidently favors the amplification of the ground oscillations.

Cabo Cruz, in the eastern end of Southeastern Cuba (**Figures 3(a), 3(b)**), was discovered and named by Cristóbal Colón on 3 May 1494, during his second journey. It is a coastal bar with marine terraces of up to 190 m in altitude and approximately 120 km² (**Figure 3(c)**) [29]. It is some 30 km from Niquero (**Figure 3(d)**). This latter location and its surroundings, constitutes a region of plains neighboring the Gulf of Guacanayabo, into which the rivers of the northwest Sierra Maestra flow. The Cabo Cruz submarine area was studied tectonically by Calais and Mercier de Lépinau [24], who concluded that it is a narrow E-W trending depression, bordered to the north and south by equal numbers of Oriente fault segments. These comprise a set of horst-grabens inside a discontinuous trace of the Oriente fault system.

3. Some General Cuban Data

Cuba was discovered in 1492 by Cristóbal Colón; however it was not until 1512 that the Spanish became established there. To understand the importance of the earthquake under discussion and the information contained in contemporary documents, the historical and demographic situation of Cuba, and in particular of Bayamo, must be

taken into account. **Table 2** shows the different cities and towns founded in Cuba by Don Diego Velázquez de Cuellar, all of them endowed with a church [6]. By the year 1544, more than forty churches and five hospitals existed on the island-Bayamo (in 1518), Santiago de Cuba (in 1520), La Habana (in 1521), Puerto Príncipe (in 1523),

and Sancti Spíritus (in 1523)-. All of them had barbers, medical assistants, or itinerant quacks, but no doctors [32]. Population data appear in **Table 3** [6]. All these structures have enabled an evaluation to be made of the damage produced by the earthquake, and consequently, an estimation of seismic intensity.

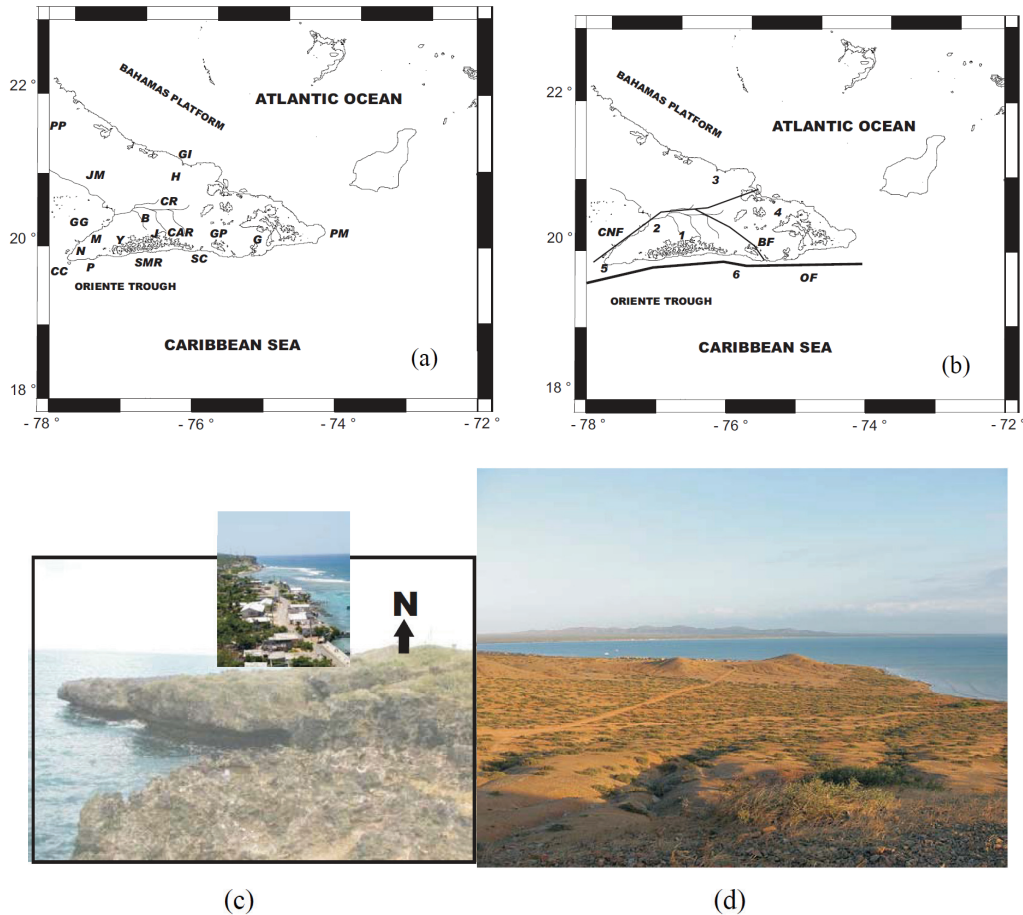


Figure 3. a) Eastern Cuba. Localities (B = Bayamo, CC = Cabo Cruz, CR = Cauto river, CAR = Cautillo river, G = Guantánamo, GG = Guacanayabo Gulf, GI = Gibara, GP = Gran Piedra Mountains, H = Holguín, J = Jiguani, JM = Jobabo Mines, M = Manzanillo, N = Niquero, P = Pílon, PM = Punta de Maisí, SC = Santiago de Cuba, SMR = Sierra Maestra Range, Y = Yara); **b) Main structures of Eastern Cuba.** (1 = Sierra Maestra Range, 2 = Cauto basin, 3 = Holguín Heights, 4 = Nipe-Cristal-Sagua-Baracoa Mountains, 5 = Cabo Cruz basin, 6 = Santiago de Cuba deformed belt; faults: BF = Baconao, CNF = Cauto-Nipe, OF = Oriente); **c) Photo of Cabo Cruz area and the Jaimanitas Formation in the marine terraces (karst); d) Relief and red soil type in Niquero area.**

Table 2. Data of the population census.

