MONOGRAFÍA

ESTUDIOS DE SISMICIDAD Y SISMOTECTÓNICA DE CUBA Y EL CARIBE

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DEDICATORIA

La publicación está dedicada a honrar y recordar al especialista cubano en SismometríaManuel Alonso SERRANO HERRERA (1943-2016). Él en su quehacer constante y tenaz participó activamente, como un gran instrumentista, en el establecimiento y funcionamiento de la red de estaciones sísmicas de Cuba; así como también en la instalación y la explotación, eficiente, de estaciones temporales y en la formación de los actuales técnicos cubanos y de Nicaragua. Es de destacar su labor en la creación de redes locales con transmisión telemétrica en un momento en que serias limitaciones financieras hacían imposible su compra en el exterior. Sus amplios conocimientos en sismología hacían que aparte de su imprescindible responsabilidad por la observación, participara activamente en las investigaciones que en el campo de la sismología se desarrollaban en Cuba. En particular el primer autor, una vez más, manifiesta su sincero agradecimiento por la ayuda, desinteresada y muy valiosa, del Licenciado Serrano Herrera para la preparación en Percepción Remota y Sismotectónica, facilitando información sobre esas temáticas.

Quienes conocimos y trabajamos con Manuel siempre recordaremos su sonrisa, su calma y su disposición a ayudar. Seguidamente se presenta una relación de algunos resultados de este trabajador de la Ciencia.

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"…Es solo a través del trabajo y del esfuerzo doloroso, con una energía siniestra y un coraje resuelto, que avanzamos hacia cosas mejores…" (Theodore Roosevelt, Estados Unidos de Norteamérica, 1858-1919)

DESCRIPCIÓN

Esta monografía sismológica, con 118 páginas, recoge en cinco capítulos las características y los datos principales de la sismicidad histórica e instrumental de Cuba en el marco del Caribe, y su relación con estructuras sismogénicas. El volumen es un resumen de la actividad científica de los autores en el marco del **Proyecto Científico KUK-AHPAN RTI2018-094827-B-C21**.

La estructura del texto recoge en capítulos -a modo de artículos- con un conjunto de tablas y figuras, y una amplia bibliografía **(ver tabla resumen al final de esta parte)** que sustentan los argumentos de los autores y permiten al lector concretar las ideas fundamentales sobre el conocimiento científico en la Sismología de la región.

El primer capítulo -**Estudio Sismogénico de la Falla Surcubana**- está dedicado exclusivamente, y por vez primera, a la falla Surcubana. Ella es una estructura marina segmentada y sísmicamente activa, dentro de la placa Norteamericana, que limita la parte meridional del megabloque Cuba con 7 nudos de articulación. La comparativa entre las fallas Surcubana y Nortecubana -límite septentrional del megabloque- muestra entre otras cosas que: la primera tiene mayor deformación en su extensión longitudinal, la actividad sísmica es significativamente menor ($M_{máx}$=4,3), no tiene tsunamis locales, ni soluciones de mecanismos focales, y tampoco muertos ni heridos asociados. Además, se reafirma que: **1)** los mecanismos de generación de terremotos en Cuba son de dos tipos: -fallas y nudos de fallas-; **2)** es la Unidad Sismotectónica Suroriental de Cuba, vinculada con la falla activa Oriente, la de mayor actividad y peligro en Cuba.

En cuanto al segundo capítulo -**Comments on the Nortecubana Fault**- se tiene un análisis exhautivo sobre este límite septentrional del megabloque cubano. El trabajo es una continuación de otros resultados de los autores que reafirman la segmentación de esta estructura; así como su diferenciación por la actividad en 4 segmentos, siendo el Occidental, entre el Cabo de San Antonio y las inmediaciones de Matanzas-Las Villas, el más activo y con mayor deformación. También se distingue que este segmento es el de mayor actividad sísmica histórica; pero en la etapa instrumental resulta ser el segmento Central el más activo, y con la asociación demostrada de 2 tsunamis locales del siglo XX. En el segmento occidental se localizan dos regiones sísmicamente significativas: **1)** la deformación transversal de Cochinos-Hicacos; **2)** las zonas con actividad antrópica por extracción de petróleo. Están expuestos los datos sobre la no existencia de una relación geodinámica, contemporánea, de la falla Nortecubana con la falla Septentrional de Haití. Esta última tiene una capacidad sismogénica muy superior, incluso que la falla Oriente (la estructura más activa del megabloque cubano), y que constituye un límite de placas.

Los capítulos 3, 4 y 5 son la lógica continuación de las investigaciones realizadas, por el primer autor, en los Fondos bibliográficos y documentales del Archivo de Indias, y en Bibliotecas de España, Francia, Jamaica, México, Portugal, Puerto Rico, Reino Unido, y Républica Dominicana, durante varios años, con fondos de diferentes Proyectos Científicos de la Facultad de Ciencias Físicas de la Universidad Complutense de Madrid, sobre los fuertes terremotos ocurridos en Cuba en los años 1551, 1766, 1800, 1826, 1842 y 1852 (Cotilla, 2004; Cotilla y Córdoba, 2010; y Cotilla y Udías, 2000). Esa línea de trabajo de búsqueda de las fuentes de datos originales se diseñó y argumentó con dos Proyectos de Investigación de Álvarez *et al.* (1985) y Álvarez *et al.* (1990).

El tercer capítulo -**General Reflections on the Main Earthquakes in Cuba and Their Seismic Hazard**- contiene un análisis de los principales terremotos, históricos e instrumentales, de Cuba. En ese sentido se seleccionaron 23 terremotos y se asociaron con cuatro unidades sismotectónicas. Para cada uno de ellos se indica un conjunto de 22 características. Así, se reafirma que es Santiago de Cuba la ciudad con mayor peligro sísmico. Además, el conjunto se compara con los terremotos fuertes del Caribe Septentrional y se expone, por vez primera, la no excepcionalidad de la funesta acción del par terremoto-huracán. Hay un diagnóstico sobre los terremotos más fuertes en 19 ciudades cubanas. Son expuestos los datos y mapas que distorsionan la actividad y el peligro sísmico de la parte Occidental del País.

Los capítulos cuarto y quinto están dedicados a dos fuertes terremotos del año 1766 en Cuba y Venezuela. En el capítulo -**Cuba-Venezuela Earthquakes of 1766: Part I- General Historic Data Review and Treatment**- se dan elementos sobre las características socio – económicas de esos territorios españoles y sus afectaciones por los sismos, y sus condiciones tectónicas diferentes. Mientras que en el siguiente capítulo -**Cuba-Venezuela Earthquakes of 1766: Part II- Modeling the Macroseismic Field and Final Results**- se realiza, por primera vez, un estudio del campo macrosísmico de los dos eventos sísmicos con métodos estadísticos.

Al final de las exposiciones capitulares se da un conjunto de Comentarios Finales que reafirman lo expuesto. Mientras que en la siguiente tabla se muestran datos estadísticos básicos del contenido de los capítulos que caracterizan el volumen del trabajo.

	Elementos				
Capítulo	**Páginas**	**Figuras**	**Tablas**	**Referencias**	**Referencias de los autores**
1	17	6	8	97	28
2	16	6	6	92	23
3	25	8	15	125	51
4	28	7	19	198	16
5	19	7	23	68	19
Total	**105**	**34**	**71**	**680**	**138**

DESCRIPTION

This seismological monograph, with 118 pages, collects in five chapters the characteristics and main data of the historical and instrumental seismicity of Cuba in the Caribbean, and its relationship with seismogenic structures. The volume is a summary of the scientific activity of the authors within the framework of ***the Scientific Project KUK-AHPAN RTI2018-094827-B-C21****.*

The structure of the text includes each chapter - as an article - with a set of tables and figures, and an extensive bibliography (see summary table at the end of this part) that support the authors' arguments and allows the reader to specify the fundamental ideas on scientific knowledge about the Seismology of the region.

The first chapter ***-Seismogenic Study of the Surcubana Fault-*** *is dedicated exclusively, and for the first time, to the Surcubana fault. It is a segmented and seismically active marine structure, within the North American plate, which limits the southern part of the Cuba megablock with 7 joint knots. The comparison between the Surcubana and Nortecubana faults - the northern limit of the megablock - shows, among other things, that: the first has greater deformation in its longitudinal extension, the seismic activity is significantly lower (Mmax=4.3), it does not have local tsunamis, nor focal mechanism solutions, and no associated deaths or injuries. Furthermore, it is reaffirmed that:* ***1)*** *the earthquake generation mechanisms in Cuba are of two types: -faults and fault nodes-;* ***2)*** *is the Southeastern Seismotectonic Unit of Cuba, linked to the active Oriente fault, the most active and dangerous in Cuba.*

As for the second chapter ***- Comments on the Nortecubana Fault -*** *there is an exhaustive analysis of this northern limit of the Cuban megablock. The work is a continuation of other results of the authors that reaffirm the segmentation of this structure; as well as its differentiation by activity into 4 segments, the Western one, between Cabo de San Antonio and the surroundings of Matanzas-Las Villas, being the most active and with the greatest deformation. It is also distinguished that this segment is the one with the greatest historical seismic activity; but in the instrumental stage the Central segment turns out to be the most active, and with the demonstrated association of 2 local tsunamis of the 20th century. In the western segment, two seismically significant regions are located:* ***1)*** *the Cochinos-Hicacos transverse deformation;* ***2)*** *anthropogenic activity due to oil extraction. The data on the contemporary geodynamic non-relationship of the North Cuban fault with the North fault of Haiti are exposed. The latter has a much higher seismogenic capacity, even than the Oriente fault (the most active structure of the Cuban megablock), and which constitutes a plate boundary.*

Chapters 3, 4 and 5 are the logical continuation of the research carried out, by the first author, in the bibliographic and documentary collections of the Archivo de Indias, and in Libraries of Spain, France, Jamaica, Mexico, Portugal, Puerto Rico, United Kingdom Kingdom, and the Dominican Republic, for several years, with funds from different Scientific Projects of the Faculty of Physical Sciences of the Complutense University of Madrid, on the strong earthquakes that occurred in Cuba in the years 1551, 1766, 1800, 1826, 1842 and 1852 (Cotilla, 2004; Cotilla and Córdoba, 2010; and Cotilla and Udías, 2000). This line of work to search for original data sources was designed and argued with two Research Projects by Álvarez et al. (1985) and Álvarez et al. (1990).

The third chapter ***- General Reflections on the Main Earthquakes in Cuba and Their Seismic Hazard -*** *contains an analysis of the main earthquakes, historical and instrumental, in Cuba. In this sense, 23 earthquakes were selected and associated with four seismotectonic units. For each of them, a set of 22 characteristics is indicated. Thus, it is reaffirmed that Santiago de Cuba is the city with the greatest seismic danger. Furthermore, the set is compared with the strong earthquakes of the Northern Caribbean and exposes, for the first time, the non-exceptionality of the disastrous action of the earthquake-hurricane pair. There is a diagnosis of the strongest earthquakes in 19 Cuban cities. The data and maps that distort the seismic activity and danger of the Western part of the Country are exposed.*

The fourth and fifth chapters are dedicated to two strong earthquakes in 1766 in Cuba and Venezuela. In the chapter ***-Cuba-Venezuela Earthquakes of 1766: Part I- General Historic Data Review and Treatment-*** *elements are given about the socio-economic characteristics of these Spanish territories and their effects by earthquakes, and their different tectonic conditions. While in the next chapter* ***-Cuba-Venezuela Earthquakes of 1766: Part II- Modeling the***

Macroseismic Field and Final Results- *a study of the macroseismic field of the two seismic events is carried out, for the first time, with statistical methods.*

At the end of the chapter presentations, a set of Final Comments is given that reaffirm what has been stated. While the following table shows basic statistical data of the content of the chapters that characterize the volume of the work.

	Items				
Chapter	**Pages**	**Figures**	**Tables**	**References**	**Author referencees**
1	17	6	8	97	28
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"…los hombres se fortalecen al darse cuenta de que la mano que les ayuda está al final de su propio brazo…" (S.J. Phillips)

ÍNDICE

Nicolás COPÉRNICO (Polonia (1473-1543)): "Hay charlatanes, totalmente ignorantes de las matemáticas, que se atreven a condenar mi hipótesis sobre la autoridad de alguna parte de la Biblia retorcida para adaptarse a su propósito. No los valoro y desprecio su juicio infundado."

1- Estudio Sismogénico de la Falla Surcubana

1-Estudio Sismogénico de la Falla Surcubana
{*Seismogenic Study of the Surcubana Fault*}

RESUMEN: Ésta es la primera investigación dedicada exclusivamente a la falla Surcubana. Estructura marina de aproximadamente 1.100 km de longitud que es el límite meridional del megabloque Cuba con 7 nudos de articulación. La falla pertenece a la placa Norteamericana y la comparativa con su equivalente al norte, la falla Nortecubana, muestra algunas grandes diferencias. La falla Surcubana tiene mayor deformación en su extensión longitudinal, la actividad sísmica es significativamente menor ($M_{máx}$=4,3), no tiene tsunamis locales, ni soluciones de mecanismos focales, y tampoco muertos y heridos. La investigación considera que la falla es activa y segmentada con sismicidad de tipo interior de placa.

Palabras clave: falla activa, Caribe, Cuba, interior de placa.

Introducción

En Cuba se han desarrollado estudios sobre fallas activas desde los años 80. Ellos permitieron tener en estos momentos un mapa de estructuras activas con un nivel de fiabilidad muy aceptable. Este resultado ha sido favorecido, fundamentalmente, por la instalación y el mejoramiento de redes de estaciones sismológicas permanentes, tanto nacionales como internacionales.

Cuba es un archipiélago de las Antillas Mayores que ha sufrido históricamente los efectos de terremotos moderados y fuertes (**Figura 1**). No obstante, Haití, Jamaica, Puerto Rico y la República Dominicana han mostrado un nivel sísmico mucho mayor. En la figura se aprecia también la diversidad de estructuras continentales y oceánicas que rodean al archipiélago.

En el artículo, por primera vez, se analiza y discute en profundidad la existencia y actividad de la falla Surcubana [**SCF**]. Ésta es una extensa estructura marina del sur de Cuba. El trabajo es parte del Proyecto Científico KUK-AHPAN RTI2018-094827-B-C21.

1.1 Datos Fundamentales Sobre Neotectónica y Sismicidad

Los siguientes trabajos fueron usados para desarrollar la parte neotectónica [6, 8, 13, 14, 17-19, 22-27, 29. 31, 32, 35-39, 41, 42, 45, 47, 48, 49, 51-57, 60-63, 66, 70, 77, 79-82, 84, 86-89, 93, 96]. En resumen sabemos que: **1)** la placa Caribe se originó en el Pacifico; **2)** con su desplazamiento al este provoca deformaciones en sus bordes norte y sur, donde aparecen movimientos laterales; **3)** en este complejo proceso geodinámico se produce el cierre marítimo trasero por la interposición de la América Central; **4)** en la zona Pacífico-América Central tiene lugar una colisión con subducción (volcanes y terremotos) de la Placa Cocos bajo la del Caribe; **5)** Cuba es un megabloque ubicado en el borde sur de la placa Norteamericana que interactúa con la del Caribe (**Figura 1**); **6)** este megabloque recibe de forma diferencial la influencia directa de la interacción de las placas Caribe y Norteamericana; **7)** el megabloque está diferenciado en cuatro Unidades Sismotectónicas delimitadas por un conjunto de tres fallas principales: Oriente, Nortecubana y Surcubana;

8) se reconocen en Cuba un total de trece fallas activas (Tabla 1) siendo la Oriente la más activa; 9) hay también en ella 17 nudos; 10) su segmento Cabo Cruz-Baconao, donde Santiago de Cuba, es el más peligroso desde el punto de vista geológico; 11) las fallas Oriente y Nortecubana no tienen relación de continuidad con la falla Septentrional de La Española; 12) el segmento de Playa Panchita-Remedios y Caibarién (falla Nortecubana) es el único en Cuba donde se han generado tsunamis locales (dos) (Figura 2); 13) las fallas delimitadas están segmentadas; 14) en las tablas 1 y 2 aparecen otras características de las tres fallas principales de Cuba.

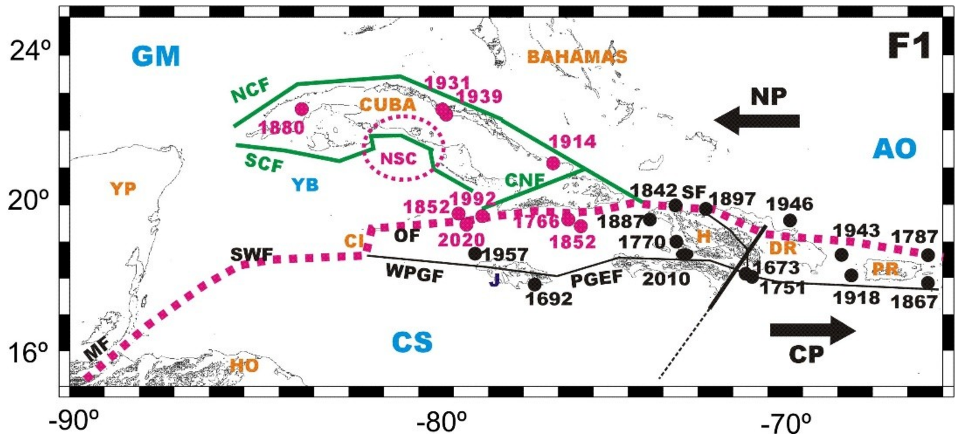


Figura 1. Localización de Cuba en el Caribe. Aparecen: 1) Países (CI=Islas Caimán, DR=República Dominicana, H=Haití, HO=Honduras, J=Jamaica, PR=Puerto Rico (en marrón)); 2) Epicentros: 2.1) círculos negros (año); 2.2) círculos rojos (año); 3) Fallas: 3.1) líneas en verde (CNF=Cauto-Nipe, NF=Nortecubana, OF=Oriente, SCF=Surcubana); 3.2) líneas en blanco (OF=Oriente, PGEF=Plantain Garden-Enriquillo, WPGF=Walton-Platain Garden); 3.3) línea roja discontinua (MF=Motagua, SF=Septentrional, SWF=Swan-Walton); 4) NSC=Nudo neotectónico de la Falla Surcubana y principal zona de deformación (discontinua y círculo rojo); 5) Placas (CP=Caribe, NP=Norteamericana); 6) Región (AO=Océano Atlántico, CS=Mar Caribe, GM=Golfo of México, YB=Cuenca de Yucatán, YP=Península de Yucatán (en marrón)).

Los datos de sismicidad se tomaron de las siguientes fuentes: 2, 3, 9, 10, 13-24, 27-33, 37-43, 50, 64, 65, y 92. A partir de ellos se sostiene que Cuba: 1) tiene dos tipos de sismicidad (interior (Norteamericana) y entre placas (Caribe-Norteamericana)); 2) la mayor actividad sísmica está en Cabo Cruz-Baconao (Figura 2, Tabla 3); 3) la magnitud máxima registrada y conocida es 7,7; 4) en la figura 3 están los terremotos más importantes del Caribe; 5) existen casos de sismicidad inducida por exploración-explotación de petróleo y gas en el norte de Pinar del Río-Varadero-Corralillo, asociados con la falla Nortecubana (Figura 3).

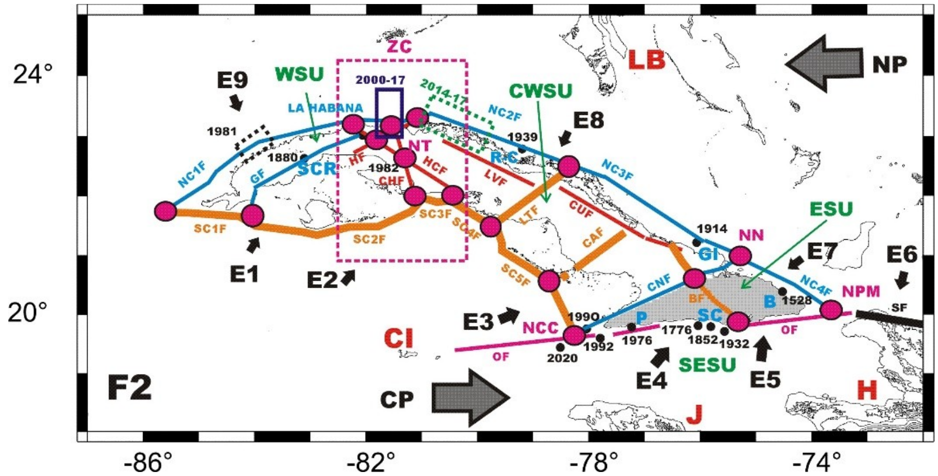


Figura 2. Resumen de la Sismotectónica de Cuba (Cotilla, [19]). Aparecen: 1) Áreas de sismicidad inducida: 1981, 2000 y 2014-2017 (rectángulos: línea discontinua negra, línea continua morada, línea discontinua verde); 2) Países (CI=Islas Caimán, H=Haití, J=Jamaica, LB=Las Bahamas); 3) Epicentros (círculos y años en negro); 4) Fallas: 4.1) líneas negras: SF=Septentrional; 4.2) 1ª Categoría (línea roja): FO=Oriente); 4.3) 2ª Categoría (línea y letra azul): CNF=Cauto-Nipe, GF=Guane. NCF=Nortecubana (segmentos con letras azules: FNC-1): 4.4) 3ª Categoría (líneas y letras en naranja): CF=Cochinos, HF=Hicacos, HCF=Habana-Cienfuegos, LF=Las Villas; 4.5) 4ª Categoría (líneas y letras en marrón): SCF=Surcubana (cuatro segmentos); 5) Localidades (letras azules; B=Baracoa, GI=Gibara, P=Pilón, R-C=Remedios-Caibarién, SC=Santiago de Cuba, SCR=San Cristóbal); 6) Nudos (círculos y letras rojas: NCC=Cabo Cruz, NN=Nipe, NPM=Punta de Maisí, NT=Torriente-Jagüey Grande); 7) Placas (CP=Caribe, NP=Norteamericana); 8) Dirección del movimiento de las placas (flechas gruesas grises); 9) Tensor $\sigma_{hmáx}$ (flechas gruesas negras con letras y números: E1-9); 10) Unidad Sismotectónica (letras verdes: WSU=Occidental, CWSU=Centro Occidental, ESU=Oriental, SESU=Suroriental); 11) ZC=Área de cambio estructural significativo (rectángulo discontinuo y círculo discontinuo en rojo).