Year	Data
1527	Only Spaniards: Baracoa = 12, Puerto Príncipe = 20, Sancti Spíritus = 26, Santiago de Cuba = 20, Trinidad = 12, Bayamo, La Habana and in other localities = 300 (Total = 390)
1556	3,000 Spaniards on the island: Santiago de Cuba = 450, La Habana = 360, Bayamo = 300, Sancti Spíritus = 200, Puerto Príncipe = 200, Trinidad = 150, Baracoa = 120, Tunas = 100, Cienfuegos = 60, Remedios = 60, Guantánamo = 50, Holguín = 50, Matanzas = 50, San Cristóbal = 30, Consolación del Norte = 30, and in other localities = 790

Table 3. First villages and its dates of foundation.

Date	First denomination	Actually	Date	First denomination	Actually
03.10.1512	Nuestra Señora de la Asunción de Baracoa	Baracoa	19.01.1514	Sancti Spiritus	Sancti Spiritus
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

The Governor of Cuba initially lived in Bayamo city. Later, in 1517, the residence was moved to Santiago de Cuba (**Figures 1(b), 2, 3(a)**), and finally, from 1550 onwards, the Governor-then Don Gonzalo Pérez de Ángulo (1548-1553)-established his residence on a permanent basis in La Habana (**Figure 2**), given the importance of this port as a point of control for all ships and fleets on their way to the metropolis or to the mainland. However, by 1600 Cuba was under the jurisdiction of Santo Domingo (Hispaniola) (**Figures 1(a), 1(b), 1(c)**) by a Real Order of the Spanish King Carlos I (1516-1556). On the 8 October 1607, the Spanish King-Felipe II (1598-1621)-divided the island of Cuba into two Governmental administrations, namely, Santiago de Cuba and La Habana (the second one subordinate to the first up until 1628). These administrative elements have subsequently enabled a literature search on historic earthquakes to be carried out successfully.

4. The 1551 Earthquake

4.1. Initial Data

Various authors have referred to the 1551 earthquake in Bayamo, including Álvarez *et al.* [10,11], Bacardí [33], Cotilla [4,6,14], Cotilla and Udías [5], de la Pezuela [34,35], Grases [36], Herrera [37], Montelieu [38], Poey [7-9], Salterain y Legarra [39], Somohano [40], and Tomblin and Robson [41], but Poey [8] was the first to write about it, "*Tremblement de terre à Bayamo*". Shortly after, he reaffirmed his previous work about "1551 earthquake Cuba (Bayamo)" [7]. However, he did not provide data concerning the time, the day, or the month. Later authors refer only to the information provided by Poey, without contributing anything new with regard to this matter.

The earthquake occurred 59 years after the discovery of Cuba, and 39 years after the founding of the Bayamo city (1512). At that time (1551), the economic and social development of Bayamo had been equal to, or slightly inferior to, that of La Habana and Santiago de Cuba (site of the island Government), because up to 1517, when Santiago de Cuba was named the capital, it had been the capital city of Cuba. As a capital city, it had a coat of arms, and the official residences of both the Governor and of the Bishop of the Diocese, among others, were

located there. In 1616, the Cauto River (the most important in Cuba) was navigable as far as the Cautillo River (**Figure 3(a)**). This enabled the movement of goods, principally between Bayamo and Santiago de Cuba. However, its course was modified by a hurricane, bringing a definitive halt to the economic activity, and resulting in the impoverishment of the region. The fluvial course of the Cauto River has subsequently been modified at least twice by tropical cyclones, in 1964 and 2007.

Bayamo and its surroundings formed a center of smuggling activities in Eastern Cuba. In fact this was the main source of discontent among the authorities of the metropolis, and contributed to the war in the XIXth century. The town received resources and goods that were then re-distributed throughout the Eastern District (Holguín, Gibara, Mayarí, Minas de Jobabo, Puerto Príncipe, etc.) (**Figures 3(a), 3(b)**). Although the area was frequently attacked by pirates and corsairs, the wealth of financial resources available favored significant development of both the town and the surrounding area (Yara, Niquero, Manzanillo, Jiguaní, etc.) (**Figures 3(a), 3(b), 4(a)**). In addition to the town of the same name, the jurisdiction of Bayamo included the nearby localities mentioned above, the farms in the area, and those coastal sites that were also inhabited, principally by soldiers, miners, farmers and fishermen. Cuba's first public school and first cemetery were in Bayamo. The first church in Bayamo was originally built (in 1514) in the style of a thatched hut ("bohío") typical to the region, being replaced shortly after by a stone construction built with blocks of limestone (in 1522), in order to welcome the scores of faithful devotees of San Salvador. This was destroyed during the earthquake of 1551, and reconstructed in 1613; however, it was in ruins again following the seism of October 1624 [7-9]. Although Poey mentions "*Tremblement à Bayamo*" in his work, but the authors have not located any other document which confirms this. The event of 1624 will be commented later on.