Partiendo de la tabla 3 se puede asegurar que los terremotos en Cuba ocurren en fallas y nudos de fallas. Esto se propuso, por primera vez, en ocasión del terremoto perceptible del 16.12.1982 en Torriente-Jagüey Grande (Figura 2). El terremoto (M=5,0/I=7 (MSK)) se localizó en la intersección de las fallas Cochinos y Habana-Cienfuegos [35] y su explicación neotectónica se basó en las ideas de Zhidkov [97].

Cuba tiene un nivel bajo de peligrosidad sísmica en comparación con el de las islas vecinas (Jamaica, La Española (Haití y República Dominicana), y Puerto Rico) (Figura 3). No obstante, la Unidad Sismotectónica Suroriental es la más peligrosa en Cuba (~70 muertos y ~1.300 heridos). En el resto de Cuba se han reportado sólo 3 muertos y 35 heridos. La zona sísmogenética más activa de ella es la falla Oriente, donde se han generado ~13 terremotos fuertes (M≥6). La NCF es también activa, pero los valores de actividad son menores que en la OF. La figura 4 presenta la sismicidad (1502-2018) determinada por el CENAIS. De ella es factible interpretar la relación de los terremotos con la SCF. Además, se elaboraron tres tablas (4-6) para precisar esta relación. Con respecto a la tabla 4 se debe señalar que las redes internacionales sólo han registrado tres eventos, y el más débil tiene M=3,8. Los datos indican que la actividad es de nivel bajo, así como la frecuencia de ocurrencia. No obstante, las tablas 5 y 6 muestran que hay 81 reportes de terremotos para el período 1492-1999. También se confirman las observaciones de Cotilla [13] sobre lo contradictorio de las determinaciones de epicentros y las grandes diferencias en el tiempo sobre la SCF al observar (**Tablas 4-6**). Aquí consideramos que las diferencias se deben a dos factores: **1)** poco interés del Servicio Sismológico Nacional cubano (Parte III, **tabla 5**); **2)** bajo nivel de actividad sísmica (Partes I-III, **tabla5**).

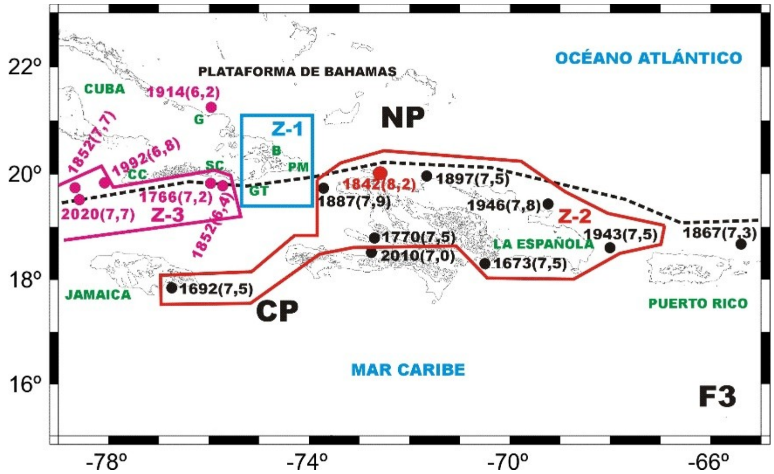


Figura 3. Mayores terremotos del Norte del Caribe. Aparecen: **1)** Epicentros: **1.1)** Jamaica-La Española-Puerto Rico (círculo negro [año (M)]); **1.2)** Cuba (círculo rojo [año (M)]); **1.3)** la mayor M (círculo y año en naranja); **2)** Localidades (B=Baracoa, CC=Cabo Cruz, G=Gibara, GT=Guantánamo, PM=Punta de Maisí, SC=Santiago de Cuba); **3)** Límite de placas (línea discontinua negra); **4)** Placas (CP=Caribe, NP=Norteamericana); **5)** zona de: **5.1)** baja sismicidad (rectángulo (Z-1, en azul)); **5.2)** M≥7,5 (rectángulo (Z-2, en naranja)); **5.3)** Cabo Cruz con M [6,4-7,7] (rectángulo (Z-3, en rojo)).

Tabla 1. Principales fallas de Cuba.

Nº	Falla/ Siglas	$M_{máx}$/ $h_{máx}$ (km)/ Categoría/ Segmentos	L (km)/ Ancho (km)/ Tipo	Terremotos
1	Baconao/ BF	5,1/ 10/ 4/ 2	240/ 10/ C	SI
2	Cubitas/ CF	4,1/ 10/ 3/ 2	190/ 20/ C	SI
3	Camagüey/ CAF	3,0/ 10/ 4/ 1	180/ 30/ C	SI
4	Cauto-Nipe/ CNF	6,6/ 10/ 2/ 2	150/ 10/ C	SI
5	Cochinos/ CHF	5,0/ 20/ 3/ 2	200/ 30/ C	SI
6	Guane/ GF	5,9/ 30/ 2/ 3	280/ 10/ C	SI
7	Habana-Cienfuegos/HCF	5,0/ 10/ 3/ 4	310/ 10/ C	SI
8	Hicacos/ HF	3,0/ 20/ 3/ 3	230/ 20/ C	SI
9	La Trocha/ LTF	4,6/ 10/ 4/ 1	200/ 30/ C	SI
10	Las Villas/ LVF	4,5/ 10/ 3/ 2	250/ 30/ C	SI
11	Nortecubana/ NCF	6,2/ 35/ 2/ 5	>1.000/ 20/ T	SI
12	Oriente/ OF	7,7/ 20/ 1/ 3	>1.000/ 200/ T	SI
13	Surcubana/ SCF	4,1/ 10/ 4/ 5	>1.000/ 10/ C	SI

Nota: C=cortical, T=trans-cortical.

Tabla 2. Características de algunas fallas de Cuba.

Nº	Siglas	Ks	Nudos	Localizado en zona	Límite de	Tsunami local	Espesor de la capa sismoactiva (km)	Tipo de sismicidad	Muertos/ Heridos
11	NCF	0,82	6	Marina	Megabloque	2	12	Interior	-/ 2
12	OF	0,97	3	Marina	Placas	-	30	Interior	80/ 700
13	SC	0,67	7	Marina	Megabloque	-	10	Interior	-/ -

Nota: Ks=Coeficiente de Sinuosidad.

Tabla 3. **Terremotos más importantes de Cuba.**

Nº	Fecha	$M_{máx}/I_{máx}$ (MSK-1978)	Muertos/ Heridos/ Pérdidas Económicas (10^6 $)	Localidad/ Unidad Sismotectónica	Asociada con
1	1551.10.18	6,6/ 8	-/ 7/ 0,01	Cabo Cruz/ SESU	Nudo CC
2	1766.06.11	7,2/ 9	40/ 700/ 10	Santiago de Cuba/ SESU	OF
3	1842.07.07	6,8/ 8	2/ 10/ 0,5	Santiago de Cuba/ SESU	Nudo CC
4	1852.08.20	6,4/ 9	2/ 200/ 2	Santiago de Cuba/ SESU	OF
5	1880.01.23	6,2/ 8	3/ 20/ 1	San Cristóbal/ WSU	GF
6	1914.02.28	6,2/ 8	-/ 2/ 0,01	Gibara/ CWSU	NCF
7	1932.02.03	6,75/ 8	25/ 350/ 20	Santiago de Cuba/ SESU	OF
8	1992.05.25	6,8/ 7	-/ 40/ -	Cabo Cruz/ SESU	Nudo CC
9	2020.01.28	7,7/ 3	-/ -/ -	Cabo Cruz/ SESU	Nudo CC

Notas: SESU=Unidad Sismotectónica Suroriental, WSU=Unidad Sismotectónica Occidental, CWSU=Unidad Sismotectónica Centro Occidental, CC=Cabo Cruz, GF=Falla Guane, NCF=Falla Nortecubana, OF=Falla.

Tabla 4. **Terremotos determinados en los alrededores de la Falla Surcubana (USGS).**

Nº	Fecha/ Tiempo	Coordenadas (N W)	M/ h(km)
1	8.08.1996/ 22:25:11	22,110 80,184	3,8/ 10
2	22.10.2005/12:13:15	21,843 80,918	4,1/ 10
3	21.01.2015/ 04:07:13	22,127 81,422	4,1/ 16,1

En la **figura 3** se presenta la diferenciación de los terremotos por magnitud en la región norte. Al este de la Punta de Maisí las magnitudes son mayores, y resalta el valor de M=8,2 (en la parte norte de La Española). Se identificaron tres zonas de actividad sísmica: **1)** la zona de sismicidad atípica del contacto de las placas Caribe-Norteamericana de acuerdo a Cotilla y Córdoba [29], con un nivel muy bajo (Z-1); **2)** el área del mayor potencial sísmico en el norte del Caribe, previamente indicado y discutido por Cotilla *et al*. [34], (Z-2); **3)** el segmento más activo de la falla Oriente [36, 38], (Z-3).

Tabla 5. **Terremotos en la falla Surcubana (Álvarez *et al.*, [3]).**

Nº	Fecha	Coordenadas (N W)	M /h (km)	Nº	Fecha	Coordenadas (N W)	M /h (km)
	PARTE-I						
1	5.01.1824	21,80 79,98	4,3/ 10	8	1936	21,84 78,77	3,0/ 10
2	28.04.1861	21,80 79,98	3,1/ 10	9	23.07.1943	21,92 80,02	3,2/ 10
3	1871	21,87 82,78	4,2/ 10	10	28.	21,80 79,98	3,0/ 10
4	03.1872	21,77 83,54	3,5/ 10	11	27.10.1945	21,93 79,45	2,9/ 10
	PARTE-II			12	22.12.1951	21,94 78,43	3,3/ 10
Nº	**Fecha**	**Coordenadas (N W)**	**M /h (km)**	13	1955	21,92 80,13	3,0/ 10
5	24.01.1909	21,80 79,98	4,3/ 10	14	1958	21,97 78,86	2,9/ 10
6	1925	21,84 78,77	3,0/ 15	15	07.1966	21,25 78,16	2,8/ 10
7	1932	21,87 79,84	3,5/ 10	16	1.07.	21.25 78,16	2,8/ 10
	PARTE-III						
Nº	**Fecha**	**Coordenadas**	**M /h (km)**	**Nº**	**Fecha**	**Coordenadas**	**M /h (km)**

		(N W)				(N W)	
17	26.07.1971	21,90 79,10	3,3/ 10	50	28.07.1974	21,96 78,39	-/ -
18	27.03.1974	21,56 78,06	3,2/ -	51	31.	21,70 77,35	-/ -
19	8.04.	21,80 78,05	3,8/ 5	52	2.08.	21,90 78,10	-/ -
20	10.	21,85 78,12	2,8/ 10	53	13.	21,85 78,05	-/ -
21	13.	21,85 78,12	2,15/ 10	54	14.	21,95 78,15	-/ -
22	15.	21,85 78,12	2,8/ 10	55	28.	21,73 78,30	4,0/ 18
23	30.	21,75 78,15	3,4/ 20	56	28.	21,90 78,15	-/ -
24	10.05.	21,85 78,12	2,5/ 10	57	28.	21,90 78,15	-/ -
25	16.	21,88 78,72	3,4/ -	58	28.	21,80 78,10	-/ -
26	16.	21,14 79,26	-/ -	59	7.09.	21,90 78,10	-/ -
27	17.	21,17 79,25	3,5/ -	60	7.	21,85 79,95	-/ -
28	19.	21,95 78,20	-/ -	61	7.	21,80 79,95	-/ -
29	21.	21,80 78,20	-/ -	62	9.	21,90 78,10	-/ -
30	23.	21,90 78,20	-/ -	63	9.	21,90 78,10	-/ -
31	23.	19,74 78,40	-/ -	64	9.	21,68 79,54	-/ -
32	24.	21,92 78,12	-/ -	65	9.	21,80 79,53	-/ -
33	24.	21,85 78,27	-/ -	66	9.	21,75 78,50	-/ -
34	15.06.	21,85 78,10	2,15/ 10	67	11.	21,90 78,50	-/ -
35	15.	21,85 78,10	-/ -	68	11.	21,95 78,15	-/ -
36	19.	21,60 79,60	-/ -	69	12.	21,90 78,10	-/ -
37	21.	21,57 79,63	-/ -	70	12.	21,90 78,10	-/ -
38	21.	21,85 79,25	-/ -	71	13.	21,90 78,15	-/ -
39	27.	21,70 79,20	2,8/ 10	72	15.	21,75 78,15	-/ -
40	27.	21,85 79,30	-/ -	73	27.	21,95 78,15	-/ -
41	29.	21,63 79,78	-/ -	75	7.10.	21,90 78,15	-/ -
42	29.	21,57 79,63	-/ -	75	9.	21,70 79,50	-/ -
43	29.	21,65 79,70	-/ -	76	12.	21,85 78,12	2,1/ -
44	30.	21,62 79,74	-/ -	77	5.11.	21,97 78,20	3,7/ 10
45	30.	21,65 79,65	-/ -	78	24.10.1976	21,93 79,98	4,1/ 10/
46	2.07.	21,57 79,55	-/ -	79	11.02.1977	21,85 78,2	3,0/ 5
47	2.	21,55 79,50	-/ -	80	12.01.1985	21,83 80,29	2,8/ 15
48	22.	21,90 78,10	-/ -	81	12.01.1986	21,90 80,29	2,9/ 15
49	25.	21,80 78,65	-/ -				

Tabla 6. Resumen de la tabla 5.

Periodo/ $M_{máx}$/ $h_{máx}$ (km)			
1502-1872/ 4,3/ 10	1909-1966/ 4,3/ 15	1971-1986/ 4,1/ 20	Total/ 4,3/ 20
4 eventos	12 eventos	65 eventos	81 eventos
Años (1971, 1974, 1976, 1977, 1985, 1986)=6 eventos		Año (1974)=59 eventos	

Los autores han analizado lo siguiente: 1) los agrupamientos de epicentros en el Caribe norte [13, 33, 39]; 2) la cinemática de la SCF en su relación con los sistemas de fallas Cochinos, Guane, Habana-Cienfuegos, e Hicacos en los alrededores de la Bahía de Cienfuegos y el Bloque de Guamuhaya [19-21, 24]; 3) la ausencia de series de terremotos y determinaciones de mecanismos focales en la SCF [14, 31, 38]; 4) la segmentación de la SCF y la caracterización de su segmento más activo SC2, Bahía de Cochinos-Bahía de Cienfuegos-Bloque de Guamuhaya [36, 38].

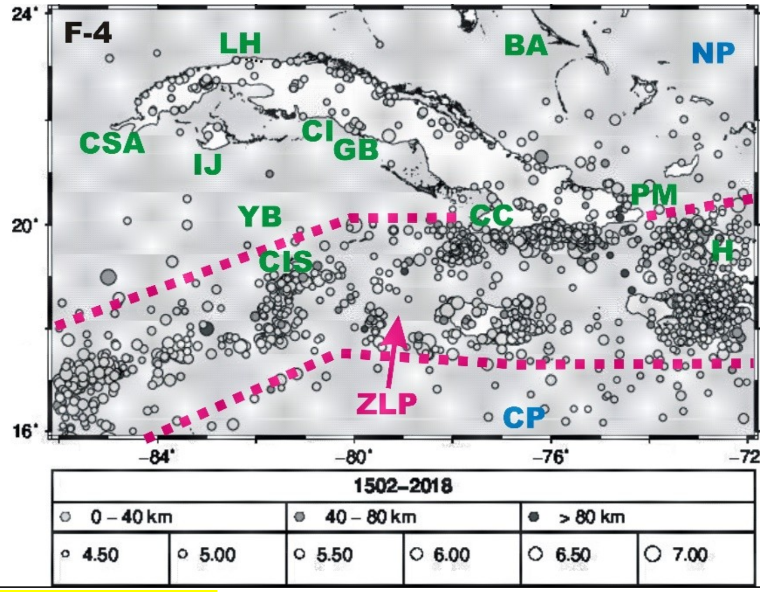


Figura 4. Sismicidad de Cuba (CENAIS). Aparecen: 1) Países (en color verde (BA=Bahamas, H=Haití, CIS=Islas Caimán)); 2) Límite de Zona Límite de Placa (línea discontinua roja); 3) Epicentros (círculos, ver la leyenda); 4) Localidades (en verde (CC=Cabo Cruz, CI=Cienfuegos, CSA=Cabo de San Antonio, GB=Guamuhaya Block, IJ=Isla de la Juventud, LH=La Habana, PM=Punta de Maisí, YB=Cuenca de Yucatán)); 5) Placas (en color azul (CP=Caribe, NP=Norteamericana)); 6) PBZ=Zona Límite de Placas (en rojo).

1.2 Algunas Características de las Fallas Activas

Los científicos de especializados en Ciencias de la Tierra identifican y describen estructuras geológicas activas así como sus grados de actividad [5-9, 45, 46, 58, 60, 64, 69, 71, 76, 78, 83, 89-92, 95, 97]. Se sabe que en el caso de las rupturas corticales o fracturas (fallas): 1) las más importantes están asociadas con las fronteras de las placas, 2) las menos importantes con el interior de las placas [6, 9, 17, 20, 21, 31, 38, 54, 83]. En la actualidad está demostrado, que a pesar del gran conocimiento acumulado, no hay una definición simple de fractura activa. Una estructura de ese tipo requiere información acerca de: dimensiones, localización, terremotos (históricos y registrados) [13, 53, 83]. Con ese objetivo se usan diferentes métodos: geológico, geomorfológico, geodésico y sismológico. Ello involucra a otros conceptos como: 1) índices (geológico y geomorfológico) para la delimitación de la falla; 2) tipo de falla (activa, inactiva, potencialmente activa); 3) segmento de falla; 4) categoría de falla; 5) período de recurrencia.

En el proyecto de investigación de Álvarez *et al.* [2] se decidió seguir las recomendaciones del Profesor Dr. Peter Bankwitz de aplicar la teledetección para el estudio de los alineamientos principales y sus intersecciones con fines de estimación de la peligrosidad sísmica [35]. Los especialistas J.F. Albear, K.N. Krestnikov, L. Lyskov, G.V. Makarov, G. Millán, E. Nagy, J. Pilarsky, V.S. Shein, V.G. Trifonov, y E.C. González-Clemente asesoraron al equipo de investigación para aplicar métodos geomorfológicos de tipo cuantitativo para validar los resultados de la teledetección [13, 35].

Por otra parte, sabemos que el Académico Profesor Vladimir Vladimirovich Belousov [7] consideró que las grandes fallas están localizadas en las zonas de interacción de grandes bloques y su articulación con estructuras de su interior. Posteriormente, Bankwitz *et al*. [6] demostraron que para Europa las grandes zonas de debilidad tectónica tienen diferente comportamiento y expresión en el relieve ante la ocurrencia de terremotos. Cotilla *et al*. [27] y Cotilla y Franzke [30]. Además, encontraron y explicaron esas características en el megabloque cubano y elaboraron un mapa sismotectónico.

1.3 La Falla Surcubana

La SCF se describe de forma diferente en los siguientes trabajos: 2, 8, 13-17, 19-27, 30,-33, 36-39, 45-47, 49, 52, 55-57, 66, 72-75. 84-86, y 93. A partir de ellos, y considerando los comentarios realizados al final de la sección anterior, y el análisis de la sismicidad realizado antes, se confeccionaron dos **tablas (7 y 8)** con el objetivo de fundamentar la existencia y la actividad contemporánea de la SCF.

Por otra parte, de los resultados de Rosencratz [80], se conoce que: **1)** la Cuenca de Yucatán tiene tres bloques: **1.1)** la plataforma de Yucatán; **1.2)** el bloque central que es el mayor y más complejo; **1.3)** el bloque este que se relaciona con la estructura de las Islas Caimán y la falla La Trocha; **2)** su figura 3 muestra fuertes inflexiones de dirección N-S hacia el SE de la Isla de la Juventud y desde las Islas Caimán; **3)** a partir de su figura 4 se pueden ver: **3.1)** la diferenciación en bloques y la relación de continuidad SW-NE con la falla La Trocha hacia el este del Bloque Guamuhaya; **3.2)** una banda gravimétrica de anomalías de Bouguer alargada entre la Bahía de Cochinos y la falla Camagüey en dirección a Cabo Cruz, la cual es una depresión, a modo de bloque deprimido, anormal. Interpretamos esos datos como la confirmación de la SCF en el límite de la Cuenca de Yucatán y el megabloque cubano.

La experiencia de los autores en los estudios de la sismotectónica de Cuba, apunta a que es necesario valorar tres trabajos para comprender la diferenciación sismogénica del megabloque. Dichos trabajos son: Cotilla *et al*. [37, 38], y González *et al*. [47]. Con el Mapa Neotectónico de Cuba [37] se determina que: **1)** las estructuras del megabloque corresponden a las direcciones fundamentales de los segmentos de las fallas Nortecubana y Surcubana; **2)** las dimensiones y figura de las neo estructuras se diferencian en el segmento entre La Habana y la falla La Trocha. Hay dos tipos: **2.1)** rectangular paralelo a la costa norte (entre la localidad de Corralillo y la falla La Trocha); **2.2)** aproximadamente cuadrangular entre las fallas Cochinos y La Trocha, donde se encuentra el Bloque Guamuhaya; **3)** en la vecindad de la falla Cochinos existe una deformación estructural significativa; **4)** hacia el este del macizo metamórfico de Guamuhaya (o Bloque Guamuhaya) se localiza una estructura plana y no deformada.