In La Ilustración Española y Americana [42] the following report appears: "*In November 1518, the famous Spanish conqueror Diego Velázquez laid the first foundations of Bayamo*" (this detail is incorrect; it was on the 5 November 1513), "*and at first, the task of colonization was taken very seriously. However this undertaking was soon to be paralyzed by emigration to Mexico and other*

parts of the American continent, leaving Bayamo with scarcely 100 inhabitants” (erroneous, there were ~200 inhabitants) “when an earthquake destroyed both housing and the first church” (imprecise; neither the day nor month of the earthquake in which the earthquake took place are mentioned, and the report only indicates that the first church was destroyed).

Population census data for Bayamo, given in **Table 2**, for the years 1527 and 1556, mention ~200 and 300 Spaniards, respectively (an increase of ~100 people in 29 years, a significant number for the time). This increase can be accounted for by the economic status of the town (church, Government House, Archbishopal House, etc., all of them built with limestone blocks), the fertile lands, the favorable position for fishing in the Gulf of Guacanayabo (Figures 3(a), 4(a)), the navigability of the Cauto River at that time, smuggling, etc.

4.2. New Data

In the present study, new documentation has been uncovered in the AI. Among the contemporary documents there are some sketches and maps of Cuba and Bayamo. We following types should be mentioned: 1) a topographic map of Bayamo and its surroundings (SANTO

DOMINGO 582-AI denomination-) from the year 1548 (**Figure 4(a)**); 2) a map of Cuba (SANTO DOMINGO 574-AI denomination-) from the year 1600; and, 3) a sketch of Middle Eastern Cuba (SANTO DOMINGO 608-AI denomination-) from the year 1640 (**Figure 5(a)**). A joint assessment of these documents make it possible to: 1) estimate the level of territorial occupation and the spatial distribution of Spanish towns on the island in its eastern part; 2) establish the names of population centers at that time; and, 3) determine the true position of the main towns and villages. Thus it has been possible to establish that the town of Bayamo, founded by Velásquez, was located very near to the coast on the Gulf of Guacanayabo, south of the Cauto River, on the eastern bank of the Bayamo River (which flows into the Cauto River (**Figures 3(a), 4(a), 5(a)**). In other words, it was located on the same site it occupies today, and not, as some authors have suggested, on the site of the town of Yara (where Spaniards fought a fierce battle in 1513 against the natives led by their chief Hatüey, who was eventually burnt alive). In addition, the map of Bayamo clearly shows the existence of the church and the Governor’s House, as well as their respective dimensions.