Tabla 7. **Referencias que reconocen a la falla Surcubana.**

Nº	Referencia	Figura	Tabla	Comentarios
1	Belousov (1980), Krestnikov *et al*. (1983)	1	-	Figura de las zonas sismogénicas en Cuba Central para la Central Electronuclear de Cienfuegos. Se incluye como zona sísmica
2	Chuy *et al*. (1984)	-	-	Transcortical/ No Activa- Potencialmente Activa- Activa/ Terremotos en Santa Cruz del Sur 23.11.1949/ L>1.000 km/ Transcortical/ Movimientos Neotectónicos Fuertes-Fuerte y Moderados movimientos/ Categoría III/ Trazo seguro en Isla de la Juventud-La Trocha/ Categoría IIB y M≤6,5 en La Trocha-Cabo Cruz y Trazo Supuesto en Cabo de San Antonio-Isla de la Juventud
3	Cotilla (1993)	2	-	-
4	Cotilla (1998A)	3	-	-
5	Cotilla (1998B)	4, 9	4	-
6	Cotilla (2011)	3, 7, 9	-	Hay 7 nudos: NC-SC, G-SC, CH-SC, HCI-SC, LTR-SC, CA-SC, CN-CC-SC/ Se considera falla activa como CA, CH, CN, G, HCI, LTR, NC, OR
7	Cotilla (2014)	3, 4	6	-
8	Cotilla (2017)	3B	1, 3	-
9	Cotilla y Álvarez (1998)	27	-	Hay 6 nudos: NC-SC/ C-SC/ CH-SC/ ALHC-SC/ LTRO-SC/ CC-CN-SC
10	Cotilla y Álvarez (1998A)	3, 4, 5	-	-
11	Cotilla y Córdoba (2007)	1, 4, 5	-	-
12	Cotilla y Franzke (1999)	1	-	-
13	Cotilla *et al*. (1997A)	2	-	-
14	Cotilla *et al*. (1994)	-	6 (Partes A y B)	Trazo complete reconocido por 4 trabajos y Parcialmente por 7/ Límite del Megabloque/ Transcortical/ L>1.000/ Ancho=5-50 km/ M=6,0-5,5/ 6,5-6,0/ 7-6,5
15	Cotilla *et al*. (1991)	-	-	Transcortical, No Activa- Potencialmente Activa-Active/ Terremoto en Santa Cruz del Sur 23.11.1949
16	Cotilla *et al*. (1991A)	-	11	L>1.000 km/ Transcortical/ Movimientos Neotectónicos fuertes: Fuertes-Moderados/ Categoría II y III/ Segura/ Segmento: **1)** Isla de la Juventud-LaTrocha/ Categoría IIB/ M≤6,5; **2)** La Trocha-Cabo Cruz y Cabo de San Antonio-Isla de la Juventud=Supuesta
17	Cotilla *et al*. (1996)	1, 2	1	-
18	González *et al*. (1994)	-	-	Dividida en 3 segmentos (M_{max}6,0/ $h_{máx}$=15): Occidental, Central, Oriental/ Gradv=3,3/ gradΔg=1-10/ Longitud (km)=350/ Profundidad de la capa sismogeneradora=15 km/ Categoría III/ $M_{máx}$ por dimensión=6-7,1 (6,5)/ $M_{áax}$ por (gradV)=6,3/ $M_{máx}$ por (gradΔg)=6,0-6,7/ $M_{máx}$ propuesta=6,0/ $M_{máx}$ observada=4,6
19	Hernández *et al.* (1988), Ionin *et al.* (1977), Iturralde-Vinent (1984)	-	-	Se reconoce el trazo completo

20	Orbera and Marquetti (1984)	6	-	Terremotos con ML>3
21	Orbera *et al.* ()1987, 1990)	-	-	Categoría V/ M?-6,0/ Reconocida por el 50% de los métodos aplicados/ Espesor de la capa sismogenética=15 km/ Longitud=350 km/ Profundidad de los terremotos=10-20 km

Notas: 1) Nudos: NC-SC=Nortecubana-Surcubana, G-SC=Guane-Surcubana, CH-SC=Cochinos-Surcubana, HCI-SC=Habana-Cienfuegos-Surcubana, LTR-SC=La Trocha-Surcubana, CA-SC=Camagüey-Surcubana, CN-CC-SC=Cauto-Nipe-Oriente-Surcubana; 2) Fallas: CA=Camagüey, CH=Cochinos, CN=Cauto-Nipe, G=Guane, HCI=Habana-Cienfuegos, LTR=La Trocha, NC=Nortecubana, OR=Oriente.

Tabla 8. Fallas de Cuba y principales terremotos de acuerdo a varias fuentes (Cotilla y Córdoba [26]).

Nº	Falla/ Tipo	$M_{máx}$	Segmento/ Nudo	Terremoto perceptible (Intensidad-MSK)/ Total
1	Cauto-Nipe/ T	6,6	2/ 2	1551, 1624, 1856, 1858, 1926, 1987 (2 eventos) 1990, 1992, 1995/ 10
2	Cochinos/ C	5,0	3/ 3	1903, 1927, 1928, 1964, 1974, 1982/ 6
3	La Trocha/ C	4,6	4/ 1	1943, 1970, 1971/ 3
4	Surcubana/ T	4,1	4/ 7	5.01.1824 (VI), 28.04.1846 (IV), 10.09.1846, 18.04.1847, 30.08.1849, 24.01.1909, 27.05.1914, 30.07.1943, 28.04.1946 (III), 19.06.1949, 23.11.1949 (IV), 02.1955 (III), 11.11.1970 (IV), 23.10.1976/ 14

Nota: C=cortical, T=transcortical.

En el Mapa Morfoestructural de Cuba [47], se ve que: 1) la divisoria principal de primer orden de la red fluvial está mucho más cerca de la línea costera norte y es aproximadamente paralela a ella; 2) hay cinco conjuntos de fallas (Cauto-Nipe, Cochinos, La Trocha, Nortecubana, y Surcubana); 3) hay tres grandes bloques: Occidental (falla Cauto-Nipe-Cabo de San Antonio), Este (falla Cauto-Nipe - Punta de Maisí), y Sureste (en la parte marina entre Cabo Cruz y Punta de Maisí); 4) la figura geométrica de las morfoestructuras mantiene una disposición muy ajustada a la distancia entre las líneas de costa norte y sur; 5) el segmento de la SCF entre las fallas Cochinos y La Trocha es linear y corresponde al borde sur del Bloque Guamuhaya. Éste es un gran macizo metamórfico con una altura $h_{máx}$=1.140 m. Los autores mencionados consideran tres transectos de dirección aproximada sur-norte a través del megabloque cubano para interpretar la relación entre la estructura geológica, las morfoestructuras y los terremotos fuertes (**Figura 5**). Dichos transectos son: 1) Cuenca de Yucatán-Golfo de México; 2) Cuenca de Yucatán-Plataforma de Bahamas; 3) Fosa de Oriente-Océano Atlántico. En el primero de ellos se asocia el fuerte terremoto (año 1880) con la falla Guane [15] que se localiza dentro del megabloque. El segundo transecto atraviesa la zona de mayor deformación estructural dentro del megabloque y la actividad sísmica resulta ser mayor en la falla Nortecubana. La tercera sección muestra la mayor sismicidad de Cuba en el área de la falla de Oriente.

La **figura 5** muestra un extenso alineamiento de dirección N-S desde las Islas Caimán hasta la Península de Hicacos, a través de la Bahía de Cochinos. Esta estructura lineal separa las morfoestructuras M1 y M2 y se corresponde al área principal de cambio estructural de Cuba. Además, Cotilla *et al.* [36] discuten todos los trabajos neotectónicos y morfoestructurales en Cuba y plantean que: 1) la transmisión de los principales esfuerzos tectónicos desde la PBZ hacia las fallas Surcubana y Nortecubana tiene valores diferentes; 2) la mayor deformación está asociada con la SCF debido a su interacción de una estructura oceánica (Cuenca de Yucatán) con el megabloque cubano; 3) la menor deformación de la falla Nortecubana en el segmento Pinar del Río-La Habana corresponde a la interacción entre el megabloque y la estructura oceánica del Golfo de México; 4) el segmento lineal de la falla Nortecubana, entre Matanzas y Gibara, muestra una compresión definida entre la Plataforma de Bahamas y el megabloque. Las **figuras 6A-C** presentan un resumen del modelado neotectónico.

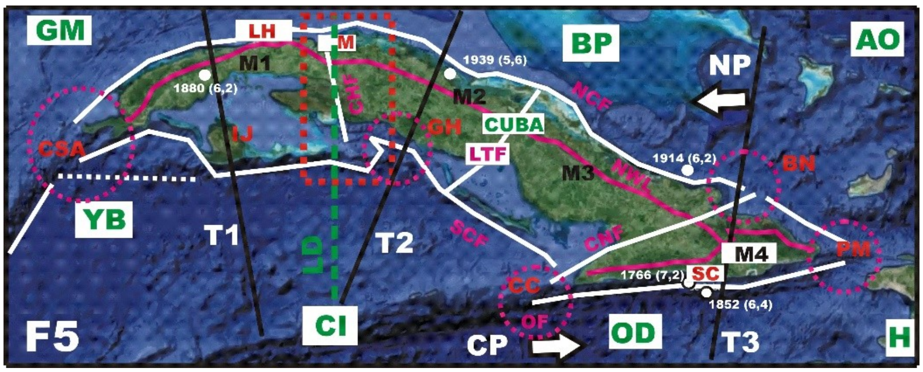
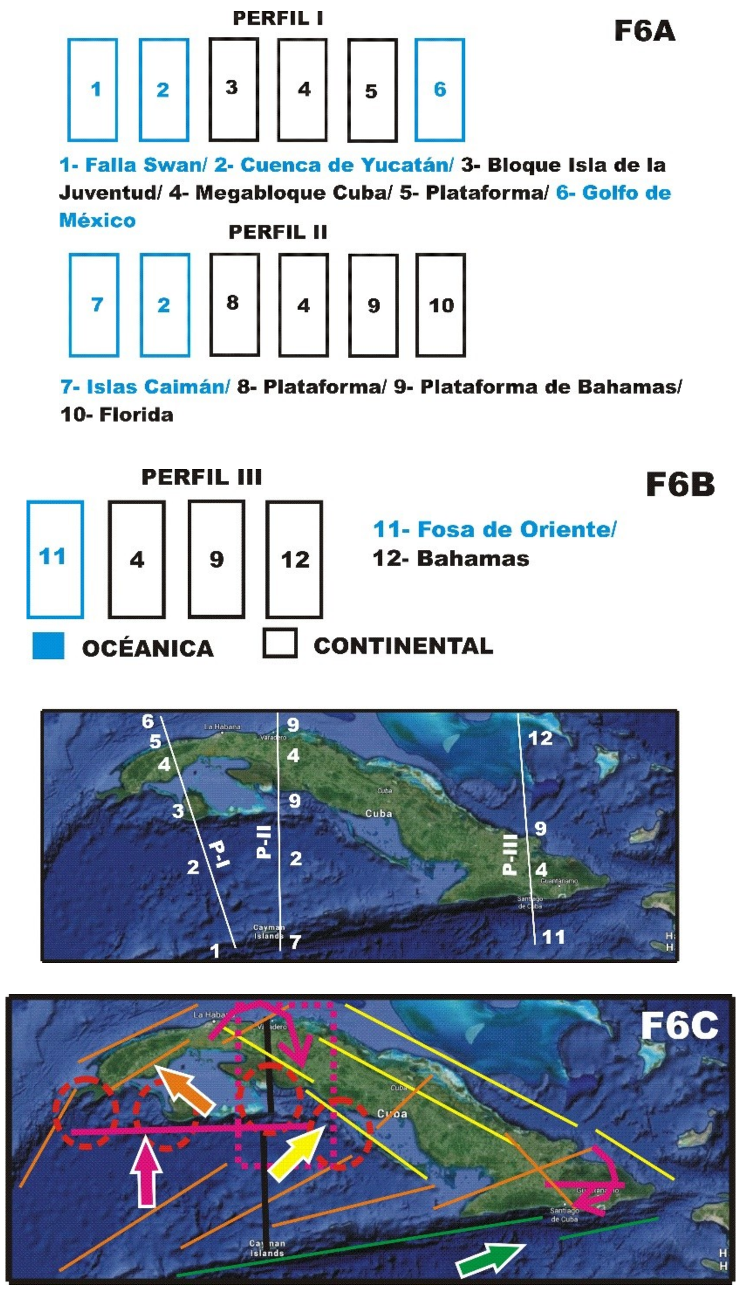


Figura 5. Esquema morfoestructural de Cuba (González et al. [47]). Aparecen: 1) Alineamientos (línea discontinua blanca); 2) Área de cambio estructural (línea discontinua naranja); 3) Epicentros (círculos blancos, año, y (M)); 4) Fallas (líneas blancas: CHF=Cochinos, CNF=Cauto-Nipe, LTF=La Trocha, NCF=Nortecubana, OF=Oriente, SCF=Surcubana); 5) Nudos (círculos discontinuos rojos); 6) Localidades (en naranja: BN=Bahía de Nipe, CC=Cabo Cruz, CSA=Cabo de San Antonio, GH=Guamuhaya, IJ=Isla de la Juventud, LH=La Habana, M=Matanzas, PM=Punta de Maisí, SC=Santiago de Cuba); 7) LD=Línea de la zona de debilidad tectónica principal (línea discontinua verde); 8) Morfoestructuras principales (en negro: M1-M4); 9) MWL=Divisoria Principal de Primer Orden de la red fluvial (línea continua en rojo); 10) Placas (CP=Caribe, NP=Norteamericana, en blanco); 11) T1-T3=Transectos (líneas negras); 12) Regiones (en verde: AO=Océano Atlántico, BP=Plataforma de Bahamas, CI=Islas Caimán, GM=Golfo de México, OD=Fosa de Oriente, YB=Cuenca de Yucatán); 13) Sentido de movimiento (flechas blancas).

Se ha demostrado que en el megabloque Cuba, y su entorno inmediato, existe una relación directa entre: 1) la cantidad de fracturas (l≥5 km) (27); 2) la densidad fluvial (ríos de orden ≥3) Cotilla *et al*. [37]; 3) los tipos de morfoestructuras [47], y los tipos de corteza determinados por Prol *et al*. [79].

1.4 Discusión y Conclusiones

Los estudios de sismotectónica en Cuba han sido diversos en contenido y metodología [16, 19]. De otra parte, hay trabajos que analizan y discuten la génesis de Cuba y sus alrededores inmediatos. Con ellos es posible establecer una regionalización que responda a las magnitudes de los terremotos indicados en la **figura 3**. Los autores consideran que la **figura 2** tiene esa información. Las tres líneas tectónicas que sirven como límites del megabloque Cuba son activas y tienen diferentes categorías. Todas son de tipo marino y están segmentadas. Dos de ellas (fallas Nortecubana y Surcubana) son extensas y aproximadamente paralelas a las líneas de costas respectivas, e interactúan con las estructuras marinas y continentales. Ellas pertenecen a la placa Norteamericana y su sismicidad es de interior de placa. La tercera es el límite con la placa del Caribe, donde se produce la mayor actividad sísmica y determinan las mayores magnitudes de los terremotos.



Figuras 6A-C. Transectos y modelo neotectónico de Cuba. Aparecen: 1) Alineamientos principales (NE=naranja, NW=amarillo, ENE=rojo); 2) Zona de deformación principal=rectángulo discontinuo rojo; 3) Estimado del esfuerzo promedio=flecha gruesa (N-S=roja, NE=amarilla, NW=naranja, ENE=verde); 4) Sentido del movimiento relativo=flecha curva roja; 5) Dirección de cambio estructural (círculo discontinuo rojo).

Al comparar las figuras 2 y 5 resaltamos lo siguiente: 1) coinciden las principales zonas de fallas; 2) las fallas están segmentada; 3) la SCF tiene mayor deformación que la falla

Nortecubana; 4) hay varias zonas de articulación neotectónica -nudos- que facilitan la segmentación estructural y su caracterización. Algunos especialistas han asumido la existencia de un flujo astenosférico desde el Pacífico hasta el Caribe a través de un canal localizado en la vecindad de Panamá donde no hay raíces profundas [1, 40, 70]. En particular, Martín de Blas [63] presenta dos figuras con las anomalías de Bouguer y la transmisión de flujo de calor. De esos mapas se deduce que hay un flujo desde Panamá hasta la Cuenca de Yucatán que se desvía hacia el este, pasando por el sureste de Cuba y convergiendo en Bahamas. De ellos se verifica que el noroccidente de Cuba tiene los menores valores del flujo de calor y que su límite este coincide con la línea N-S indicada en la **figura 2**.

Finalmente, aseguramos que la falla Surcubana se caracteriza por: 1) 81 terremotos (1502-1999)/ $M_{máx}$=4,3/ longitud ~1.100 km/ 7 nudos; 2) no tener reportes de tsunamis locales, ni solución de mecanismo focal, ni víctimas mortales asociadas; 3) tener el área de mayor actividad sísmica entre la fallas Cochinos y La Trocha; 4) mostrar menor actividad sísmica que la falla Nortecubana; 5) ser una zona de sismicidad de interior de placa.

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Isaac ASIMOV (Rusia, 1920-1992): "El aspecto más triste de la vida es que la ciencia reúne el conocimiento más rápidamente que la sociedad la sabiduría."

2- Comments on the Nortecubana Fault

2- Comments on the Nortecubana Fault
{*Comentarios Sobre la Falla Nortecubana*}

Abstract- Nortecubana Fault is a complex marine geological structure, arched and segmented into four parts, between Cabo de San Antonio and Punta de Maisí. Its linear extension is ~1,200 km and has two directions SW-NE and NW-SE. The figure is concave to the south and responds to a zone of structural deformation in the vicinity of La Habana-Peninsula de Hicacos. It is the northern limit of the Cuban mega block at the southern edge of the North American Plate and has at least 380 earthquakes and 2 local tsunamis (years: 1931 and 1939). The M_{max} registered in the sea is 6,2 (I_{max}=7 MSK) in 1914 for Gibara. The active depth of its four seismic segments is 10-75 km. The central segment (Punta de Hicacos-Ciego de Ávila) is the longest. The Ciego de Ávila-Bahía de Nipe segment, near Gibara, has the highest seismic level. There are three induced series of earthquakes in 1981 and 2014-2017 earthquakes occurred on the Nortecubana Fault and one in 2000-2017 associated with Hicacos Fault. Nortecubana Fault has no continuity link with the Septentrional Hispaniola Fault (M_{max}=8,2/ more than 10 local tsunamis).

Keywords: Active fault, earthquake, seismicity, tsunami

Introduction

Cuba, from the physic-geographical point of view, is an archipelago that together with other islands (Jamaica, Hispaniola (Haiti and Dominican Republic) and Puerto Rico) form the Greater Antilles Arc (**Figure 1**). This group has suffered and continues to suffer the effects of two natural phenomena, hurricanes and earthquakes. Our focus is on the second of these. The first earthquake in Cuba was reported in 1528 in Baracoa city, founded village (and capital of Cuba) by the Spaniards since their arrival in 1492. The city is in the northeastern part, near Punta de Maisí.

A characteristic of Cuba is the location of important urban and tourist centers along its coasts and particularly in the northern part. In addition to the population and its material goods, it is necessary to consider, in the studies of seismic hazard, the port infrastructures located there. The zone of greatest seismic activity in Cuba is in the southeastern zone, Cabo Cruz-Santiago de Cuba (**Figure 1**). But, the work target is the Nortecubana Fault, responsible of the Baracoa´s earthquake.

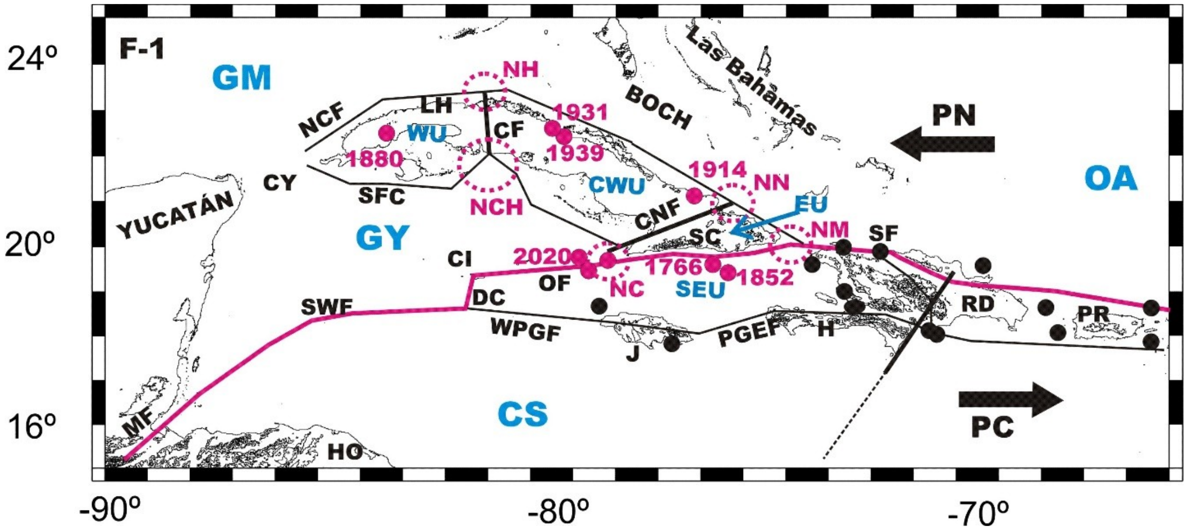

Figure 1. Neotectonic Units and Seismicity (Cotilla *et al*. [30]). Appears: **1)** epicentre (circle in black and red colors (year); **2)** thick black arrow (direction of movement of the plates: PC=Caribbean, PN=North American); **3)** locality and region (LH=La Habana, SC=Santiago de Cuba DC=Oceanic Crust Dispersion Center, BOCH=Old Channel of The Bahamas, CY=Yucatan Channel); **4)** bodies of water (blue acronym: GM=Gulf of Mexico, GY=Gulf of Yucatan, CS=Caribbean Sea, OA=Atlantic Ocean); **5)** knot (discontinuous circle and acronym in red: NC=Cabo Cruz, NCH=Cochinos, NH=Hicacos, NM=Maisí, NN=Nipe); **6)** country (H=Haití, HO=Honduras, CI=Cayman Islands, J=Jamaica, PR=Puerto Rico, RD=Dominican Republic); **7)** Neotectonic Unit (CWU=Central Western, WU=Western, EU=Eastern, SEU=South Eastern); **8)** fault zone **8.1)** continuous black line: CF=Cochinos, NCF=Nortecubana, SCF=Surcubana; **8.2)** continuous red line (Plate Boundary): MF=Motagua, OF=Oriente, PGEF=Plantain Garden-Enriquillo, SF=Septentrional, SWF=Swan-Walton, WPGF=Walton-Plantain Garden.