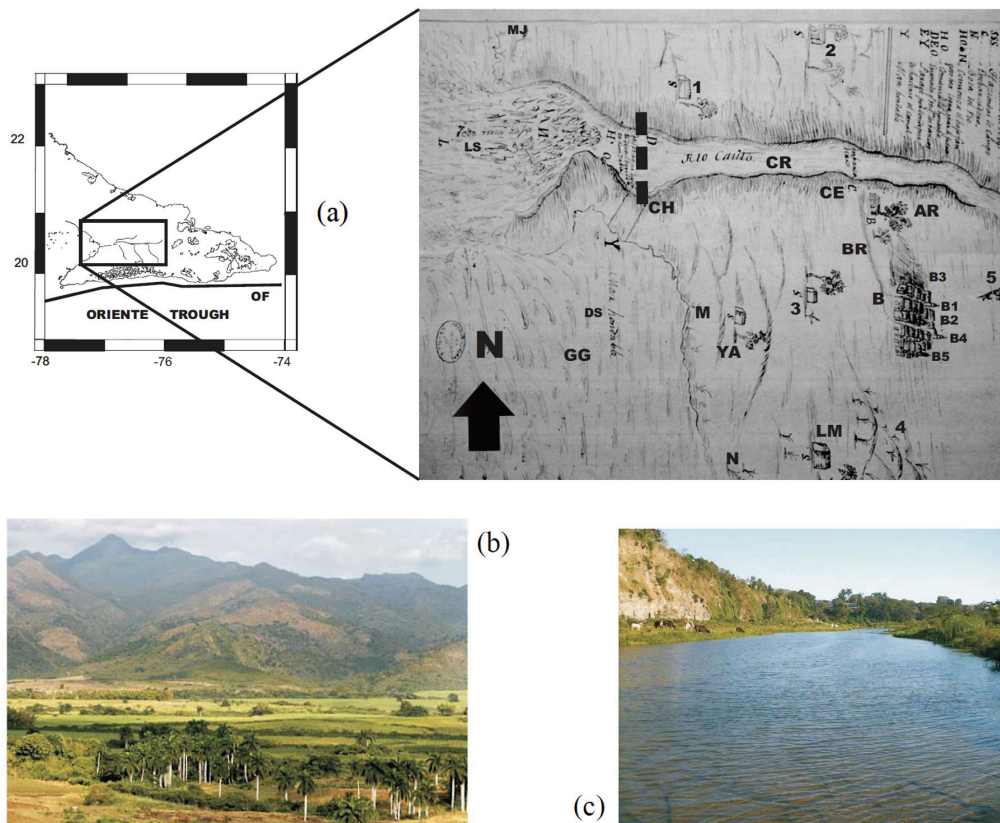


Figure 4. a) Topographic scheme of Bayamo [SANTO DOMINGO 582 of 1548 (-AI denomination-)]. (AR = Almacén del Rey, B = Bayamo, B1 = Cathedral, B2 = Hospital, B3 = Government House, B4 = Cuartel, B5 = Archbishopal House, BR = Bayamo river, CE = Cauto Embarcadero, CH = Iron Chain, CR = Cauto river, DS = Deep sea, GG = Guacanayabo Gulf, LM = La Merced, LS = Low sea, M = Manzanillo, MJ = Jobabo mines, N = Niquero, YA = Yara, farms = 1, 2, 3, 4, 5); **b) Panoramic view of the northern Sierra Maestra Range from Bayamo;** **c) Segment of Cauto River near Bayamo.**

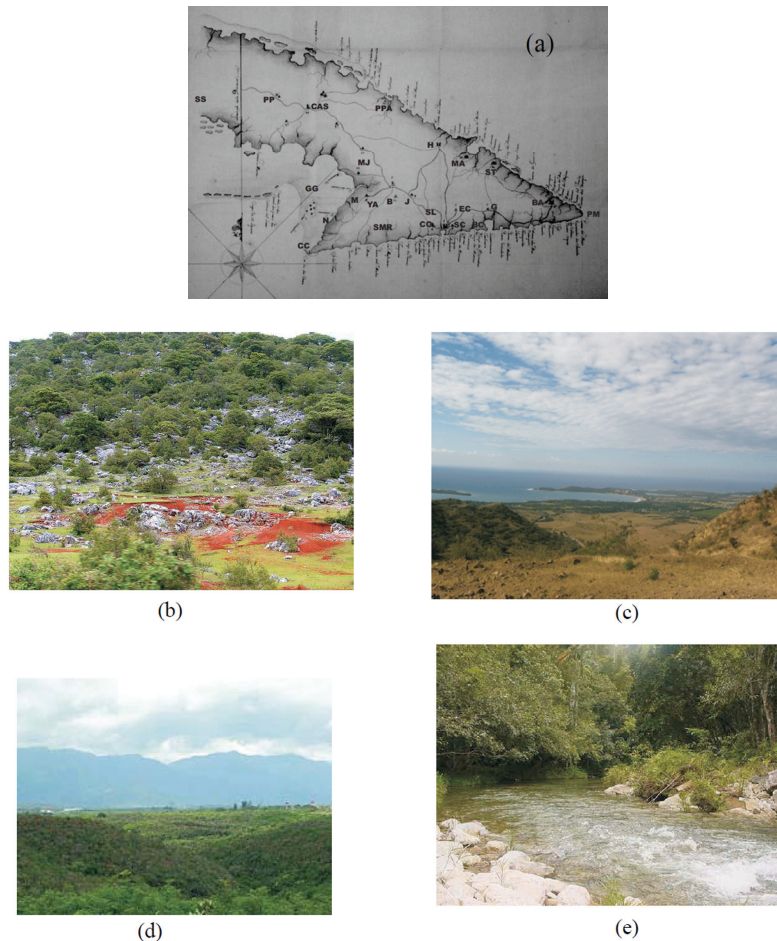


Figure 5. a) Map of the Eastern Cuba [SANTO DOMINGO 608 of 1640 (-AI denomination-)]. See **Figure 3(a)**. (B= Bayamo, BA = Baracoa, BC= Baconao, CAS= Cascorro, CC= Cabo Cruz, CO = El Cobre, G= Guantánamo, GG= Guacanayabo Gulf, H= Holguín, J= Jiguani, M= Manzanillo, MA= Mayari, MJ= Jobabo mines, N= Niquero, PP= Puerto Príncipe= Camagüey, PPA= Puerto Padre, SC= Santiago de Cuba, SL= San Luis, SMR= Sierra Maestra Range, SS= Sancti Spiritus, ST= Sagua de Tánamo, Y= Yara); **b) Photo of the relief and rock types in San Luis area;** **c) View of Manzanillo and Guacanayabo Gulf areas;** **d) View from Las Mercedes to northern of Sierra Maestra Range;** **e) Photo of a mountain river in Jiguani.**

The map of 1548 (SANTO DOMINGO 582) (**Figure 4(a)**) shows, among other things: 1) the dimension of the Cauto River and its navigability upstream, including beyond the town of Bayamo; 2) the town of Bayamo, together with the Cathedral, the Governor's House, and the residential neighborhoods; 3) the river port (today Cauto Embarcadero); 4) the King's Storehouse; and, 5) five farms; etc. This geographic position for Bayamo is supported by the fact that the town would thus have had direct access to the sea (the Gulf of Guacanayabo) close to the mouth of the Cauto River, making navigation inland feasible even as far as Jiguani (**Figures 3(a), 5(a)**), and from there the journey to Santiago de Cuba by road was relatively flat and straightforward, continuing as far as San Luis (**Figures 5(a), 5(b)**).

It should be mentioned that between the XVIth and XIXth centuries, at least 10 maps that include the island of Cuba have been edited [43], and the scientific works

of the following authors can be cited: 1) Juan de la Cosa (in 1500); 2) Abraham Ortelius (in 1580); 3) Heyronymi Benzoni (in 1594); 4) Guiljelmus Blaen (in 1638); 5) N. Sanson d'Abuille (in 1656); 6) Pieter Vander A. A. (in 1728); and 7) Esteban Pichardo (in 1855). In general the cartography of these maps improves with successive editions. However, the map of 1728 has serious errors still, for example: 1) placing Bayamo city in Holguín area (**Figures 3(a), 5(a)**); 2) denominating the Cauto River as the Zaza River (which is in the Central region of the island). Even at that time, Guantánamo (**Figures 3(a), 5(a)**) was being called Puerto Grande. In the year 1638, the Cauto River was designated on the map as the Bahamas River, and on the same map, the town of Manzanillo (**Figures 3(a), 4(a), 5(a), 5(c)**) appears for the first time. With regard to the cartographic deficiencies in the maps of Cuba, Pichardo [44] commented: "many earlier and current maps have been compiled by people who have not so much as stepped on

Cuban territory..." Such comment explains all deficiencies in the mentioned Cuban maps.

The three maps located by the authors in the AI were drawn up in 1548-1640 and it can be seen that the contents are similar to those of maps 2-4 mentioned above. However, the geographic position of Cuban localities given in the materials located in the AI is considerably more accurate than that given in map number 7 (by Pichardo). We are of the opinion that this is due to the fact that they were the work of specialists who were familiar with the territory that they represented, and are therefore reliable. In addition four contemporary hand-written documents relating to the earthquake of 1551 have been located in the AI. A summary of these materials follows:

(Document 1.-) GOVERNMENT PAPERS: 1492-1858. SANTO DOMINGO, JUDICIAL DISTRICTS: 1511, 1512-1858 [-AI denomination-]. (Correspondence of Don Juan de Hiniestrosa, Governor of the village of San Salvador de Bayamo, with Don Gonzalo Pérez de Ángulo, Governor of Cuba)

San Salvador de Bayamo, 28 Octubre 1551

His Excellency, Don Gonzalo Pérez de Ángulo
General Governor of Cuba

It is my duty to inform your Excellency of the events which took place on the 18th (according to the date in the wording of the document, October 1551) in San Salvador de Bayamo. Close to midday (11-12 o'clock), work was interrupted by a dreadful shake (the main earthquake). Many have been injured, and the town has suffered serious damage... (There were no deaths)... The principal and most severe damage was sustained by the solid and regal barracks, which collapsed, with one person being injured. The Parochial Church which adjoins the barracks, and the hospital (Figure 4(a)), were completely destroyed... all the farms (according to the 1548 map, there were farms to the south and north of the Cauto River, in the area around Bayamo) suffered severe damage as a result of the violence of the movements of the earth... (Destruction)... in the town, on the 18th day at midday, terror struck in the hearts of the men and women laboring in the fields. Beasts fled, sixteen houses in the village collapsed, and another three, although still standing, have huge cracks in their walls... two wounded were found... the Embarcadero (on the south bank of the River Cauto, today called Cauto Embarcadero, Figure 4(a)) was destroyed, causing damage to four ships and injuring two people... the Church, built of solid stone, has been completely destroyed, the central pillars hang by a miracle... the barracks collapsed, and one person was injured... the stables fell... the prison and the hospital are in ruins... the well in the Square has collapsed... five houses on the riverside (Bayamo) were overturned and sank into the mud (liquefaction)... muddy, stinking water flowed from the banks of the river... beasts sprawled on the ground... The King's Storehouse (on the southern bank of the Cauto River and