2.1 Notes About Fault`s Activity

Fault and earthquakes are very well known by specialists. Nevertheless, their relation in the majority of time result quite complicate. Along the history several academic results are published and used around the World [6, 11, 43, 44, 55, 59, 72, 83, 84, 87, 92].

Fault refers to a brittle deformation zone formed by rock strata that have or have not been through the soil consolidation process. A fault can be classified into two main types: active and inactive. We put our attention to the first one. An active fault is a 3-D structure that has relation with at least an earthquake and is likely to become the source of another one sometime in the future. It is commonly considered to be active if it has been movement observed or evidence of seismic activity during the last 10.000 years. Such structure is considered to be a geologic hazard and related to earthquakes as a cause. Some effects of movement can included landslides and rock falls, liquefaction, strong ground motion, surface faulting, tectonic deformation, tsunamis and seiches.

The largest active faults are associated with the plate boundaries. There are several geologic and geomorphologic methods in order to determine a fault and its activity. More recently, using space photos and images it is possible to recognize the boundaries and figure of the faults. Other results from Guelfand *et al*. [42] and Assinovskaya *et al*. [5] allowed to define the activity in regions with strong earthquakes potential. But, another type of region and seismicity is determined inside the plates. It is denominated as intraplate

[49, 75, 81, 85, 89]. In summary an active fault is a neotectonic structure that: 1) it has been offset during the present seismotectonic regime; 2) it has the probability or potential for future renewal or recurrence of offset; 3) it has evidence of recent activity, as may be shown by physiographic evidence; 4) it may have associated earthquake activity. We are going follow these elements in our research as the Rule 1 of Cotilla [16].

2.2 The Nortecubana Fault

The Nortecubana Fault (**Figure 1**) has been studied over time by different specialists [14, 30, 32, 33, 52, 62-64, 78, 79]. It is described in the northern marine part of Cuba, between Cabo de San Antonio and Punta de Maisí. Its figure corresponds to the layout and configuration of the coastline. It has a length of ~1.200 km. The structural inflection of the Island, including this fault, is in the vicinity of La Habana-Matanzas. The Nortecubana Fault is a seismic active structure, and has several perceptible earthquakes and two local tsunamis.

Cotilla [16] considers that the Nortecubana Fault, as the southern structure of the North American plate, has four segments (**Figure 2**): FNC1 (Cabo de San Antonio-La Habana), FNC2 (La Habana-Ciego de Ávila), FNC3 (Ciego de Ávila-Nipe) and FNC4 (Nipe-Punta de Maisí). In the segments: 1) FNC3 occurred the Gibara earthquake of 1914 M_{max}=6,2/ I_{max}=7 MSK; 2) FNC2 two local tsunamis hit in 1931 and 1939 the localities of Playa Panchita and Caibarién; 3) FNC1 and FNC2 were noticeable two earthquakes series. They were produced by geophysical exploration work for gas and oil, years 1981 and 2014-2017.

On the other side, it has been determined that the Nortecubana Fault is not linked to the Septentrional Fault (Fig. 2) (M_{max}=8,0/ >10 local tsunamis/ ~500 deaths) [19, 22, 23, 25, 29, 69]. The latter one is part of the Caribbean and North American Plate Boundary (**Figure 1**).

2.3 Neotectonic and Seismicity

The following references are used for the preparation of the heading: Álvarez *et al*. [1, 2]; Cobiella [12, 13]; Cotilla [14-18]; Cotilla and Córdoba [19-24]; Cotilla and Udías [25]; Cotilla *et al*. [26, 27, 29, 30-34]; Dixon *et al*. [36]; Erickson *et al*. [38]; Hernández *et al*. [45]; Iturralde [47]; Levchenko and Riabujin [52]; Linares *et al*. [53]; Mann and Burke [56]; Mann *et al*. [57, 58]; MINBAS [62, 63]; MINCM, [64]; Moretti *et al*. [65]; Mossakovsky *et al*. [66]; NPE [69]; Núñez-Escribano [70]; Núñez *et al*. [71]; Prentice *et al*. [73]; Quintas *et al*. [74]; Rubio *et al*. [76]; Shein *et al*. [78-80]; WSM [90].

The relative motion between the Caribbean and North American Plates controls the tectonic regime of the area at a regional scale. It was argued that the eastward motion of the Caribbean Plate relative to the North American Plate occurs at a rate of 12-40 mm/yr. It was estimated 18±3 mm/year for Southeastern Cuba. The eastward motion of the Caribbean Plate produces a left-lateral strike slip deformation along the Bartlett-Cayman Fault Zone and left-lateral strike slip along the Walton-Plantain Garden-Enriquillo Fault Zone. There are four important local structures that affect the tectonic regime in the area: 1) the Mid-Cayman Rise Spreading Center (Cayman Islands); 2) the Cabo Cruz Basin; 3) the Santiago de Cuba Deformed Belt; 4) the Maisí Area. All they account for more than 85% of the seismicity along this part, related with Oriente Fault and included in the Plate Boundary Zone. The general pattern of the seismicity in the Caribbean region is in figure 3. Large earthquakes occur along the Plate Boundary near Hispaniola, Jamaica and Puerto Rico Islands.

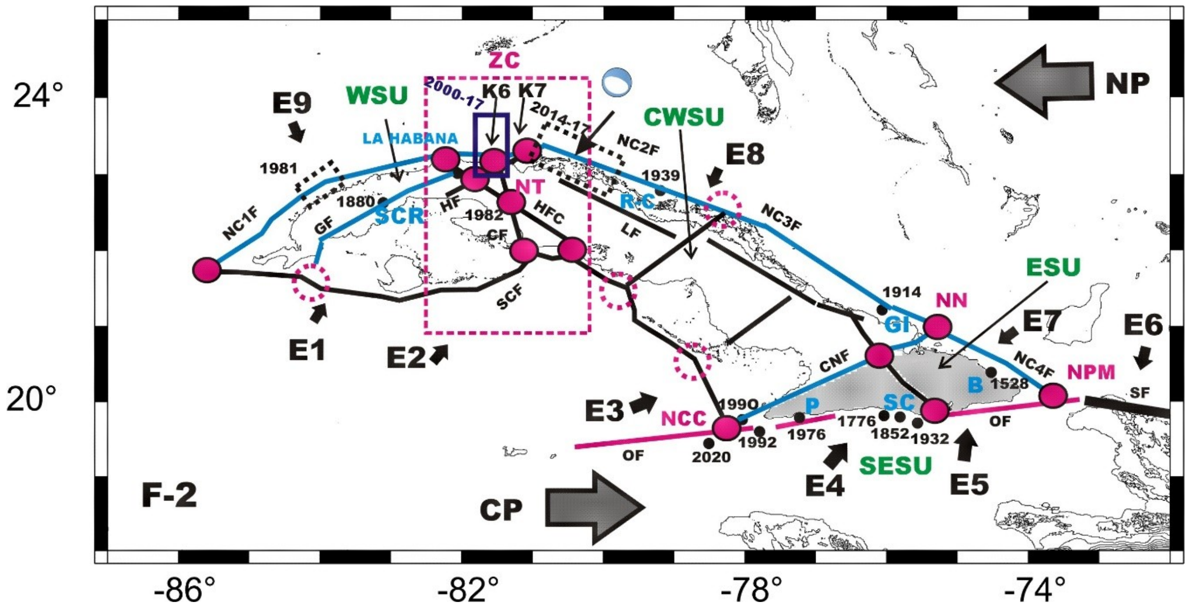

Figure 2. Simplified Seismotectonic map of Cuba. Appears: 1) areas of induced seismicity in: 1.1) 1981 and 2014-2017 (black discontinuous rectangle); 1.2) 2000-2017 (black continuos rectangle); 2) epicentre (circle and year in black); 3) fault: 3.1) black line: CF=Cochinos, HF=Hicacos, HCF=Habana-Cienfuegos, LF=Las Villas, SF=Septentrional, SCF=Surcubana; 3.2) 2nd Category faults (blue line): FCN=Cauto-Nipe, FG=Guane. FNC=Nortecubana (with blue letter, segments: FNC-1): 3.3) 1st Category faults (red line): OF=Oriente); 4) locality (blue letter; B=Baracoa, GI=Gibara, P=Pilón, R-C=Remedios-Caibarién, SC=Santiago de Cuba, SCR=San Cristóbal); 5) knot (circle and red letter: NCC=Cabo Cruz, NN=Nipe, NPM=Punta de Maisí, NT=Torriente-Jagüey Grande, K6=Matanzas Bay, K7=Varadero Bay); 6) plate (CP=Caribbean, NP=North American); 7) direction of movement of the plates (thick gray arrow); 8) tensor $\sigma_{hmáx}$ (thick black arrow and letter-number E1-9); tensor $\sigma_{hmáx}$ (thick black arrow and letter-number E1-9); 9) Seismic momentum tensor (USGS) 2014.09.1 (M_W=5,0) in Corralillo; 10) Seismotectonic Unit (green letter: WSU=Western, CWSU=Central Western, ESU=Eastern, SESU=South Eastern); 11) ZC=Area of significant structural change (dashed rectangle and dashed circle, in red).

Cuba is a mega block in the southern part of the North American Plate. The active Plate Boundary runs along the southeastern coast. It was identified two types of seismicity: 1) inter plate; 2) intraplate. The first type is due to the direct interaction of the Caribbean and North American Plates. It is located in the Oriente Fault where occur the greatest number of earthquakes and those of greatest magnitude (Ms>7,0). The intraplate earthquakes take place in the rest of the Cuban territory and the adjacent marine area out of the Plate Boundary Zone. They are significantly less strong and less frequent than the previous mentioned type. Low magnitude seismicity (Ms<4,0) occurs throughout the Western region of the island.

From them we can distinguish a significant and regular decrease of the seismicity from the contact zone of the Caribbean-North American Plates, in the southeastern part, towards the interior of the Cuban territory in the western part. This corresponds directly to the neotectonic situation and the influence of the plate systems that support the existence of four independent Seismotectonic Units: Western, Central-Western, Eastern and Southeastern (**Figure 2,** Table 1).

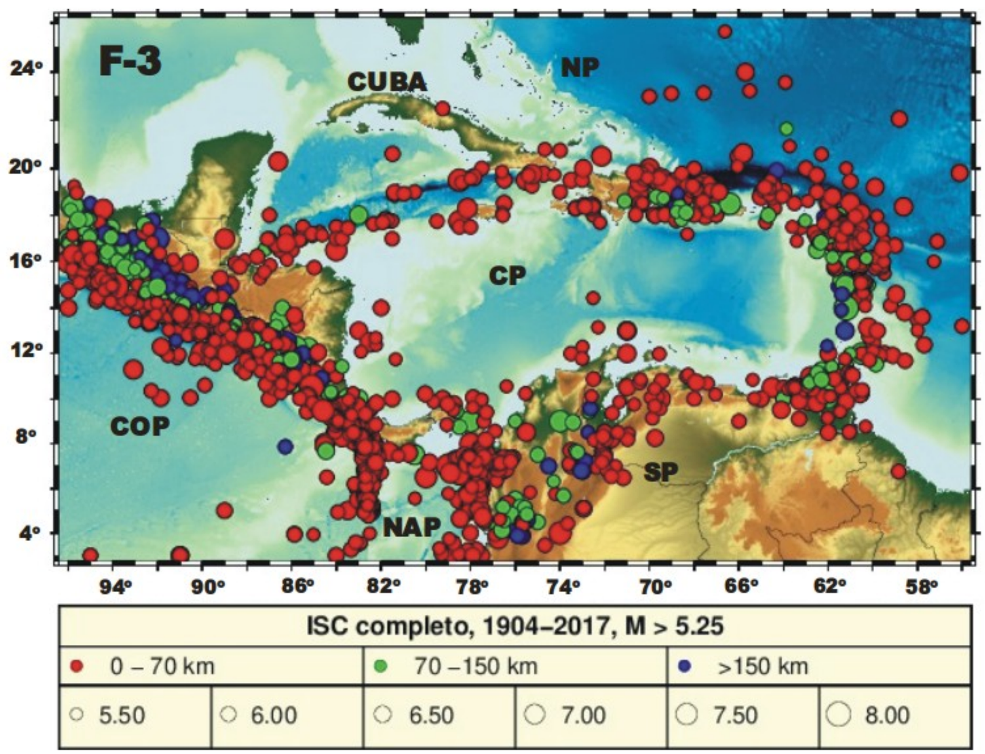

Figure 3. Seismicity in the Caribbean. Plate (CP=Caribbean, COP=Cocos, NP=North American, NAP=Nazca, SP=South American).

Dutton [37], Wilson and O'Halloran [88], McClain and Meyer [60], Liu and Zoback [54], Campbell [8], Sykes [81], Scholz *et al*. [77], Johnston and Kanter [49], Talwani and Rajendran [82], Gubbins [41], Leonov [50], Wysession *et al*. [91], Johnston [48], Amorèse *et al.* [3], Weiran *et al.* [86] and Middleton *et al*. [61] among others, created a basis for the studies of intraplate seismicity. In the same line of reasoning, Leroy and Mauffret [51], based on seismic surveys, determined that the Caribbean Plate has active deformation zones. Also, Cuba has an articulated set of intraplate blocks and regions that include: **1)** Corralillo and its surroundings that are in a morphological structure with a tendency to descend that includes a series of low and flat plains, related to keys and mangroves, and where there is no superficial river network. In this environment there are three active fault zones, Cochinos, Hicacos and Nortecubana (**Tables 2-3**); **2)** a large deformation or structural change area and which has seven joint knots, in the morphotectonic plane; 3) gas and oil bags. In this environment, several perceptible seismic events have occurred that were recorded by international stations in 2014-2017 (Figure 4, Table 4).

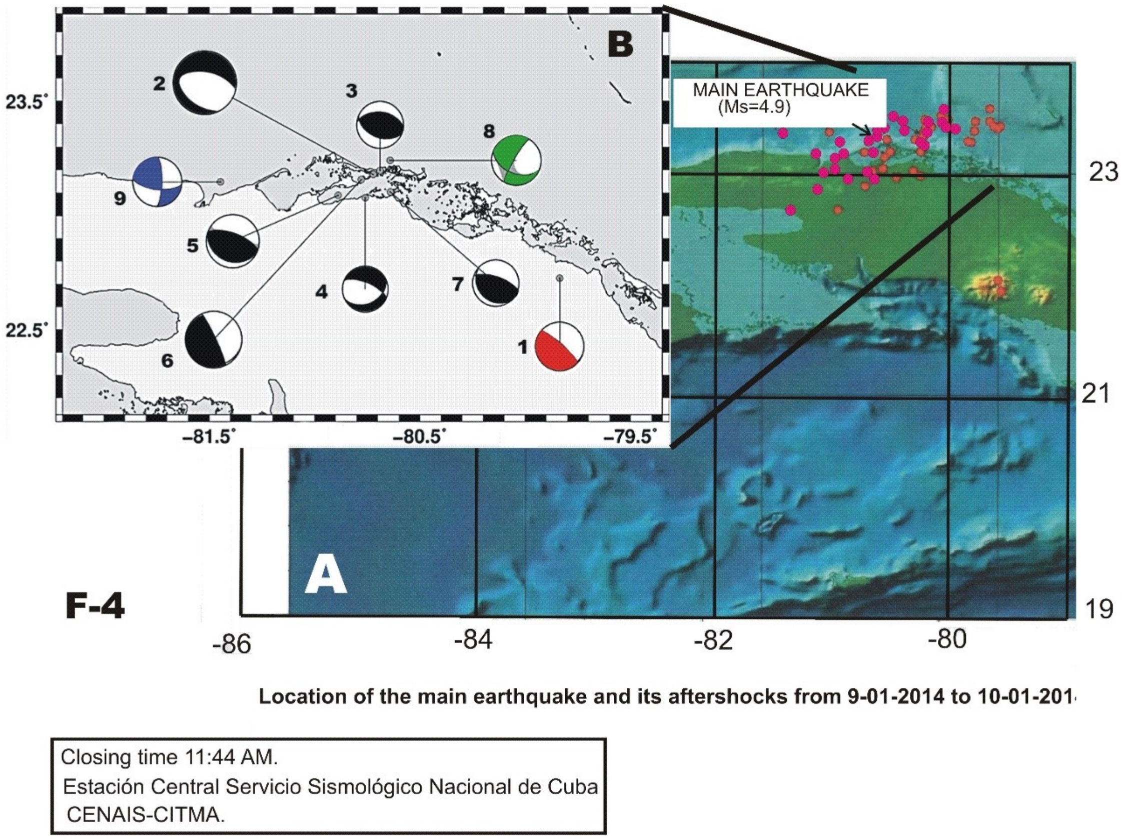

Figure 4. Seismicity and tensors in the Corralillo environment. 4A. Modified from the Special Information Bulletin No. 2/ 2014 [9]; 4B. Moment tensors and fault plans (modified from Braunmiller *et al*. [7]. Appears: 1) eight moment tensors with overlapping fault plane solutions associated with the North Cuban fault, near Corralillo (2-9); 2) each has the date and time (1=2012.11.20/ 00:19 (red color)/ in black color: 2=2014.01.09/ 20:57, 3=2014.01.10/ 02:25, 4=2014.01.10/ 11:23, 5=2014.02.05/ 03:09, 6=2014.03.09/ 11:26, 7=2014.03.30/ 21:50/ 8=2015.08.16/ 11:47 (green color)/ 9=2017.07.30/ 03:41 (blue color)); 3) the solution to the 2014.01.9 earthquake is of Arango-Arias *et al*. [4] and the other 8 solutions are from Braunmiller *et al*. [7].

The figures 5A-D show very well the existence of the Nortecubana Fault. They are in correspondence with expressed before about an active fault (historic and registered seismic events). When the requirement on number of stations used in hypocenters location grows (from A to D), weak seismicity tends to disappear, but middle magnitude events maintain. Another data about the activity of this fault are the events induced by gas and oil geophysical works. Cotilla *et al*. [30] studied two different group of these events: 1) year 1981 in FNC1 (northern of Pinar del Río); 2) period 2014-2017 in FNC3 (in the vicinity of Corralillo) (Figure 6). These events were perceptible.

Table 1. **Data from the three strongest earthquakes in Western and Central-Western Units.**

Date/ Region/ Fault	M/ I (MSK)	Coordinates (N W)	Aftershocks	Isosists/ Epicentre in	Tipe/ Shape index	Area (10^3 km^2)	Rupture (km)
1880.01.23/ Western/ G	6,2/ 8	22,70 83,00	65	Yes/ Ground	Full/ 0,68	40	35
1914.02.28/ Central-Eastern/ NC	6,2/ 7	21,30 76,20	9	Yes/ Sea	Half/ 0,75	25	15
1939.08.15/ Central/ NC	5,6/ 7	22,50 79,25	24	Yes/ Sea	Half/ 0,71	19	20

Notes: 1) G=Guane Fault, NC=Nortecubana Fault; 2) the highest values in all tables are indicated in red color.

Table 2. **Some historical earthquakes in the Nortecubana Fault.**

Segment			
Western/ Total	**Central/ Total**	**Eastern/ Total**	**Total**
1810, 1812, 1835, 1843, 1849, 1852/ 6	1824, 1837, 1852 (3)/ 5	1528/ 1	**12**

Table 3. **Summary of earthquakes associated with the Nortecubana Fault.**

	Segment/ rank of M/ rank of h (km)				
Earthquakes	**Western**	**Central**	**Eastern**	**Total**	**Years**
Historics	21/ 2,5-4,2/ 10-20	13/ 3,1-4,5/ 10-15	1/ 5,0/ 10	35	408
Recorded	25/ 2,5-4,4/ 10-20	166/ 0,1-6,2/ 2-74	111/ 0,2-5,6/ 2-74	302	123
Total	**46**	**179**	**112**	**337**	**530**

Table 4. **Data from three international sources for three earthquakes of Corralillo in 2014.**

Source	Month.Day	Time	M	h (km)	Coordinates (N W)	Source	Month.Day	Time	M	h (km)	Coordinates (N W)
USGS	02.05	3:19:32	4,3	12	23,168 80,821	USGS	09.01	20:57:43	5,0	10	23,182 80,728
GEOFON		:38	4,4	12	23,21 80,70	GEOFON		:44	5,0	10	23,23 80,76
EMSC		:31	4,4	14	23,25 80,69	EMSC	-	-	-	-	-
USGS	03.09	11:26:18	4,7	9	23,183 80,751	**Source**	**Month.Day**	**Plane**	**N1**	**Plane**	**N2**
GEOFON		:18	4,7	10	23,27 80,69	USGS*	09.01	113 25	-88	291 65	-91*
EMSC		:18	4,8	10	23,17 80,77	GEOFON		107 38	-93	281 52	-93

Note: * See figures 2 and 4.

Table 5. **Data of two actives Cuban faults.**

Fault	Seismotectonic Unit	Type of seismicity	Category/ Segments	L/ W/ D	M_{max}	Earthquakes/ Total	Isoseismal	Knots
CH	Western	Intraplate	III/ 2	200/ 30/ 20	5,0	1903, 1927, 1928, 1964, 1974, 1982, 2015/ 6	YES	3
H	Western	Intraplate	III/ 3	230/ 20/ 20	3,0	1812, 1843, 1852, 1852 (2), 1880, 1914, (2), 1974, 1978/ 10	NO	2

Note: Fault (CH=Cochinos, H=Hicacos); L=Longitude (km), W=Wide (km), D=Depth (km).

It is quite important to understand that recording of weak seismicity depend of the existing local seismic stations. Then, the Central-Western part of Cuba are less documented, as can be seen when the increasing the number of stations recording an earthquake grows. Nevertheless, at Varadero-Santa Marta localities, Matanzas province, there were registered and reported some earthquakes (7.10.2000/ M=2,7 and 2,8/ I_{max}=V) [10]. After that and according with the USGS it was registered the most strong earthquake in the same area on 30.07.2017 (M=4,4/ I=V/ h=10 km/ 3:41:29/ 23,148 N -81,446 W). All they were perceptible. Cotilla [14] argued the existence of an articulation knot with the Hicacos, Cochinos (**Table 5**) and Nortecubana Faults (**Figure** 2). Later on the first author showed the knot Matanzas Bay (figure 6 of Cotilla [16]) and the differentiation of the seismic activity with two knots K6 (Matanzas Bay) and K7 (Varadero) (figure 3a of Cotilla [18]).

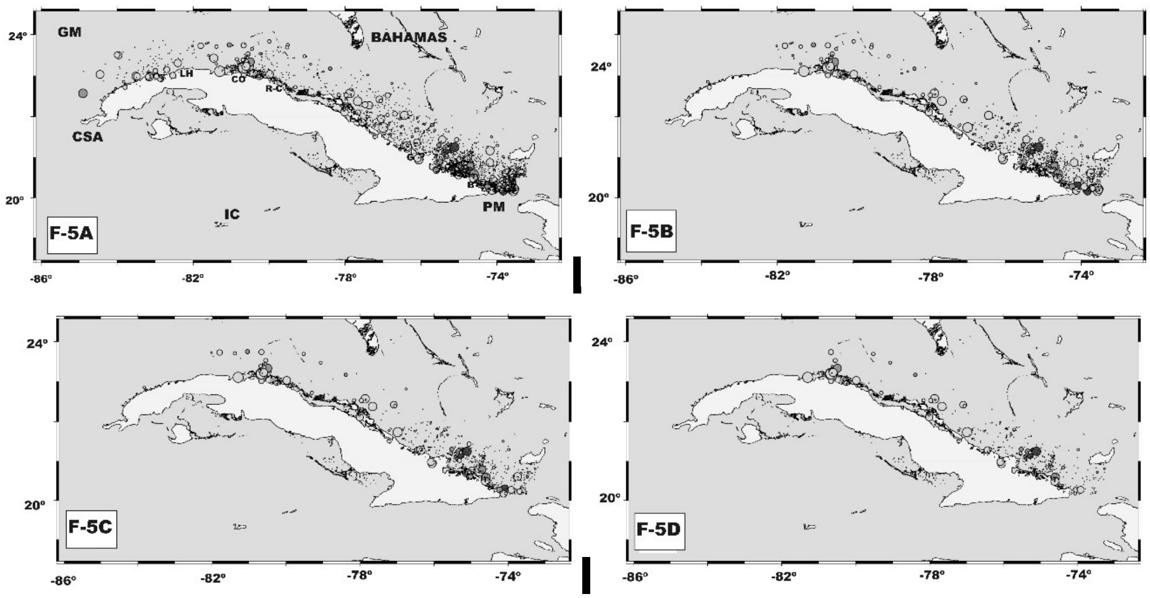

Figure 5. Maps of registered seismicity (until 2018, CENAIS [9]). Appears: B=Baracoa, CO=Corralillo, G=Gibara, GM=Gulf of Mexico, IC=Cayman Islands, LH=La Habana, PM=Punta de Maisí, R-C=Remedios-Caibarién. There are 4 possibilities of determination: 5A) 1 or more stations; 5B) 2 or more stattions; 5C) 3 or more stations; 5D) 4 or more stations.

Cotilla *et al*. [30] maintain that the events of 1981 and 2014-217, mentioned above, correspond to the induced seismicity in the adjacent faults by the oil exploitation. They argued that the continuous extraction of gas and oil deforms the subterranean chambers and consequently varies the stress field in the region. Although we have no real volume data about oil and gas exploitation in Varadero-Santa Marta area, we consider that the conditions are propitious to induced seismicity also, and those mentioned earthquakes could be induced ones. In addition, we sustain that: **1)** the largest magnitude of future induced earthquakes in Cuba by oil and gas extraction should be always lesser than 5,0. The overall oil and equivalent gas production in Cuba is about 4.10^6 tons at a year, distributed in a lot of small reservoirs; then, no big stress modifications may be present; **2)** it would be essential to install a seismic station in that area to record weak events with greater certainty.

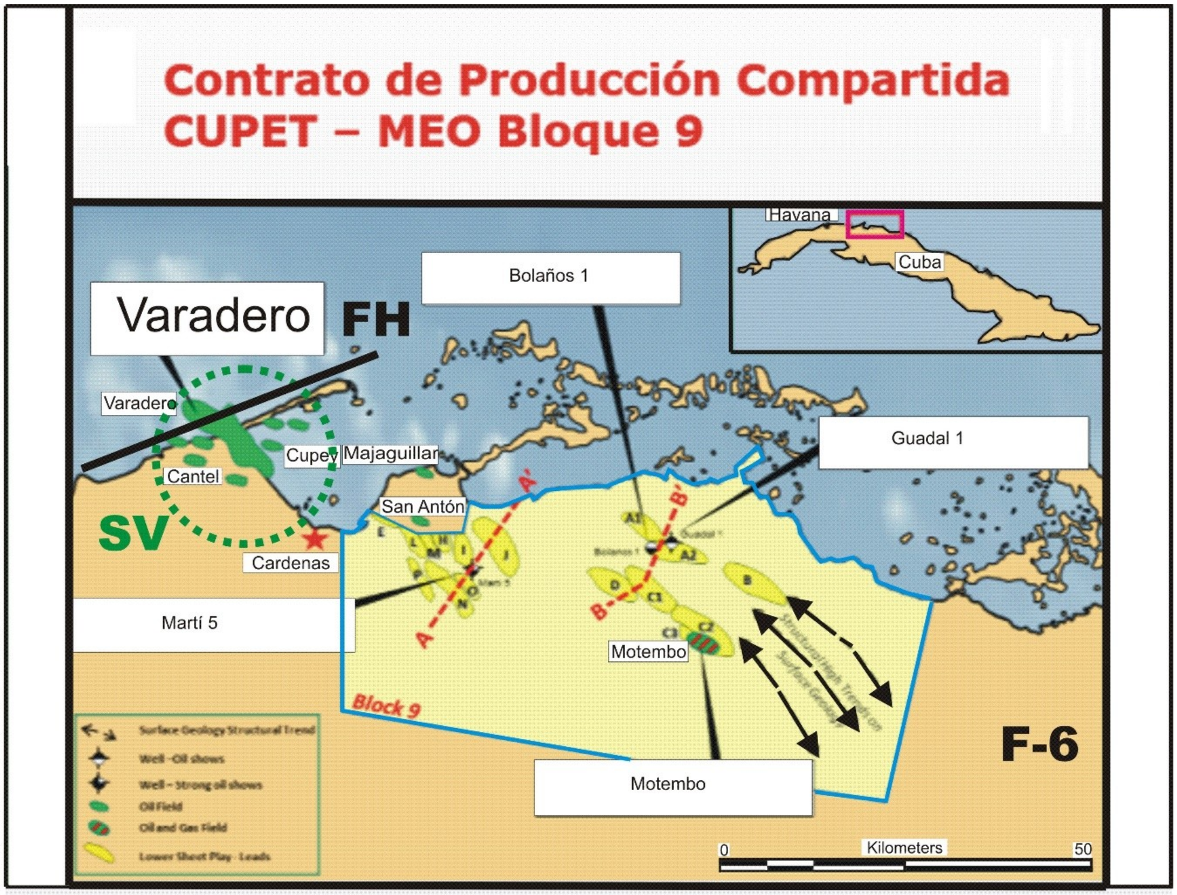

Figure 6. Modified image of *"Petróleo en Cuba: ¿dónde está el oro negro?"* (In: *CubaDebate* (16.09.2016/ María del Carmen Ramón)). They appear, immediately, to the west of Cárdenas: 1) Block 9. Landscape rectangle and adjacent to the N coast; 2) four areas of work (Bolaños 1, Guadal 1, Martí 5, Motembo). All in the municipalities of Corralillo, Quemado de Güines and Sagua La Grande; 3) in green are the oil bags of Varadero and San Anton, outside that block; 4) MEO=is an Australian company that signed a contract with CUPET to be exploited the Block 9; 5) FH=Hicacos Fault (line and acronym); 6) seismic group in Varadero (discontinue circle in green color).

Table 6. Data on active study faults.

	Fault		
Characteristic	**Nortecubana**	**Oriente**	**Septentrional**
Active fault features (Rule 1)	3	3	**4**
Country associated	Cuba	Cuba	Hispaniola (Haití and Dominican Republic)
Dead/ injured	No/ 2	80/ 700	**~5.000/ 10.000**
Earthquakes ($M \geq 7,0$)	No	1	**12**
Economic losses (10^6 U.S.D.)	~0,2	~60	**~200**
Focus depth (km)	10-75	10-70	**0-200**
I_{max} (MSK)	7	9	**10**
Induced seismicity	Yes	No	No
Local tsunami	2	No	**10**
Located at	North	South	North
Longitude (km)	**~1.200**	~750	~750
M_{max}	6,2	7,7	**8,2**
Paleo seismological research	No	No	Yes
Period of recurrence of strong	**>150**	90	70

earthquakes (year) [T]			
Regional Category	IV	II	**I**
Segments	**4**	3	2
Seismicity type	Intraplate	Inter plates	Inter plates
Seismic dislocation	No	No	Some
Thickness of the seismic layer (km)	~12	~30	**~90**

Cotilla *et al*. [30] maintain that the events of 1981 and 2014-217, mentioned above, correspond to the induced seismicity in the adjacent faults by the oil exploitation. They argued that the continuous extraction of gas and oil deforms the subterranean chambers and consequently varies the stress field in the region. Although we have no real volume data about oil and gas exploitation in Varadero-Santa Marta area, we consider that the conditions are propitious to induced seismicity also, and those mentioned earthquakes could be induced ones. In addition, we sustain that: 1) the largest magnitude of future induced earthquakes in Cuba by oil and gas extraction should be always lesser than 5,0. The overall oil and equivalent gas production in Cuba is about 4.10^6 tons at a year, distributed in a lot of small reservoirs; then, no big stress modifications may be present; 2) it would be essential to install a seismic station in that area to record weak events with greater certainty.

2.4 Discussion

The neotectonic framework of the Caribbean was well adjusted with Mann and Burke [56]. It shows the main differences between the structures of Cuba and Hispaniola. The contribution of Mann *et al*. [57] and Dixon *et al*. [36] regarding the dynamics of the plates improved it. But, the relationship between some few structures in the region remained uncertain. Prentice *et al*. [73] and Mann *et al*. [58] made the first paleo seismological researches in Hispaniola and confirm the activity of the main faults. Cotilla [15] and Cotilla and Córdoba [20, 24] improved the tsunami catalogue and point out that North of Hispaniola is the most active in the region.

The investigations of NPE [67], Cobiella [12, 13], Cotilla *et al*. [26, 27], Quintas *et al*. [74] and Rubio *et al*. [76] demonstrated that Oriente Fault and Northern Hispaniola Fault do not have, in the contemporary stage, a relationship of continuity. Subsequently, the results of Cotilla *et al*. [29], Cotilla and Córdoba [19], Núñez-Escribano [70] and Núñez *et al*. [71] confirmed it. In these last ones, it was argued that: 1) Cuba is in the North American plate [32]; 2) the Nortecubana Fault is an active structure of plate interior [14]; 3) the Nortecubana and Oriente Faults form an articulation knot to justify a seismogenic model of the Eastern Seismotectonic Unit of Cuba [34].

Cotilla and Cordoba [22] indicated other geological and geomorphological differences between Guantanamo (Cuba) and northern Haiti regions. Cotilla and Córdoba [23] used morphostructural data, reports of historical and registered earthquakes, isoseismals and focal mechanism solutions of this area to assured that there are no relation between these faults. Cotilla *et al.* [32] and Cotilla [18] exposed that the transmission of efforts from the limit of Caribbean-North American Plates to Cuba was the cause of crust deformations and seismic activity. They explain that there is: **1)** a morphostructral contrast (Yucatan Basin and Gulf of Mexico) between the Western Seismotectonic Unit and the Nortecubana and Surcubana Faults (**Figures 1-2**); **2)** an important area of structural change (La Habana-Península de Hicacos) that deforms these faults and morphostructures and has 9 knots (Fig. 2); **3)** a significant increase in seismicity along the Nortecubana Fault from west to east.

Later on, Cotilla *et al*. [30] showed that in some areas of weak tectonics, induced earthquakes can occur. The differences among the three mentioned faults of our interest are explained from several elements: **1)** Cuba is an active mega block located to the north of the plate boundary. North of Cuba is the Nortecubana Fault where there are important differences in the effort transmission (distance and type of crust); **2)** in the eastern part of Cuba the effort transmission is direct from the Oriente Fault to the Eastern Seismotectonic Unit and the closest Nortecubana Fault that has a different type of crust to the north; **3)** northeast of Punta de Maisí, the Septentrional Fault has a more efficient transmission by interacting between two areas of modified oceanic crust.

Table 6 has a summary of the most significant data for the Nortecubana, Oriente and Septentrional Faults. From this information, it is clear that the most active fault; **1)** of the region is the Septentrional; **2)** of Cuba is Oriente.

Conclusions

The authors argue that the main elements about the Nortecubana Fault have been well discussed and confirmed. Among them are the following: **1)** the presence in northern Cuba of interior seismicity type of the North American Plate; **2)** the existence of the Nortecubana Fault with ~1.200 km in length; **3)** the condition of the Nortecubana Fault as the active northern limit of the Cuban mega block at the southern edge of the North American Plate; **4)** the segmentation of the Nortecubana Fault in four parts as a heterogeneous seismic system; being the Central Eastern segment, FNC3, the one with the highest level and where the strongest event has occurred (M_{max}=6,2/ I_{max}=7 MSK/ T>150 years); **5)** the occurrence, in segments FNC2 and FNC3, of more than 380 earthquakes; **6)** the FNC2 segment has associated two local tsunamis (1931 and 1939).

The main conclusions are: **1)** the depth of the four seismic zones of the Nortecubana Fault is between 10-35 km; **2)** the seismic activity of: **2.1)** 2014-2017 in the FNC3 segment, was caused by geophysical research works and gas and oil extraction, as it happened in 1981 at FNC1 segment, together with the changes of tensions in the crust as a result of more than 90 years of exploitation of the gas-naphtha Motembo field; **2.2)** 2000 in Varadero-Santa Marta (FNC2 segment) may be caused also by gas and oil extraction; **3)** induced seismicity, due to the characteristics of reservoirs, should be always less than Mw=5; **4)** Septentrional Fault is the most active in the region; **5)** Oriente Fault is the most active in Cuba; **6)** Oriente and Nortecubana Faults have no relation of continuity with the Septentrional Fault.

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Louis PASTEUR (Francia,1822-1895): "Un poco de ciencia nos aleja de Dios, pero mucha ciencia nos acerca a Él."

3- General Reflections on the Main Earthquakes in Cuba and Their Seismic Hazard

3-General Reflections on the Main Earthquakes in Cuba and Their Seismic Hazard {*Reflexiones Generales Sobre los Principales Sismos en Cuba y su Peligrosidad Sísmica*}

Abstract- General thoughts on the main earthquakes in Cuba and their seismic hazard are done. The selection of 23 earthquakes is associated with four Seismotectonic Units. For each one, a set of 22 characteristics is presented. Santiago de Cuba is the city with the greatest seismic hazard. This set is compared with the strong earthquakes of the Northern Caribbean and shows the non-exceptional nature of the disastrous action of the earthquake-hurricane couple. There is a diagnosis about strong earthquakes in Cuba. The malicious and unhealthy misrepresentations of data from two perceptible earthquakes in 1982 and 1995 in Western Cuba are shown and discussed.

Keywords: Caribbean, Data distortion, historical seismicity, seismic hazard.

Introduction

The Antilles are a group of islands that form a concave arc of ~4.800 km in the Caribbean between the Gulf of Mexico and Venezuela. They are subdivided into two groups: Greatest (~38x10^6 inhabitants/ 207.409 km^2/ ~1.600 km) and Lesser (~2,5x10^6 inhabitants/ 8.556 km^2/ ~850 km) (**Figure 1A**). Cuba (11.338.138 inhabitants/ 109.884 km^2) is an archipelago of the Greater Antilles oriented to west-east. (**Figure 1B**). It is supported that: **a)** the seismic history begins in 1528, twenty-six years after the first earthquake in Hispaniola; **b)** seismicity is of medium-low level; **c)** there are two types of seismicity (inter-plate (Caribbean-North American) and intra-plate (North American)); **d)** the area with the highest seismic activity is the southeastern region, where the Oriente fault segment, with more than 20 strong and perceptible earthquakes, is the most active (**Figure 2**); **e)** there have been ~100 fatalities and ~1.400 injuries from earthquakes; **f)** the most disastrous occurred in 1766/06/11 (40 deaths/ 700 wounded/ Santiago de Cuba); **g)** the estimated and recorded maximum magnitudes coincide, spatially, and have the value of 7,7. Both in the vicinity of Cabo Cruz, where there is a crossing of the Oriente and Cauto-Nipe faults; **h)** events of the above-mentioned magnitude did not result in fatalities; **i)** has been affected by strong earthquakes in Jamaica, Hispaniola (Haiti-Dominican Republic) and Puerto Rico; **j)** is surrounded by three bodies of water: the Gulf of Mexico (1,6x10^6 km^2), the Caribbean Sea (2,8x10^6 km^2) and the Atlantic Ocean; but only two local tsunamis have occurred (1931 and 1939), associated with the Nortecubana fault (**Figure 2**); **k)** tsunamis from two very strong earthquakes were felt in Santiago de Cuba: **k.1)** Lisboa 1755/11/01 (M8,5); **k.2)** Islas Vírgenes 1867/11/18 (M7,5); **l)** the greatest danger is from tropical cyclones and hurricanes. The following have been recorded in the area 116 (1791-2017).

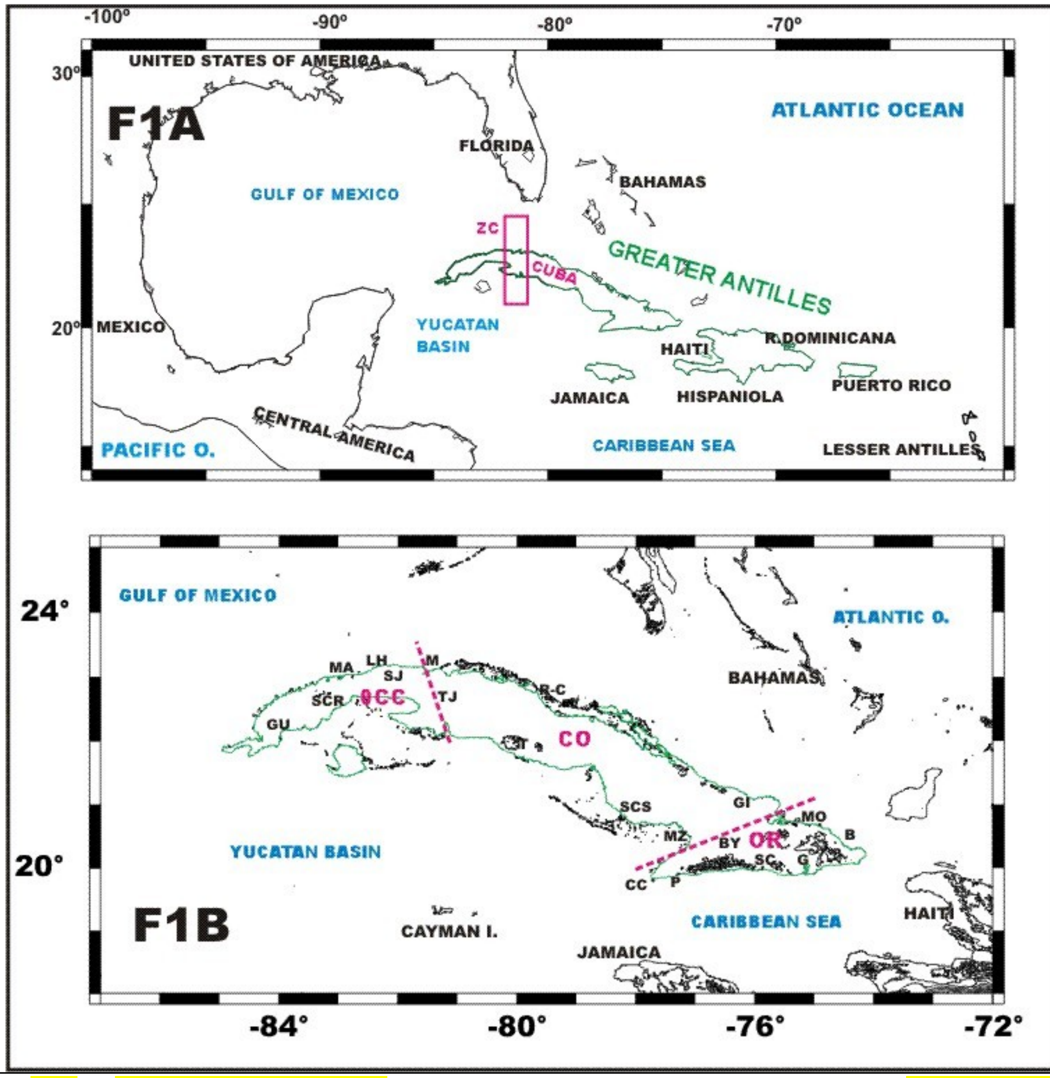

Figure 1. Cuba. **A)** Location of Cuba in the Antilles. Appear: ZC=Zone of structural change (red rectangle). **B)** Regions and localities of Cuba. Appear: **1)** Physical-geographical regions (boundaries (red lines and letters): OCC=Western, CO=Centre-Western, OR=Eastern); **2)** Cities (B=Baracoa, BY=Bayamo, CC=Cabo Cruz, G=Guantánamo, GI=Gibara, GU=Guane, LH=La Habana, M=Matanzas, MA=Mariel, MO=Moa, MZ=Manzanillo, P=Pilón, RC=Remedios-Caibarién, SC=Santiago de Cuba, SCR=San Cristóbal, SCS=Santa Cruz del Sur, SJ=San José de Las Lajas, T=Trinidad, TJ=Torriente-Jagüey Grande) (see Table 1); **3)** ZC=Structural change zone (red rectangle). **The legend is maintained in all the figures**.