to the east of the Embarcadero, Figure 4(a)) has been destroyed. All the merchandise and goods were lost... three canons and the defensive line of heavy iron chain (an army obstacle in the Cauto River which impeded the entry of enemy ships) have sunk into the mud... (liquefaction)... the land is fertile and flat, and the hills only rise in the distance, to the south as an enormous mass, the Gran Sierra (nowadays known as the Sierra Maestra Range [Figures 1(c), 3(a), 3(b), 4(b), 5(a)])... the oldest inhabitants here say that the plain here is different to that of Cuba (at that time, Santiago de Cuba was frequently referred to as Cuba, and vice versa), always jerking and shaking... the danger was not felt in Cuba... (Santiago de Cuba seismicity was perfectly well known, but in Bayamo any report)... the night was pitiful and cold... people kept vigil and there were sudden shocks (aftershocks)... a procession carried a statue of the Sainly and Divine Patron Saint (San Salvador) in their arms... the sub-lieutenant Fernando Rodríguez de Castro returned from patrolling the hills to the south (Sierra Maestra Range) and from the coastal posts of Cabo Cruz, Niquero and La Costa (today Manzanillo) (Figures 3(a), 3(c), 5(a), 5(c)), with the garrison detachment. He reports that at midday on the 18th October, they noted the ground moving beneath their feet, and heard noises like thunder emanating from beneath the ground... the noises came from the south (Cabo Cruz), and huge, solid rocks could be seen strewn across the road to La Merced (in the mountainous part of the Sierra Maestra range, on the northern side, today Las Mercedes) (Figures 4(a), 5(d))... the beasts of burden refused to advance... the cracks in the road were 12 varas (~9 m) wide (1 Castilian vara = 0.8359 m)... two soldiers fell in their saddles to the ground... in Yara, all the houses, around twenty or more, were in ruins... the timbers and pillars scattered... (This town is on a low alluvial plain well irrigated by fluvial currents from the Sierra Maestra. Therefore, it is highly probable that liquefaction occurred)... the sub-lieutenant ordered two soldiers to return at a gallop to the coastal posts (Cabo Cruz and Niquero [Figures 3(a), 3(d), 4(a), 5(d)]) in order to acquaint themselves of the situation there, whilst the rest marched to La Costa (Manzanillo)... they informed him that Cabo Cruz was in ruins... two canons were overturned... but that there had been no injuries... the posts at Niquero and La Costa (Manzanillo)... lost everything, and a soldier received a heavy blow when he fell... all canons were overturned... Jiguani ([Figures 3(a), 5(a), 5(e)] town on the western bank of the Cautillo River) was fiercely and brutally shaken, and the houses ruined, the church and the heavy wood barracks destroyed... (the above-mentioned towns appear in Figure 3(a))

... on the night of the 16th and the morning of the 17th, short, strong earth tremors had been noticed (foreshocks)... the ground collapsed and moved like an angry sea... never before has such an event been heard of

here...

(Document 2.-) CUBA 2007 [-AI denomination-]
San Salvador de Bayamo, 19 December 1551
His Excellency, Don Gonzalo Pérez de Ángulo
General Governor of Cuba

...with regard to the inspection of the barracks in this town of San Salvador de Bayamo, the captain Don Bartolomé Quesada de Castro was very surprised and saddened to see the serious damage caused to the town and the destruction of the barracks. He reports that in Sancti Spiritus and Jobabo Mines (Figures 3(a), 4(a), 5(a)) a strong earth tremor was felt at mid-morning (12 hours) on the 18th day (October) in the barracks. And in the neighboring town of Santa María de Puerto Príncipe (now Camagüey, [Figures 3(a), 5(a)]), the Garrison officer in command assured him that three strong earth tremors had been felt on the 18th and 19th at dinner time and at night... (The authors can confirm the occurrence on 18 October of an earthquake and of some aftershocks. In addition, information on perceptibility was gathered in Sancti Spiritus and Camagüey but any subterranean noise was perceptible [Figure 5(a)]).

(Document 3.-) CUBA 2027 [-AI denomination-]
San Salvador de Bayamo, 20 December 1551
His Excellency, Don Gonzalo Pérez de Ángulo
General Governor of Cuba

... I can report with pride of the Crown's loyal troops, who have undertaken the repair of the coastal posts... [Cabo Cruz, Niquero and Manzanillo]

(Document 4.-) CUBA 2070 [-AI denomination-]
San Salvador de Bayamo, 14 February 1552
His Excellency, Don Gonzalo Pérez de Ángulo
General Governor of Cuba

...the town's barracks have been rebuilt with timber, and one part serves as a jail. The troops are in good humor, and the terror is fading...

4.3. Earthquake Parameters and Intensity Values Identify the Headings

Using these data (Documents 1-4) the authors have established that the town of San Salvador of Bayamo was located on the present site of Bayamo and not at Yara (Figures 3(a), 4(a), 5(a)) and since the foundation of the town in 1513, earthquakes had never previously been reported. In addition, it can be stated that: 1) the exact date of the occurrence of this earthquake was the 18 October 1551; 2) the approximate time of the seismic event was around midday (11-12 hours); 3) there were at least two foreshocks, on the 16 and 17 October; 4) there were three aftershocks on the 18 October; 5) subterranean noises originating from the south-southwest, Cabo Cruz, were heard up to Bayamo city; 6) there were only seven persons injured, but no deaths; 7) there was panic among the population of Bayamo and alarm and nervousness

among the beasts of burden in everywhere; 8) the army post at Cabo Cruz was destroyed and the two heavy cannons overturned, severe subterranean noises [I = 9 degrees, MSK]; 9) the greatest damage to the ground (cracks and large block rocks) was in the surrounding area of the Sierra Maestra Range (La Merced) and soldiers were shaken in their saddles and two fell to the ground together with the saddles [I = 9-8 degrees, MSK]; 10) other two army posts in Niquero and Manzanillo were heavy damaged and all cannons overturned [I = 9-8 degrees, MSK]; 11) the church in Bayamo (built of solid limestone blocks) was totally destroyed, along with the residential neighborhood, the hospital, the jail, the storehouse, and the dock [I = 8 degrees, MSK]; 12) the town at Cauto Embarcadero and four ships were totally destroyed (liquefaction) [I = 8 degrees, MSK]; 13) 21 houses were destroyed and 3 were severely damaged in Bayamo [I = 8 degrees, MSK]; 14) the farms (outside of Bayamo on the southern and northern banks of the Cauto River, but near to the town) were destroyed [I = 8-7 degrees, MSK]; 15) over 20 robust houses (heavy woods) were destroyed in Yara (probably due to liquefaction) [I = 8-7 degrees, MSK]; 16) there were several houses destroyed in Jiguaní [I = 6 degrees, MSK]; 17) Puerto Príncipe village (Camagüey) was very strong shacked [I = 5 degrees, MSK]; 18) in Sancti Spiritus the earthquake was perceptible [I = 3 degrees, MSK].