The locations related to the earthquakes analyzed are shown in **table 1** and **figure 2**. The work is intended to cover the historical aspect of seismicity in Cuba, and to update and complement previous publications by the authors, generalizing results, in order to issue useful criteria for what has been called **"disaster management"**.

Table 1. Locations associated with earthquake perceptibility.

Locality/ Foundation/ Inhabitants ($x10^3$)	Region	Locality/ Foundation/ Inhabitants ($x10^3$)	Region	Locality/ Foundation/ Inhabitants ($x10^3$)	Region
Artemisa/ 1818/ 59,13	OCC	Matanzas/ 1693/ 145,246	OCC	**Baracoa/ 1511**/ 79,797	OR
Candelaria/ 1809/ 19,523		Pinar del Río/ 1867/ 188,614		Bayamo/ 1513/ 235,107	
Guane/ 1878/ 35,718		Banes/ 1513/ 34,452	OR	Cabo Cruz/ 1494/ 0,1	
Jagüey Grande/ 1840/ 87,771		Guantánamo/ 1796/ 228,436		Santiago de Cuba/ 1515/ 444,851	
La Habana/ 1514/ 2.141,652		Manzanillo/ 1792/ 150,199		Caibarién/ 1832/ 38,479	CO
San Cristóbal/ 1830/ 29,119		Moa/ 1939/ 57,652		Cienfuegos/ 1819/ 164,924	
Trinidad/ 1513/ 51,994		Pilón/ 1779/ 29,456		Gibara/ 1817/ 71,126	
San José de las Lajas/ 1778/ 73,136		Sagua de Tánamo/ 1735/ 46,967		Holguín/ 1545/ 350,191	

Note: CO=Centre-Western, OCC=Western, OR=Eastern.

3.1 Caribbean-Cuba Tectonic Framework

The following publications describe the tectonic framework of the study area: [33, 41, 44, 45, 49, 54, 57, 59, 60, 63-65, 72, 81, 111, 125]. Central America-Caribbean Sea is considered part of the Caribbean microplate. It lies between the North and South American, Cocos and Nazca plates (**Figure 2**). The northern boundary is a left-slip (~2.000 km) active fault system that links at its western and eastern ends to two subduction zones (Pacific and Atlantic) with seismic and volcanic activity. The eastern contact is approximately -71º W, with an age of ~$109x10^6$ years and velocity ~2 cm/year, and extends from Puerto Rico to the vicinity of Venezuela. The western part has the subduction of the Cocos plate under the Caribbean plate, with a significant successive modification of the profile and dynamic characteristics of the active edge. In the northern margin there are small convergent segments in an approximate NE-SW direction. The main structure here is the E-W-directed, pull-apart (~1.000 km) Bartlett-Caiman Trench with an oceanic crustal spreading center (~110 km wide), in Islas Caimán. This center has been active since the Middle Eocene (average expansion rate 1,5 cm/year). In the Cayman Islands-Cuba-La Florida meridian there is an abrupt change of strike in the structures from NE to SW. The concavity is considered to be related to the differentiation of the Caribbean-North American trans-compressional processes and is reflected in the concave trace of the Nortecubana and Surcubana faults. The southern edge of the microplate is much more heterogeneous, complex and active. It extends between the Panama Deformed Belt, with the Boconó and El Pilar fault systems, to the Lesser Antilles.

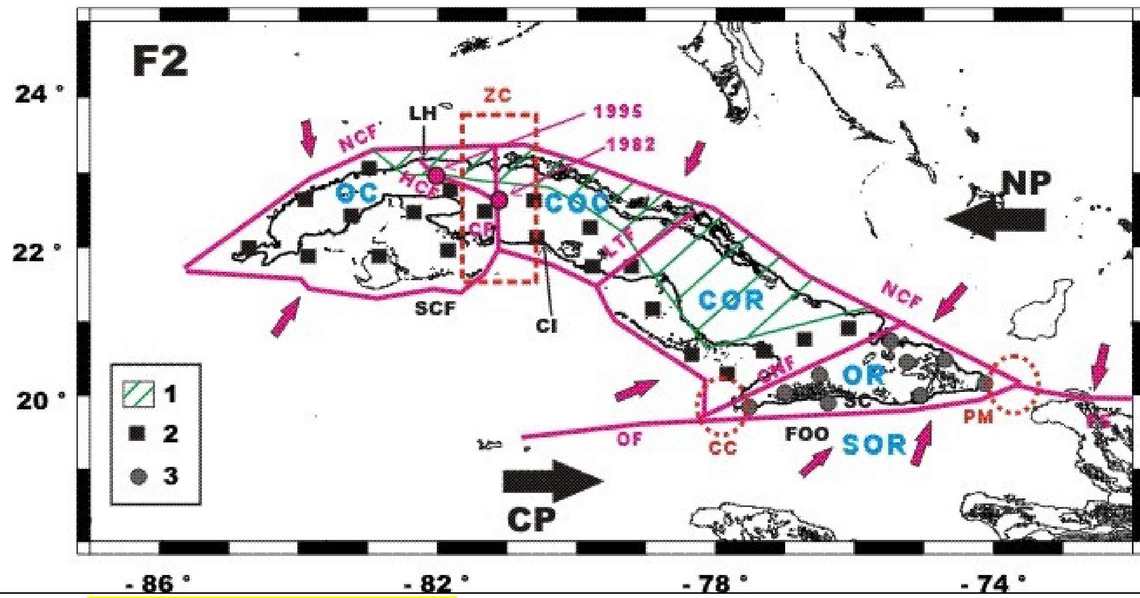

Figure 2. Simplified Neotectonic Province of Cuba (Cotilla *et al*. [60]). Appear: **1)** Neotectonic Units (blue letters: OC=Western, COC=Centre-Western, COR=Centre-Eastern, OR=Eastern, SOR=Southeastern); **2)** Faults (red lines with acronyms: CF=Cochinos, CNF=Cauto-Nipe, HCF=Habana-Cienfuegos, LTF=La Trocha, NCF=Nortecubana, OF=Oriente, SF=Septentrional, SCF=Surcubana); **3)** Knots (orange circles and letters: PM=Punta de Maisí); **4)** Sense of the plate movements (heavy black arrows: PC=Caribbean, PN=North American); **5)** Strees $\sigma_{hmáx}$ (red arrows); **6)** Crust tipes (see legend: Transitional (1=heavy, 2=thin), 3=oceanic-modified); **7)** ZC=Zone of structural change (orange discontinue rectangle); **8)** Red circles (epicenters of 1982 and 1995).

Cuba is an emerged and differentially rising megablock between its parts, which is tectonically incorporated to the southern edge of the North American plate. Its structural features, complex and heterogeneous, were acquired in two stages of geologic development: **a)** Cuban orogeny (Middle Eocene); **b)** neotectonic (Upper Post Eocene) characterized, respectively, by two types of oscillatory movements (compressive and vertical) responsible for the differentiation, the division into blocks and the development of a sedimentary cover, little deformed, which partly covers the pre-neotectonic structures, and which are reflected in the relief. The division into blocks was produced from tectonic boundaries, longitudinal and transverse, of the pre Upper Eocene stage, as areas of weakness used by new ruptures; although with a different style and trend, mainly vertical. The complexity of Cuba's structure is evidenced in geological and geophysical slices, where rock sequences from different structural-formational zones appear stacked, mixed and differently dislocated. At present, there are four Neotectonic Units (Western, Central-Western, Central-Eastern and Eastern) divided by a NW-SE transverse-diagonal fault (Cochinos) and two NE-SW (La Trocha and Cauto-Nipe). The megablock is limited to the north by the Nortecubana fault and in the Cabo Cruz-Punta de Maisí area by the Oriente fault (**Figure 2**).

3.2 Seismicity and Seismic Hazard in Cuba

The contemporary spatio-temporal location of Cuba, in the North American-Caribbean context (**Figure 1A**), decides its seismic activity [65]. The research by Álvarez *et al*. [2, 3, 5, 7] has been an important advance in the knowledge and design of subsequent work actions. We should also consider the contributions of: Chuy-Rodríguez [15]; Chuy [16, 17]; Chuy and Álvarez [18]; Chuy and Pino [20]; Chuy and Rodríguez [21]; Chuy *et al*. [22-24]; Cotilla [40]; Cotilla and Udías [53], Cotilla *et al*. [56, 57, 61]; González and Chuy [70]; González *et al.* [71]; Gutenberg and Richter [73]; Hall [74]; Iñiguez *et al*. [80]; Mallet [80]; Martínez-Fortún y Follo [82]; Morales-Pedroso [84]; Moreaus de Jones [85, 86]; Pacheco and Sykes [94]; Perrey [98-100]; Pezuela [101]; Pichardo [102]; Poey [103-108]; Reyes [109]; Robson [109]; Rutten and Raadshooven [110]; Sagra [112, 113]; Salteraín y Legarra [115]; Shepherd and Aspinall [116]; Shepherd and Lynch [117]; Sherer [118]; Valiente-Duany [121]; Viñes [122]; Viñes-Martorell and Salteraín-Legarra [124]; Wiggins and Atakan [127]. This extensive list demonstrates the interest of specialists in this type of scientific work. Thus, there are catalogs and arguments on seismic activity, which in the case of Cuba is classified as medium-low level. Cotilla [27, 31, 32, 35, 36, 38] presents an extensive discussion of the completeness and reliability of these and other data that relate to results of Cotilla [28, 29, 33, 34, 37, 39, 41, 42], Cotilla and Córdoba [44, 46-51], Cotilla and Udías [53, 55] and Cotilla *et al*. [58, 62] who made important criticisms of some works such as those of Chuy-Rodríguez [15], González and Chuy [70], Orbera [91] and Orbera *et al*. [92, 93]. These criticisms concern the high manipulation and distortion of data, as well as the failure to incorporate more up-to-date results of historical earthquakes in 1551, 1766, 1852 and 1880.

Table 2 summarizes the seismicity of Cuba. It shows the differentiation of its seismic activity into two types (between plates (Caribbean-North American) and inside plate (North American)). This characteristic has been intuitively recognized by the Cuban population. From the beginning of the colony it was assumed, by the great majority and also by scientists that earthquakes only occurred in the eastern part of Cuba. For this reason, the population is still surprised, today, when an earthquake occurs in the Central and Western parts of the country (examples: 1880/01/28, 1939/08/15 and 1982/12/16). Table 3 lists ten strong earthquakes around Cuba; and table 4 lists tsunamis in the Northern Caribbean region.

Table 2. Selection of strong earthquakes of Cuba.

Date/ Time/ M/ I (MSK1978)	Coordinates (N W)/ h (km)/ Deaths/ Injured	Date/ Time/ M/ I (MSK1978)	Coordinates (N W)/ h (km)/ Deaths/ Injured
1551.10.18/ 12:00/ 6,6/ 8	19,6 77,8/ 15/ -/ 7	1939.08.15/ 03:52:31/ 5,6/ 7	22,50 79,00/ 20/ -/10
1678.02.11/ 14:59/ 6,75/ 8	19,9 76,0/ 30/ 1/ 3	1947.08.07/ 00:40:04/ 6,6/ 7	19,600 75,313/ 35/ 1/ some
1766.06.11/ 00:00/ **7,2/ 9**	19,9 76,1/ 30/ **40/ 700**	1976.02.19/ 13:59:59/ 5,9/ 7	19,885 76,878/ 15/ 1/ 8
1852.08.20/ 14:05/ 6,4/ 9	19,75 75,32/ 30/ 2/ 200	1982.12.16/ 04:07:10/ 5,0/ 6	22,61 81,23 / 20/ -/ 2
1880.01.23/ 04:30:00/ 6,2/ 8	22,70 83,00/ 25/ 3/ 20	1992.05.25/ 16:55:04/ 6,8/ 7	19,613 77,872/ 23,1/ -/ 40
1914.02.28/ 03:21/ 6,2/ 7	20,30 76,20/ 15/ -/ 2	2020.01.28/ 19:10:24/ 7,7/ 3	19,421 78,763/ 14,8/
1932.02.03/ 06:16:03/ 6,75/ 8	19,682 75,677/ 25/ 25/ 350		

Notes: 1) The MSK scale is used throughout the text; 2) Maximum values are highlighted in bold and red. .

Table 3. **Some nearby strong earthquakes in the Caribbean.**

Date/ M	Country	Date/ M	Country	Date/ M	Country
1842.07.05/ **8,2**	Haití (**200.000 deaths**)	1692.06.07/ 7,5	Jamaica	2009.05.28/ 7,3	Honduras
1670.05.02/ 8,0	Puerto Rico	1946.08.04/ 7,5	R. Dominicana	1972.12.23/ 6,3	Nicaragua (**10.000 deaths**)
1970.07.31/ 8,0	Colombia	1976.02.04/ 7,5	Guatemala	1986.10.10/ 5,7	El Salvador
1991.04.22/ 7,6	Costa Rica				

Table 4. **Tsunamis in the Northern Caribbean.**

Country	Date/ Total events
Haití	15.09 y 21.11.1751; 1769; 3.06.1770; 11.02.1775; 3.1755; 18.12.1775; 7.05.1842; 08.03.1860; 23.09.1887/ **10**
Jamaica	1.03.1688; 7.06.1692; 3.10.1780; 1.08.1781; 27.10.1787; 11.11.1812; 12.08.1881; 14.01.1907/ **8**
Cuba	1.11.1755 (Lisboa); 18.11.1867 (Islas Vírgenes); 01.10.1931 y 04.08.1939 (Nortecubana fault)/ **4**
Puerto Rico	11.10. y 24.10.1918; 08.08.1946; 1.11.1989/ **4**
Islas Vírgenes	16.04.1690; 18.11.1867; 11.03.1874/ **3**
R. Dominicana	18.10.1751; 4.08.1946; 31.05.1953/ **3**

Note: R. Dominicana= República Dominicana.

CENAIS is the official state institution in charge of Cuba's network of seismic stations. In 2020, it ensures that there are operational: **a)** 19 stations (Very BroadBand), six in the West (Cabo San Antonio-Holguín) and 13 east of Holguín. The equipments are in the highest activity areas classified with I≥6 degrees (**Figures 3 and 5A**); **b)** 14 stations of strong ground movements around Santiago de Cuba city, where I=8. With this network, the coverage of the territory has greatly improved, but there are still areas in the western region that need to be adequately covered. The latter can be complemented, for better determinations, with the seismic networks of Jamaica and Puerto Rico, mainly.

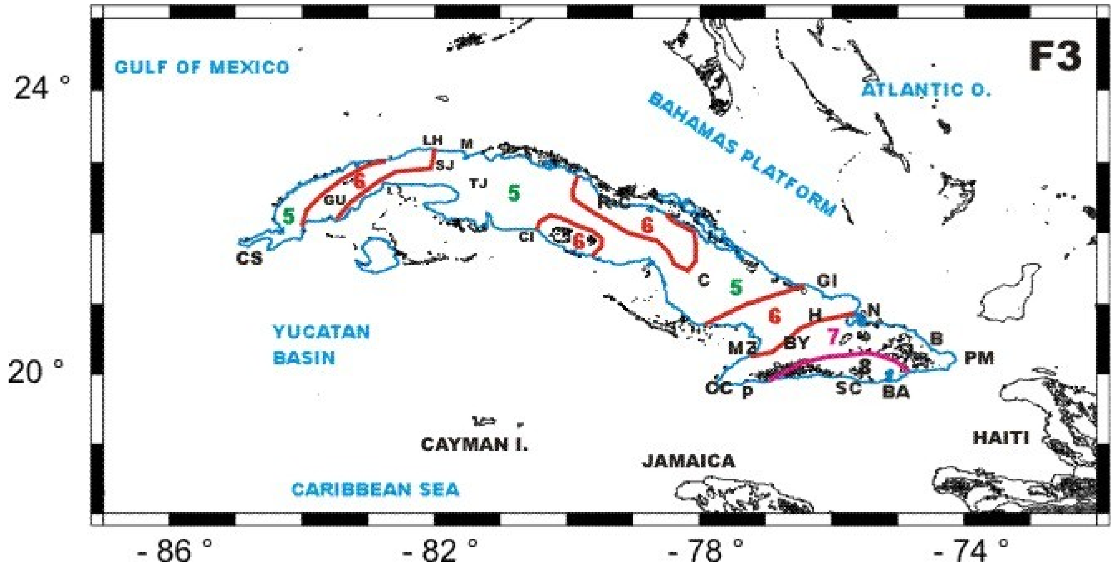

Figure 3. Seismic hazard map of Cuba (Álvarez *et al.* [5]). Appear: **1)** Seismic intensity zones (5-8 degree); **2)** Localities: B=Baracoa, BA=Baconao, BY=Bayamo, C=Camagüey, CI=Cienfuegos, CS=Cabo de San Antonio, GI=Gibara, GU=Guane, H=Holguín, MZ=Manzanillo, N=Nipe, P=Pilón, PM=Punta de Maisí, R=Remedios-Caibarién, SC=Santiago de Cuba, SJ=San José de Las Lajas, TJ=Torriente-Jagüey Grande.

The estimation of seismic hazard in Cuba has been the subject of numerous investigations, starting with the deterministic processing of information on earthquakes felt in Cuba [1, 22]. These were followed by those incorporating earthquake statistics in different zones, obtaining maps in terms of intensities for different recurrence/return periods. In the first, Álvarez *et al*. [5] give a different treatment to earthquakes in the southeastern region (source zones with occurrence statistics) and to those in the rest of the territory (alignment knots and formal treatment of seismicity). The map obtained, for a recurrence period between 100 and 300 years (which could be classified as semi-deterministic Seismic Hazard) is shown as a basis in the **figure 3**. Later on, these data were processed uniformly for the entire national territory and the first probabilistic estimates of seismic hazard in Cuba were obtained [3]. Then, attempts were made to express the probability in terms of peak acceleration [**PGA**] by converting intensities to PGA, among them [19]. The process of updating seismic hazard estimates has gone through two other stages, the first to obtain direct estimates of PGA [69] and the second to obtain uniform hazard spectra [**UHS**] [4, 69]. In both cases, logical decision tree techniques were used.

Figure 3 shows the distribution of eight seismic intensity zones in the 5-8 degree range, for a 100-year recurrence period throughout Cuba, while **figure 4** shows faults and locations, with some modifications, of figure 2 from Frometa-Alfaro *et al*. [70]. It contains the seismicity recorded by the National Seismological Service of Cuba (1998-May 2016) in the eastern region [14] and allows to differentiate on the map the spatio-temporal distribution of seismic activity: **a)** from Camagüey to Maisí (W-E); **b)** from the north of Camagüey to the north of Guantánamo, where the trace of the Nortecubana fault can be observed (NW-SE); **c)** from Cabo Cruz to Nipe (SE-NW), associated with the Cauto-Nipe fault; **d)** on the Oriente fault, with a higher density, as is appropriate for a plate boundary. Regardless of the different number of stations, in the vicinity of Camagüey and in the eastern region, the difference in the number of epicenters can be seen: **a)** west of the trace of the Cauto-Nipe fault line; **b)** this is also true for the Nortecubana fault, which has a much larger quantity east of Nipe. In that segment, in the vicinity of Moa, there was the earthquake of 1998/12/28/ 07:23:31/ M_{max}5,6/ I_{max}5/ 20,780 N 74,673 W/ h10 km/ 500 aftershocks/ reverse mechanism. The delimitation of Cotilla *et al*. [31, 37] is confirmed for: **a)** the Nortecubana fault in two segments (Puerto Padre-Gibara-Nipe and Nipe-Maisí); **b)** the three Seismotectonic Units (Central-Western (east of the Cauto-Nipe fault), Eastern (east of the Cauto-Nipe fault) and Southeastern (south, where the Oriente fault is located)) (**Figure 5B**) [27].

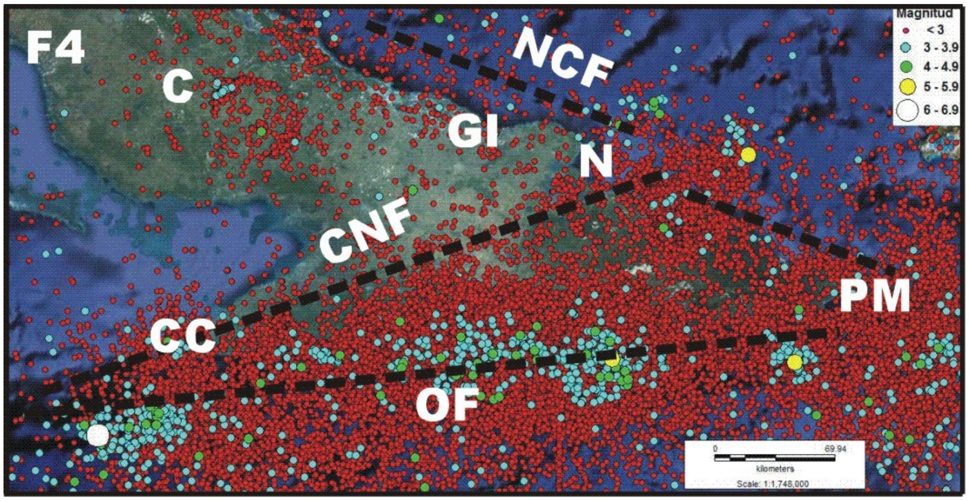

Figure 4. Scheme of the Eastern Cuba seismicity. Appear: 1) Localities (N=Nipe); 2) Fault (discontinue lines) showed in figure 2; 3) Epicenters [14].