We must comment that the intensity values of 8 and 9-8 degrees (MSK scale) in Bayamo, Cauto Embarcadero, and Niquero (and it can be assumed also in the King's Storehouse) is explained by the liquefaction phenomena and site effects. That means there are unconsolidated soils in a large fluvial basin (Cauto-Nipe). This is not the case of Cabo Cruz area.

Using these references, it is possible to construct an isoseismal scheme (Figure 6(a)), and to estimate a perceptibility area of 40,000 km². Then taking the area of greatest value as the central point and as the starting point for a line extending offshore to the south, the approximate epicentral location can be estimated as 19.6 N -77.8 W, which is situated on the knot of faults previously mentioned (Figure 2). In addition, this location has a cluster of low magnitude earthquakes with a predominant depth of 15 km (Figures 1(e), 1(f)) [1,14]. But there were also strong earthquakes in the surrounding area in October 1624 and on the 03.08.1926 [12]; more recently, other five strong earthquakes have been registered [19.02.1976 (Pilón, M = 5.7), 12.02.1989 (M = 5.1), 26.08.1990 (M = 5.1), 25.05.1992 (M = 6.9), and 04.02.2007 (M = 6.2), h~15 km] [6]. These earthquakes, except the one in Pilón (Figure 6(b)), are delimited by crossing active faults (Oriente and Cauto-Nipe) in the marine area. This is to the NE of the Cabo Cruz basin (in the marine area).

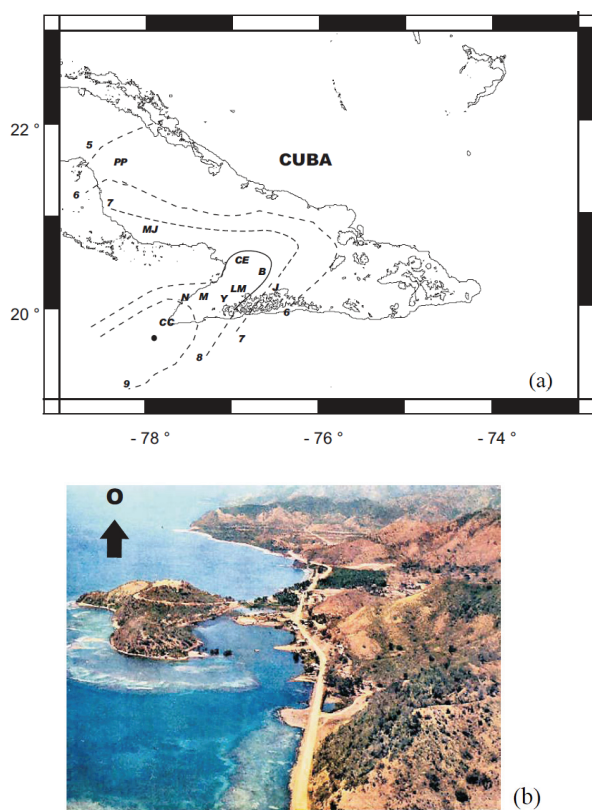


Figure 6. a) Epicentre and isoseismals scheme of the 18 October 1551. (B= Bayamo [I = 8], CC= Cabo Cruz [I = 9], CE = Cauto Embarcadero [I = 9-8], J = Jiguani [I = 6], LM = Las Mercedes [I = 9-8], M= Manzanillo [I = 8-7], MJ = Jobabo Mines [I = 7], N= Niquero [I = 8], PP = Puerto Príncipe = Camagüey [I = 5], Y = Yara [I = 8-7]; Intensity values [MSK scale] = 6); b) Photo of Pílon area from the eastern side of the Sierra Maestra Range.

The maximum intensity value of 1551 earthquake was found in Cabo Cruz, falling off 9-6 degrees (MSK scale) mainly toward the NE (Bayamo). That strike coincides with the direction of the Cauto-Nipe fault [45]. Meanwhile, a study of the latest strong earthquakes which have occurred in the same region (for example, on the 25 May 1992, in Cabo Cruz [46]) shows that the intensity, although decreasing towards the NE (Bayamo), did not exceed 7-5 degrees (MSK scale) [1,47]. Furthermore, the seism of 1992 was noticeable in Sancti Spíritus, just as it was in 1551 [46]. Therefore, we consider the focal region to be in Cabo Cruz area.

The epicenter of the 1551 earthquake has been proposed previously by other authors: 1) Morales y Pedroso [48]; 2) Álvarez *et al.* [11]; 3) Chuy [47]; and 4) Álvarez *et al.* [10]. The locations they identified differ from our proposal and this difference will be discussed. In the first place, these four works have been based exclusively on the seismic event reported by Poey [7-9]. Such data did not include information concerning the month, the day,

or the time, of the event, or information on the places where perceptibility was reported. It was simply known that a church in Bayamo had been affected. For this reason, in Cotilla and Udías [5] considered that these identifications were inadequate for being used in seismic hazard situation.