The United States of America has an important seismological service that covers the entire planet. They have a high quality earthquake hypocenter location service and an efficient tsunami warning service (US Tsunami Warning System). They support Caribbean countries, including Cuba, with real-time information. The authors have found that, in most cases, the USGS determinations differ from those provided by the Cuban network [6]. Examples: earthquakes of: a) Pilón 1976/02/19; b) Torriente-Jagüey Grande 1982/12/16.

For the first time, the following information on the 1976/02/19 earthquake in Pilón, a locality between Cabo Cruz and Santiago de Cuba, is reported in a popular science article. On page 61 of Bohemia Magazine [107], there was a photo of the landslides of blocks in the area of the Sierra Maestra, towards the narrow coastline in Pilón and a brief three-paragraph article: "...at 9:17 a.m. an earthquake with a magnitude at its epicenter estimated at 6 on the Richter scale...with a death toll of one (Eugenio Peña, construction worker) and eight injured..."

In Cuba: a) earthquake protection plans are entiry designed and controlled by the Civil Defense. This institution was founded in 1962 and is headed by the Ministry of the Armed Forces; b) three seismic construction standards have been developed under the direction of the Ministry of Construction. CENAIS participates in these activities.

Since 1996, it has been feasible, on the part of the authors, to: a) access, for the first time, to the General Archive of the Indies in Seville; b) to review, exhaustively, various archives, libraries and newspaper libraries of institutes, ministries, scientific museums and universities in: Belgium, Dominican Republic, France, Germany, Holland, Italy, Jamaica, Mexico, Portugal, Puerto Rico, Spain, United Kingdom, United States of America and United States of America. These two points made it possible to reach the original sources and to analyze and re-evaluate many data previously published and used by other specialists; c) to produce several publications on historical earthquakes [34, 37, 41, 46-50, 53, 55]: d) a comprehensive description of the history of seismology in Cuba and the

Northern Caribbean [28, 29, 31-33, 38, 52, 60]. This line of work and the range of results were outlined from the projects of Álvarez *et al*. [5]. Unfortunately, Cuban specialists have not included these results to date.

Based on these data, **tables 5-6** present the characteristics of 23 earthquakes considered by the authors as the main earthquakes in Cuba. The seismotectonic structure delineated for Cuba (**Figure 5B**) has required this information [33, 39, 41, 42, 44, 45, 49, 52, 54, 60, 63, 65]. Cuba is defined as an active Seismotectonic Province with four Units (Western, Central-Western, Eastern and Southeastern (**Table 7**)), 12 geodynamic cells and a set of 13 active faults, segmented and articulated, with 14 intersections (or knots). The Southeastern Unit and the Oriente fault are its main structures. The largest number of knots is in the Structural Change Zone, in the vicinity of La Habana-Matanzas.

It has been determined that there are two groups of strong earthquakes in the Southeastern Seismotectonic Unit: **a)** 1976/02/19, 1932/02/03 and 1947/08/07; **b)** 1551/10/18, 1992/05/25, 2007/02/04 and 2020/01/28, associated with the Oriente seismogenic fault. This is a category I structure with a recurrence period of ~90 years and the highest number of casualties, which has two different segments: **a)** Islas Caimán-Pilón (M_{max}7,7); **b)** Pilón-Baconao (M_{max}7,2), respectively. These earthquakes have other distinctive characteristics: **a)** the direction of the rupture to the west and east, respectively; **b)** the transcurrent focal mechanism in the Cayman-Pilon segment and trans-comprehensive and trans-tensive in the other one; **c)** have not generated tsunamis; **d)** perceptibility is to the NW and NE, respectively; **e)** the main event, is always accompanied by several aftershocks over time. These correspond to barrier events, including strong aftershocks.

Table 5. Main earthquakes in Cuba (Cotilla [43]).

Nº	Date/ Time	M/ I	Coordinates (N W)/ h(km)	Rupture (km)	Deaths/ Injured	U.S.D. (10^6)	Panic in the Population
1.1.1	1852.07.07/ 12:25	7,7/ 5	19,7 78,4/ 30	-	-	-	-
1.1.2	2020.01.28/ 19:10:24	7,7/ 3	19,419 78,156/ 14,9	-	-	-	-
1.1.3	1766.06.11/ 00:00	**7,2/ 9**	19,9 76,1/ 30	80	**40/ ~700**	10	Yes
1.1.4	1842.07.07/	6,8/ 8	19,75 75,35/ 30	75	2/ 10	0,5	Yes
1.1.5	1992.05.25/ 16:55:04	6,8/ 7	19,61 77,87/ 23	65	-/ 40	-	-
1.1.6	1678.02.11/ 14:59	6,75/ 8	19,9 76,0/ 30	55	1/ 3	-	Yes
1.1.7	1932.02.03/ 06:15:03	6,75/ 8	19,60 75,313/ 25	25	25/ 350	20	Yes
1.1.8	1947.08.07/ 00:40:27	6,6/ 7	19,600 75,313/ 35	20	1/ some	-	Yes
1.1.9	1551.10.18/ 12:00	6,6/ 8	19,6 77,8/ 15	50	-/ 7	<0,01	Yes
1.1.10	1858.01.28/ 22:04	6,5/ 7	19,9 76,0/ 30	-	1/ 2	-	Yes
1.1.11	1800.10.14/	6,4/ 8	19,9 75,9/ -	50	5/ 30	0,8	Yes
1.1.12	1852.08.20/ 14:05	6,4/ 9	19,75 75,32/ 30	75	2/ ~200	2	Yes
1.1.13	1826.09.18/ 09:29:00	6,4/ 9	19,75 75,35/ 30	55	3/ 20	0,8	Yes
1.1.14	2007.02.04/ 20:56:59	6,2/ 4	19,372 78,512/ 10	40	-	-	-
1.1.15	1976.02.19/ 13:59:59	5,7/ 8	19,87 76,87/ 15	20	1/ 8	-	-
2.1	1914.02.28/ 05:19	6,2/ 8	21,30 76,20/ 50	15	-/ 5	<0,01	Yes
2.2	1939.08.15/ 03:52:35	5,6/ 7	22,50 79,25/ -	20	-/ 10	-	Yes
2.3	1998.12.28/ 07:23:31	5,6/ 5	20,78 74,67/ 10	5	-	-	-
2.4	2014.01.09/ 05:25:29	5,0/ 6	23,19 80,68/ 10	-	-	-	-
3	1880.01.23/ 04:30:00	6,2/ 8	22,7 83,0/ <20	35	3/ 20	1	Yes
4.1	1982.12.16/ 20:20	5,0/ 6	22,61 81,23/ 30	5	-/ 2	0,001	Yes
4.2	1995.03.09/ 18:29:13	2,1/ 5	22,90 82,21/ 3	-	-	-	-
4.3	2015.01.21/ 04:07:10	4,1/ 5	22,216 81,422/ 16	-	-	-	-
	Total= 23 events	**M2,1-7,7**	**Total= ~90/ ~1.400/ ~34**				

Table 6. Supplementary data of Table 5.

Nº	A	B	C	D	E	F	G	H	I	J	K
1.1.1	Oriente	>1.200	1	Southeastern	Yes	-	Yes	Yes	Yes	-	-
1.1.2			1		Yes	-	Yes	-	Yes	-	Yes
1.1.3			1		Yes	85	Yes	Yes	-	Yes	-
1.1.4			1		-	77	Yes	Yes	Yes	Yes	-
1.1.5			1		Yes	65	Yes	-	Yes	Yes	Yes
1.1.6			1		-	55	Yes	Yes	-	-	-
1.1.7			1		Yes	65	Yes	-	Yes	Yes	Yes
1.1.8			1		Yes	49	Yes	-	Yes	Yes	Yes
1.1.9			1		Yes	40	Yes	Yes	Yes	Yes	-
1.1.10			1		-	40	Yes	Yes	Yes	Yes	-
1.1.11			1		-	40	Yes	Yes	Yes	Yes	-
1.1.12			1		Yes	75	Yes	Yes	Yes	Yes	-
1.1.13			1		-	50	Yes	Yes	Yes	Yes	-
1.1.14			1		Yes	50	Yes	-	Yes	-	Yes
1.1.15			1		Yes	55	Yes	-	Yes	Yes	Yes
2.1		1.100	2	Centre-Western	Yes	25	Yes	-	Yes	Yes	-
2.2			2	Centre-Western	Yes	19	Yes	-	Yes	Yes	Yes
2.3			2	Eastern	Yes	9	Yes	-	Yes	Yes	Yes
2.4			2	Eastern	Yes	9	-	-	Yes	Yes	Yes
3	Guane	280	3	Western	Yes	40	Yes	Yes	Yes	Yes	-
4.1	Knot	-	4	Western	Yes	34	Yes	-	Yes	Yes	Yes
4.2	Knot	-	4	Western	Yes	10	Yes	-	Yes	Yes	Yes
4.3	Knot	-	4	Western	Yes	10	Yes	-	Yes	Yes	Yes

Notes: A=Seismogenerating zone; Knot=Faults intersection of Habana-Cienfuegos and Cochinos; B=Longitude (km); C=Category; D=Region; E=Isosists; F=Perceptibility (10^3 km^2); G=Aftershocks; H=General Archive of Indies; I=International Agencies; J=Scientific paper; K=Focal mechanisms.

Table 7. Main characteristics of the Seismotectonic Units.

A	B	C	D	E	F	G	H
Western	Intraplate	6,2/ 8/ 25	5	100	10	58	5,4
Centre-Western	Intraplate	6,2/ 8/ 50	10	100	-	53	4,5
Eastern	Intraplate	6,6/ 8/ 30	15	100	10	<10	0,6
Southeastern	Interplate	7,7/ 9/ 60	70	80	140	100	0,6

Note: A=Seismotectonic Unit; B=Type of seismicity; C=M_{max}/ I_{max}/ h_{max} (km); D=Deaths (%) earthquakes; E=Recurrence period (years); F=Estimated number of fatalities; G=Rupture length (km); H=Estimated number of inhabitants (10^6).

Figures 5A-B indicate four characteristics: **a)** correspondence between its elements; **b)** unequal seismic hazard of the archipelago; **c)** increased seismic activity on the Caribbean plate; **d)** the zone of plate interaction (North American-Caribbean) is very well defined.

3.3 Data on Meteors in Cuba and the Caribbean

It is well known that at present: **a)** earthquakes and cyclones and hurricanes are natural phenomena, but of different genesis (Earth's interior and atmosphere, respectively); **b)** population behavior is very different during earthquakes and during cyclones and hurricanes. This is mainly due to the sudden onset of the first. The population is more accustomed to and prepared for the effects of cyclones and hurricanes [10]. The frequency of these is also much higher compared to strong earthquakes; **c)** for the case of Cuba: **c.1)** some of the effects of cyclones and hurricanes, such as: **c.2)** the entrance of the sea to the coasts has been mistaken for tsunamis; **c.3)** the allochthonous location of isolated blocks on coastal terraces has been incorrectly attributed to earthquakes; **d)** the number of cyclone and hurricane fatalities has greatly decreased over time due to the significant improvement in the number and distribution of observatories and detection and warning systems. In fact, Cuba has a good warning system for cyclones and hurricanes [13].

Cuba's geographic location and isolated position in the central-northern Caribbean Sea, as well as its relationship with the Gulf of Mexico and the Atlantic Ocean, are elements that favor the effects of cyclones and hurricanes. These are low pressure systems, on the move, which are accompanied by torrential rains and strong winds. They are classified as: **a)** according to speed into two types: **a.1)** tropical depression (<63 km/h); **a.2)** tropical storm (63->117 km/h); **b)** in five categories (Saffir-Simpson Scale): **b.1)** 119-153 km/h; **b.2)** 154-177 km/h; **b.3)** 178-209 km/h); **b.4)** 210-249 km/h; **b.5)** ≥250 km/h (**Tables 8-9**).

Christopher Columbus' diary records his observations on the storms he experienced in the Bahamas-Spanish-Cuba area. In the knowledge of cyclones and hurricanes, two specialists in Cuba, who dedicated their efforts to the meteorological field, stand out from the beginning: **a)** **Andrés Poey-Aguirre** (La Habana, 1825-Francia, 1919): **a.1)** created (1847) the scientific and literary magazine Colibrí; **a.2)** was director of the Physico-Meteorological Observatory of La Habana (1856-1862); **a.3)** recognized by the director of the Imperial Observatory in Paris, Professor Urbain Le Verrier (1811-1877), in the Spanish Cortes (1860/06/16) as a scientist, advanced in thought and action; some time later the governor of the island dismissed him; **a.4)** was a member and founder of the Royal Academy of Medical, Physical and Natural Sciences of La Habana (1861); years later he resigned from his chair; **a.5)** created the Meteorology Chair; **a.6)** also established in Mexico, at the request of France, a Meteorological Observatory (1865); **a.7)** was a member of the Royal Academy of Sciences in Paris; **a.8)** went into exile in Mexico-France (1869); **a.9)** authored several scientific articles and books; **a.10)** published the first catalogs of earthquakes in Cuba and the Caribbean; **a.11)** died forgotten and in great poverty in exile; **a.12)** the Cuban Meteorological Society awarded him (2003), post mortem, the National Meteorology Award; **b)** **Benito Viñes-Martorell, S.J.** (Spain: 1837- La Habana: 1893): **b.1)** was director of the Magnetic and Meteorological Observatory at Belén College (1858); **b.2)** created a measuring instrument (cyclonoscope); **b.3)** determined the loop (deviation) of the path of cyclones and hurricanes in the vicinity of Cuba; **b.4)** the first hurricane warning in La Habana press (1875/09/12); **b.5)** wrote several scientific papers on earthquakes and meteorology [122, 123]; **b.6)** elaborated the first work on seismotectonics in Cuba, together with the engineer Pedro Salteraín y Legarra; **b.7)** the people of La Habana gave him an impressive funeral procession. Both are considered the **"Fathers of Cuban Seismology"** [29]; both contributed a great deal to the knowledge about earthquakes.

It is considered that the first databases on cyclones and hurricanes were created in the 19th century [9, 77, 87, 88, 99, 119]. Of these, it is feasible to: **a)** to make up **tables 8-9**; **b)** know that the following number of events occurred in the period 1972-2010: **b.1)** natural in the: **b.1.1)** world 10.690; **b.1.2)** Caribbean 1.192; **c)** 23 climatic and two geophysical, with

~$230x10^3$ fatalities and total cost ~$27.000x10^6$ USD. Bello [9] states that in the period 1970-2010, 3.450.258 USD and 498.030 deaths were caused by natural disasters in the world and Latin America-Caribbean, respectively. In its table 2, for five decades, the percentage values of occurrence are: 0,011; 0,007; 0,008; 0,021; and 8,914. The last one turns out to be an anomaly, due to the earthquake in Haiti in 2010. While Campos [11] indicated in his table 1.3 (Impact of natural disasters in 16 Countries of the Latin America and the Caribbean region, period 2010-2011) that there were 25.768.174 people affected, and that Jamaica ($3,5x10^6$ inhabitants) had 3.694 (12,9 %) rate of affectation. The figures are reasonably well in line with the data in the **table 7.** Unfortunately, Cuba did not participate in this event, so it was not included in the **table 1.3**.

Table 8. Some of the most important tropical cyclones and hurricanes (Cotilla [37]).

Meteoro (Period)	Category/ Deaths	Meteoro (Period)	Category/ Deaths	Meteoro (Period)	Category/ Deaths
Storm of San Rafael (1692.10)	-	David (1979.08)	**5/ 2.000**	Katrina (2005.08)	5/ 1.833
Storm of San Fco. de Asís (1844.10)	-/ >100	Kate (1985.11)	3/ 15	Rita (2005.09)	5/ 100
Hurricane of San Marcos (1870.10)	-/ 800	Georges (1998.09)	4/ >340	Wilma (2005.10)	5/ >100
Hurricane of five days (1910.10)	-/ 1.000	Michell (2004.11)	4/ 50	Ernesto (2006.08)	2/ 5
Hurricane of 1924 (1924.10)	-/ 90	Isidore (2002.09)	4/ 5	Gustav (2008.08)	5/ 86
Hurricane of 1926 (1926.10)	-/ 650	Lili (2002.10)	4/ 15	Ike (2008.08)	4/ 145
Hurricane of Sta. Cruz del Sur (1932.11)	-/ 3.500	Charley (2004.08)	4/ 35	Sandy (2012.10)	3/ 283
Hurricane of 1944 (1944.10)	-/ 300	Iván (2004.09)	5/ 90	Irma (2017.09)	5/ >100
Cyclone Flora (1963.10)	-/ 2.000	Dennis (2005.06)	4/ 90	María (2017.09)	5/ 3.059

Table 9. Direct losses due to natural phenomena in the Caribbean.

	People		
Events	**Affected (10^6) 1972-2010**	**Deaths (10^3) 2000-2020**	**Earthquake fatalities (10^3) (1492-2020)**
Earthquakes and volcanoes	17	>230	350
Meteors	34	5	

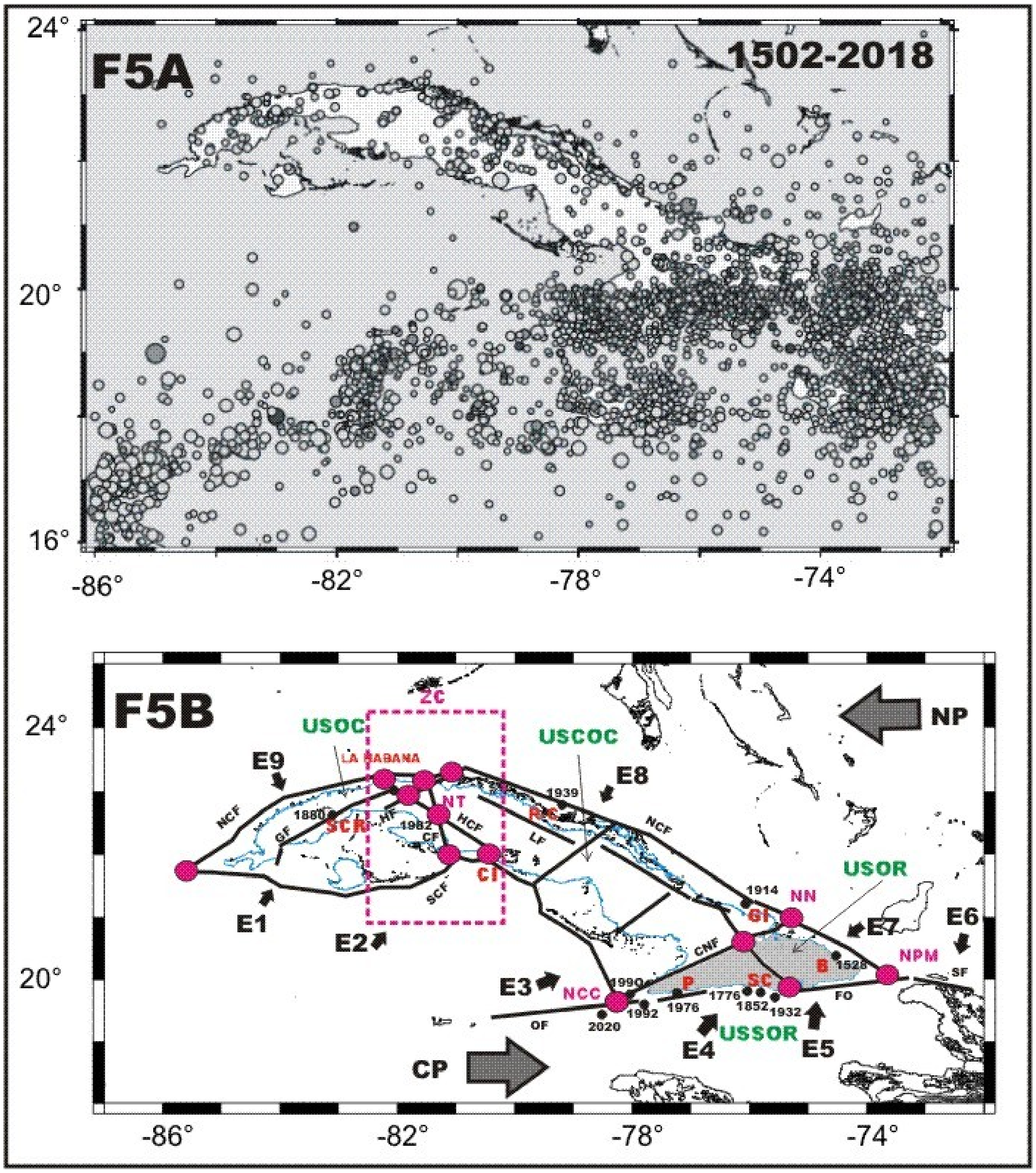

Figure 5. Seismotectonics of Cuba. A) Seismicity map of CENAIS [14]; B) Seismotectonic province of Cuba. Appear: 1) Seismotectonic Units (green leteers: USOC=Western, USCOC=Centre-Western, USOR=Eastern, USSOR=Southeastern); 2) Fault (black lines: CF, CNF, GF=Guane. HF=Hicacos, HCF=Habana-Cienfuegos, LF=Las Villas, NCF, OF, SF=Septentrional, SCF); 3) Epicenters (black circle with year (see Table 3)); 4) Stress axis $\sigma_{hmáx}$ (heavy black arrow with letter and number (E1-5)); 5) localities (orange letters); 6) Knots (red circles and letters (NCC=Cabo Cruz, NN=Nipe, NPM=Punta de Maisí, NT=Torriente-Jagüey Grande)); 7) Plates; 8) Sense of movement of the plates (heavy grain arrows); 9) ZC=Zone of structural change (discontinue red rectangle).