Morales y Pedroso [48] presented an interesting hypothesis of the occurrence of strong earthquakes in Southeastern Cuba. However, we do not share their view, and argue that the 1551 earthquake data fails to support it. For the above author, the epicenter was in the southern marine area of the Sierra Maestra Range, but on the meridian that passes through Bayamo, almost equidistant between Santiago de Cuba and Cabo Cruz. This epicenter location is approximately the same as that for the earthquake of 16 February 1976 in Pílon [12]; however, this last event only produced intensities of 5 degrees (MSK scale) in Bayamo. The other works are more recent. Álvarez *et al.* [11] presented the following data for the earthquake of 1551: 20.40 N-76.60 W, $h = 15$ km, $M = 5.8$, $I_{max} = 8$ degrees (MSK scale). Álvarez *et al.* [11] reported different data for the seism: 19.75 N-75.32 W, $h = 30$ km, $M_s = 7.3$, $I_{max} = 8$ degrees (MSK scale). With respect to these works, that the following should be observed: 1) the data is not consistent; 2) there are no discussions about such changes. An ample discussion regarding similar problems can be found in Cotilla's work [1,14], among other issues. Thus, we also reject these hypotheses.

In order to estimate the magnitude, we started with the experience and results of Cotilla [14], whereby based on the maximum intensity of 9 degrees (MSK scale) at Cabo Cruz, using the Sponheuer [49] relation ($M_s = 0.66 I_0 + 1.7 \log h - 1.4$), while assuming a depth of 15 km [14], we obtain a value of 6.6. Álvarez *et al.* [12] and Cotilla [14] determined that the seismogenetic deep of the Oriente fault is of 15-20 km. Figures 1(e) and 1(f) show the main values of hypocentres. Another expression relating magnitude and intensity was used ($M_s = 1 + 2/3 I_0$ [See: Karnik [50]]). This relation gives a magnitude value of 7.0. Also, using Shebalins' relation [51] [$I_0 = bM - s \log h + c$; $I_0 - I_i = s \log (\Delta_c^2 + h^2)^{1/2}$] we obtained $M = 6.7$ and $h = 17$ km. This last value (h) is very similar to our estimation. Consequently, it is our belief that the 18 October 1551 earthquake reached a magnitude rank of 6.6-7.0, and most probably value was 6.6. The fact that there were no deaths and only seven wounded in this earthquake can be explained as being the result of two main factors: 1) foreshocks (alerting the population to the danger); 2) time of the event, at midday (11-12 hours), when the inhabitants were working in the fields.

Finally, we shall briefly refer to the aforementioned October 1624 earthquake in Bayamo. This earthquake

happened 73 years after the event of 1551 and 8 years after closing the Cauto River to the navigation as a consequence of the damages by a strong tropical hurricane. Regardless of the scarce amount of data contributed by Poey, it is possible to assert the following concerning the earthquake: 1) the important intensity value of the seismic event; 2) the repetition of large earthquakes in the Cauto zone; 3) Bayamo's cost-reducing decrease and in consequence the low interest of the authorities, once the migration had started toward Santiago de Cuba and La Habana, and the Governor Residence had changed to La Habana. Likewise, it can be assumed that: 1) the damages at the Cathedral of Bayamo were due to the combination of two adverse factors, soil type and soil conditions; 2) the earthquake focus was located in the same region at 1551.

5. Conclusions

Eastern Cuba suffered a strong earthquake at midday on the 18 October 1551. It has been possible to confirm this data based on a collection of unpublished documents and others in the Archivo General de Indias, thus improving knowledge on the seismicity of this territory. An analysis of historical sources has shown that documents need to be judged very critically, establishing which ones provide first hand information and which more generalized literary accounts are. In addition, awareness of the socioeconomic situation, demographic conditions, building characteristics, etc. is necessary in order to reach a correct damage assessment. Failure to take these considerations into account can lead to significant errors in intensity estimations with the consequent effect on seismic risk assessment.

From the foregoing it appears that the 1551 earthquake was of a greater magnitude than believed until now. Maximum damage was experienced along the Cauto-Nipe fault. There is conclusive field evidence to show that this earthquake was associated with surface faulting. As a result of the shocks, some areas surrounding Bayamo, as well as others at some distance away were intensely damaged. From the description of the effects of the earthquake, it is clear that liquefaction of the ground had a significant effect on damage and on the intensities assigned to the Bayamo area.

According to the information found in the documents, the damage caused by this earthquake may be summarized as follows (locality = Intensity, MSK scale): Cabo Cruz = 9, Sierra Maestra (Las Mercedes) = 9-8, Bayamo = 8, Cauto Embarcadero = 8, Niquero = 8, Yara = 8-7, Manzanillo = 8-7, Jobabo Mines = 7, Jiguaní = 6, Puerto Príncipe = 5, and Sancti Spiritus = 3. The earthquake reached a magnitude of 6.6 and the epicenter was situated at 19.6 N-77.8 W.

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