3.4 Discussion

Some studies on Cuba indicate that, in general, the population's perception of earthquake risk is medium-low. Several groups of specialists [68, 75, 89, 95] argue that this is mainly due to little or no personal experience in the face of seismic events. On the other hand, Candebat-Sánchez and Chuy-Rodríguez [12] on page 28 state that: "...The seismic risk of the city is high as a consequence of the factors...high seismic hazard of the southeastern area of the country, specifically of the Santiago de Cuba city...Existence of an aging housing stock with a lack of systematic maintenance, with inadequate construction typologies for seismic zones due to their proven poor performance..."

Hernandez-Suros and Sam-Pascal [75] on page 14 argue: "...The Bayamo city was founded more than 500 years ago, so it has a quite deteriorated housing stock due to the years of exploitation and lack of maintenance. The use of low quality materials, houses built with few technical requirements without seismic-resistant criteria, the use of unskilled labor and the use of construction systems that are not appropriate for seismic zones are the elements that contribute most to the structural vulnerability of the city…". This explains, to a large extent, the altered behavior of the population in the face of strong perceptible earthquakes, such as those of the **table 5**.

It is indicated that the several strong earthquakes in southeastern Cuba, in the surroundings of Santiago de Cuba (M_{max}7,2), and the Gibara earthquake of 1914 (M_{max}6,2), in the northern zone, have not affected the colonial structures of the Primate City of Baracoa (**Figure 5**). They are ~200 and ~250 km away, respectively. This can be seen with its three 18th century fortifications. They have also not been damaged by earthquakes in northern Haiti (Septentrional fault/ M_{max}8,2) and the Nipe-Punta de Maisí segment (of the Nortecubana fault) that borders it to the north. In addition, the following four **tables** show: **10)** some earthquakes from distant sources that have affected Cuba; **11)** a selection of the strongest Caribbean earthquakes; **12)** a summary of the approximate numbers of significant earthquakes and fatalities due to them; **13)** some of the strongest earthquakes in the world, where there are no Caribbean earthquakes. A cursory comparison between Cuba and Haiti using **table 12** shows that for 528 years Cuba has had: **a)** 31 strong earthquakes less; **b)** 349.900 fewer deaths. Haiti is the country with more deaths from earthquakes in the Caribbean (**Table 11**), while Cuba also has a lower level of seismic hazard than Puerto Rico and Jamaica. The latter have been affected not only by strong earthquakes but also by tsunamis.

All the information used here on tsunamis is from Cotilla [39] and Cotilla and Córdoba [50, 51]. Thus, it is known that: **a)** there were 32 tsunamis (from distant and nearby sources) that affected the Northern Caribbean; **b)** tsunamis from far away sources are from eastern Cuba; **c)** the perceptibility in Cuba has been very low; **d)** the two local tsunamis in Cuba occurred on the north and central coast of the island, in the vicinity of Remedios-Caibarién. They respond to the seismic activity of the Nortecubana fault and the compression that supports that segment; **e)** not a few tsunamis, included in other works, have been discarded here, after multiple literature reviews (**Table 14**). This table has a set of characteristics that distinguish three Northern Caribbean countries and facilitate a comparative understanding of seismic activity and the associated hazard.

Table 10. Some earthquakes in four countries that affected Cuba (Cotilla and Córdoba [51]).

Date	M	Country	Date	M	Country	Date	M	Country
1842.07.05	8,2	Haití	1670.05.02	8,0	Puerto Rico	1692.06.07	7,5	Jamaica
1887.09.23	7,9		1787.05.02	8,0		1899.06.14	7,3	
1770.06.04	7,5		1918.10.11	7,5		1971.04.01	7,1	
2010.01.12	7,0		1943.07.29	7,7	R. Dominicana	1907.01.14	6,6	
2004.11.21	7,0		1946.08.04	7,5		1914.08.03	6,0	

Table 11. Some strong Caribbean earthquakes with fatalities.

Date/ Time	M/ I	Coordinates (N W)/ h(km)	Dead	Country
2010.01.12/ 21:53:10	7,0/ 9	18,443 52,571/ 12	300.000	Haití
1976.02.04/ 9:01:43	7,5/ 9	15,324 89,101/ 5	23.000	Guatemala
1972.12.23/ 6:29:44	6,3/ 9	12,184 86,223/ 10	>20.000	Nicaragua
1985.09.19/ 13:17:47	8,0/ 7	18,190 102,533/ 27,9	9.500	México
1943.02.08/ 02:45	8,3/ 8	16,5 62,2/	~5.000	Guadalupe
1946.08.04/ 17:51:10	7,5/ 9	19,083 69,248 / 15	2.550	R. Dominicana
1692.06.07/ 16:40	7,5/ 9	17,8 76,8 / 20	2.000	Jamaica
1986.10.10/ 17:49:24	5,7/ 8	13,827 89,118/ 7	2.000	El Salvador
1906.01.31/ 10:36	8,8/	1,0 81,5/	1.500	Colombia
1999.01.25/ 18:19:16	6,1/ 9	4,461 75,724/ 27	1.230	Colombia
1907.01.14/ 20:35	6,5/	18,2 76,7/	1.000	Jamaica
1902.04.18/ 2:23:30	7,5/ 9	14,50 91,31/ 25	900	Guatemala
2001.02.13/ 17:33:32	7,7/ 8	13,049 88,660/ 60	844	El Salvador
1910.05.04/ 7:00	6,4/ 8	-	700	Costa Rica
1918.10.11/ 10:14	7,5/ 9	18,5 67,5/	184	Puerto Rico
1970.08.16/ 6:40	7,8/ 9	38,8 65,14/ 02	145	Panamá
1992.09.02/ 00:16:01	7,7/ 9	11,742 87,340/ 44,8	116	Nicaragua
1991.04.22/ 21:56:31	7,6/ 9	9,685 83,073/ 10	97	Costa Rica
1997.07.19/ 19:24:13	7,0/ 8	10,598 63,486 / 19,9	>81	Venezuela
2009.05.28/ 08:24:26	7,3/ 8	16,731 86,217/ 19	>7	Honduras

Table 12. Approximate numbers of significant earthquakes and fatalities.

	Earthquakes (Century)							
Country	**XVI**	**XVII**	**XVIII**	**XIX**	**XX**	**XXI**	**Total**	**Deaths**
Haití	2	5	9	13	12	13	54	350.000
Guatemala	1	0	4	2	14	7	28	>25.000
Nicaragua	1	0	1	7	1	2	12	~24.000
El Salvador	1	3	0	9	13	5	31	>4.000
Cuba	1	1	1	7	9	4	23	<100
Total	**5**	**8**	**14**	**31**	**40**	**47**	**148**	**>400.000**

There are many and diverse investigations to expose and estimate the damage (to people and infrastructure) caused by strong earthquakes in the world. Two examples are in the regions of Spitak [8, 25] and Granada, Spain [83]. From them it is known that: a) Spitak-Leninakan- Kirovakan were affected by the earthquake of 1988/12/07/ M7,0/ I_{max}10/ 30.000-50.000 deaths/ 130.000 injured (total affected 180.000 (0,5 % of the total population)) and 700.000 homes destroyed. The type of buildings (Soviet time) and the engineering-geological characteristics favored the damage; **b)** in the event of an earthquake with magnitude 9 in Grenada (917.445 inhabitants), an estimated 3.548 deaths and 21.289 injured (0,3% affected).

The possibility of a strong earthquake and a powerful cyclone and hurricane in the Caribbean within a short time interval is real. This possibility has been recognized since the 20th century. It has apparently been pointed out, and rightly so, that Puerto Rico, the easternmost island of the Greater Antilles arc and by far the best equipped in terms of seismic (including tsunami detection) and meteorological equipment in the Caribbean, has recently suffered two natural catastrophes. Its seismic history includes several strong earthquakes, such as that of 1918/10/11 (M7,3/ I_{max}9/ tsunami/ 116 deaths/ >4x10^6 USD) and more recently, another on 2020/01/07 (M6,4/ I_{max}8/ one dead and eight injured/ 3,1x10^6 USD). This one came ~2 years after (2017/09) Hurricane Maria (**Table 8**) which ravaged it and resulted in losses of close to 4x10^6 USD and 3.059 dead. A similar tragedy occurred in Cuba in 1932 (**Tables 5 and 8**). The effect of the **"strong earthquake"** (M6,75)-hurricane pair produced losses of ~3.500 dead and more than 20x10^6 USD. Also in 1692, Jamaica (**Tables 4, 10 and 12**) was hit by this combination of phenomena, including a tsunami. Therefore, this combination is exceptional but real in the islands of the Greater Antilles.

Table 13. Selection of the earthquakes with the highest $M_{MÁX}$ in the world.

Date/ Time	M	Coordinates / h(km)	Country	Deaths
1960.05.22/19:11:20	9,5	38,143 S 73,407 W/ 25	Valdivia/ Chile	~1.655
1964.03.28/03:36:16	9,2	60,908 N 147,339 W/ 25	S of Alaska/ USA	~131
2004.12.26/00:58:53	9,1	03,295 N 95,982 E/ 30	Sumatra/ Indonesia	>283.100
2011.03.11/05:46:24		38,297 N 142,373 E/ 29	Honshu/ Japón	~15.703
1952.11.04/16:58:30	9,0	52,623 N 159,779 E/ 21,6	Kamchatka/ URSS	-
2010.02.27/06:34:11	8,8	36,122 S 72,898 W/ 22,9	Bio-Bio/ Chile	~523
1931.01.31/ 15:36		00,96 N 79,37 W/ -	Coast of Ecuador	-
1965.02.04/05:01:22	8,7	51,251 N 178,715 E/ 30,3	Rat Islands (Alaska)/ USA	-
1950.08.15/14:09	8,6	28,36 N 96,45 E/ -	Xizang/ India	526
2012.04.11/08:38:36		02,327 N 93,063 E/ 20	N of Sumatra/ Indonesia	~10
28.03.2005/16:09:36		02,085 N 97,108 E/ 30	N of Sumatra/ Indonesia	~1.000
1957.03.09/14:23		51,50 N 175,63 W/ 25	Andrean Islands (Alaska)/ USA	-
1946.04.01/12:29:01		53,492 N 162,832 W/ 15	S of Alaska/ USA	~159
1938.02.01/19:04:22	8,5	05,045 S 131,614 E/ 25	Banda Sea	-
1922.11.11/ 04:33		28,29 S 69,85 W/ -	Atacama/ Chile	~800
1963.10.13/05:17:59		44,872 N 149,483 E/ 35	Islas Kuriles/	-
1933.03.02/ 17:31	8,4	39,21 N 144,59 E/ -	Honshu/ Japón	2.990
1923.02.03/16:01:50		54,486 N 160,472 E/ 15	Kamchatka/ URSS	-
2001.06.23/20:33:14		16,265 S 73,641 W/ 33	S coast f Perú	~100
2007.09.12/11:10:28		04,438 S 101,367 E/ 34	S od Sumatra/ Indonesia	25

Data on the increase of international tourism in Cuba are available from several sources [26, 68, 69, 98, 116]: **a)** period 1992-1993 of 460.510-600.000 tourists; **b)** period 2014-2015 of 3.002.745-3.524.779 tourists; **c)** in 2019 Cuba had 4,75x10^6 visitors. Several digital media give the following amounts in: **a)** 2003, Santiago de Cuba 110.691 foreigner tourists [76]; **b)** more than 110.000 international tourists to Granma province [26]. In this province are the cities of Bayamo, Manzanillo and Pilón; **c)** Pinar del Río more than 212.000 visitors in 2019 [97]; **d)** Cuba had 3x10[6] foreign tourists as of August 2019 (Excelencia News Cuba). This, statistically, is **"seasonal-temporal floating population"**, which, obviously, can be affected by earthquakes; therefore, it must be considered in the analysis.

Table 14. Comparative seismic activity in part of the Northern Caribbean (Cotilla and Córdoba [50]).

	A	B	C	D	E	F	G
La Española	Gonàve-La Española-Puerto Rico	8,2/ 10/ 90	1/ 18/ 28	13	360/ 700	40	2
Jamaica	Caribbean-Gonàve	7,75/ 9/ 50	-/ 4/ 5	8	3/ 4,5	60	1
Cuba	Northamerican	7,7/ 9/ 60	-/ 3/ 13	2	0,1/ 1,4	80	4

Note: **A**=Plate; **B**=M_{max}/ I_{max}/ $h_{máx}$ (km); **C**=Number of earthquakes (M8-8,2/ 7,9-7/ 6,9-6; **D**=Local tsunamis; **E**=Deaths/ Injured (10^3); **F**=Approximate recurrence period of strong earthquakes (years); **G**=Number of Seismotectonic Units.

Finally, **table 15** is presented, which takes into consideration the: **a)** reliability of data in **tables 2 and 4-7**; **b)** real influence of strong earthquakes in the Caribbean on Cuba, and in particular on the Eastern Seismotectonic Unit (**Tables 10-11**); **c)** temporary presence of foreigners in Cuba; **d)** soundness and veracity of what has been exposed and discussed in the previous sections, in relation to strong earthquakes and the information on buildings in Cuba; **e)** repetition in time and place of strong earthquakes. It includes a diagnosis, but not a prognosis, of the possible effects of ten of its cities. All of them have been hit, in different ways, by earthquakes, and it can be seen that: **a)** the estimate is reasonably close to the percentage values in the preceding paragraph; **b)** Santiago de Cuba is the city with the highest percentage of possible damages.

Table 15. Diagnosis of damage caused by strong earthquakes in Cuba.

	Affectations	
City/ Inhabitants	Seismic zone/ Local-farmer earthquake / M_{max}	Tsunami/ Buildings/ People (%)
Santiago de Cuba/ 444.851	8/ Yes-No/ 7,2	No/ GP/ 2
Baracoa/ 79.797	7/ Yes-Yes/ 6,0	PP/ MPO/ 0,3
Bayamo/ 235.107	7/ Yes-No/ 6,6	No/ MU/ 0,8
Manzanillo/ 150.999	7/ Yes-No/ 6,6	No/ MU/ 0,8
Pilón/ 29.456	7/ Yes-No/ 5,7	No/ MU/ 0,5
Caibarién/ 38.479	6/ Yes-No/ 5,6	Yes/ PO/ 0,7
La Habana/ 2.141.652	6/ Yes-No/ 5,5	MP/ PO/ 0,2
San Cristóbal/ 29.119	6/ Yes-No/ 6,2	No/ MU/ 1
Jagüey Grande/ 87.771	5/ Yes-No/ 5,5	No/ PO/ 0,6
Mariel/ 45.016	5/ Yes-No/ 5,5	P/ PO/ 0,2

Note: GP=A large part of; MP=Very unlikely; MPO=Very few; MU=Many; P= Likely; PO=Few; PP=Unlikely.

The seismotectonic investigations of the Ministry of Basic Industry of Cuba were carried out in the 1980s-1990s applying the Russian methodology of Krestnikov [79]. Some examples include: Orbera [93]; Orbera *et al*. [92, 93] (**Figures 6A-B**). Under the heading Seismicity and seismic hazard in Cuba, it was stated that the first author published a series of papers and reports that showed the inconsistency of these works. In particular, he argued that the modifications made by Orbera *et al*. [93], to exclude the Nuclear Research Center [**CIN**] in La Habana from seismic hazard, are unquestionably evidenced by the recent occurrence of an earthquake in the town of San José de las Lajas (La Habana/ 1995/04/9/ M_s2,5/ I_{max}V) [71] (**Figure 6B**). González *et al*. [71] determined that the seismic perceptibility was towards the NW (La Habana City), on the same alignment that affects the locality of Torriente-Jagüey Grande, where the earthquake of 1982/12/16 [28, 30, 33, 45, 62, 64, 65]. The epicenter of San José de Las Lajas is only about ten kilometers from the CIN. This result differs, absolutely, from the **figure 5B** [62].

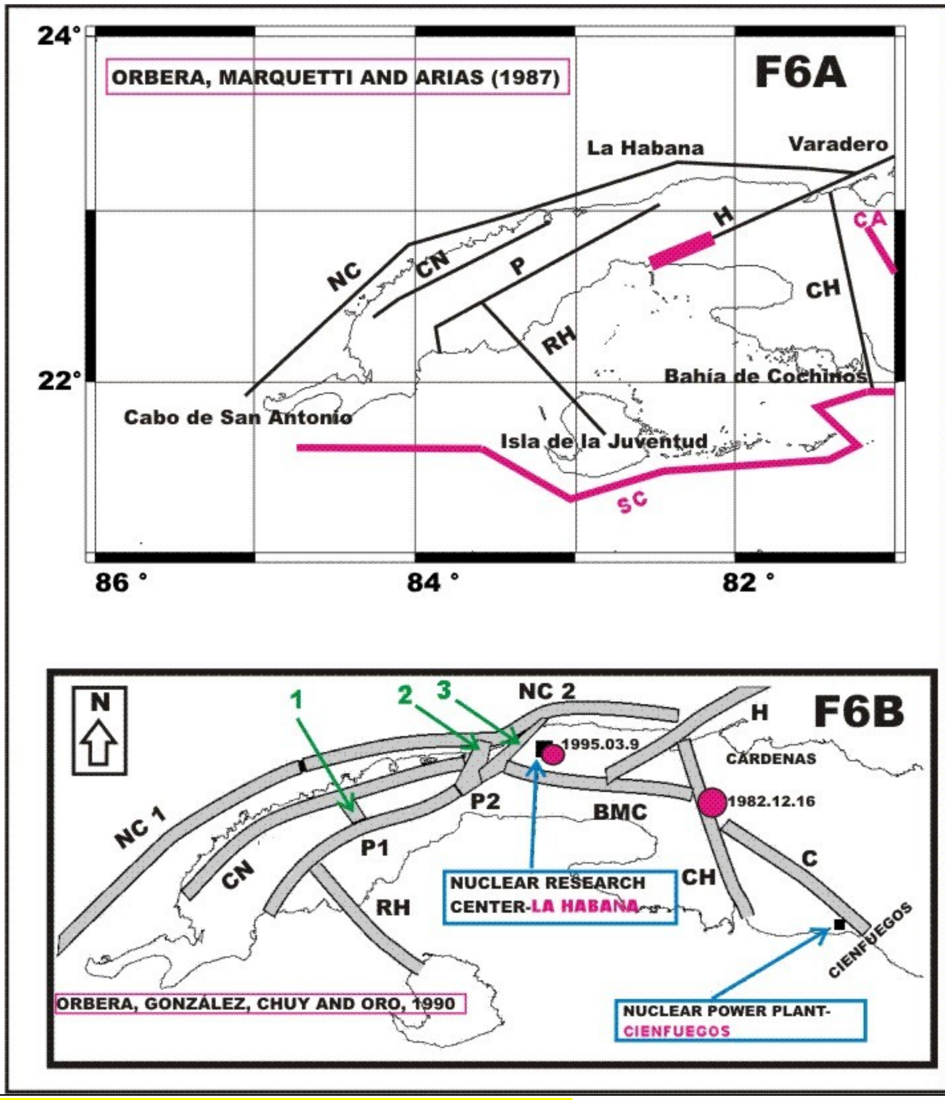

Figure 6. Two maps of the seismogenerating zones of Western Cuba. 6A) Published in 1987 by Orbera, Marquetti and Arias [92]. Appears: 1) Lines (seismogenerator zones: 1.1) In black color: CH=Cochinos, CN=Consolación del Norte, H=Hicacos, NC=Nortecubana, P=Pinar, RH=Río Hondo; 1.2) In red color: CA=Caibarién, SC=Surcubana, H segment (these 3 elements are not in figure F6B); 6B) Published in 1990 by Orbera, González, Chuy and Oro [93]. Appear: 1) Red circles (epicenters: 1982 (Torriente-Jagüey Grande), 1995 (San José de Las Lajas)); 2) Black rectangles (Nuclear projection centers); 3) Green arrows with numbers (new and segmented elements); 4) Green bands (seismogenerator zones: BMC=Bejucal-Madruga-Coliseo, C=Cienfuegos, CH=Cochinos, CN=Consolación del Norte, H=Hicacos, NC=Nortecubana, P=Pinar (P1, P2), RH=Río Hondo).

Using the work of Cotilla [30] and Cotilla *et al*. [62] as a guide for criticism, we confirm that: **1)** it is not possible, in any way, to draw isosists in the sea, as shown in **figure 7B**; **2)** the spectacular inflections of the isoseismic lines in the vicinity of the Nuclear Research Center, and the drastic change in the main axis of propagation in the vicinity of Torriente-Jagúey Grande, demonstrate, without fail, the nefast intention of these authors; **3)** the authors of these extravagant modifications are the same who held other positions on seismicity (year 1983), but without adding new information (year 1990); **4)** these modifications lead to rule out the existence of La Habana-Cienfuegos fault (**Figure 5B**), which fits the location of the 1982 and 1995 epicenters and the respective isoseismals and consequently to justify the construction of the Nuclear Research Center in La Habana.

Four recent publications [43, 56-58] validate the seismic activity in Cabo Cruz, Santiago de Cuba and Remedios-Caibarién. They also confirm the tsunamigenic activity of Remedios-Caibarién and completely rule out the generation of local tsunamis in Santiago de Cuba.

Conclussions

With that has been exposed and commented, it is possible to conclude that Cuba, as a neotectonic structure, is incorporated to the southern part of the North American plate. It shows a differentiation of seismic activity that is related to a set of 12 geodynamic cells, 13 faults and 14 intersections within the four Seismotectonic Units

Two active faults stand out in the Seismotectonic Province of Cuba: **1)** Oriente (Caribbean-North American plate boundary); **2)** Nortecubana (intra plate structure). Another significant difference between them is that the second one has associated with it the only two local tsunamis in the country. It was argued: **1)** on the differences between the Oriente and Nortecubana faults in relation to the Septentrional fault of Hispaniola; **2)** the higher category and hazard (M_{max}/ frequency of occurrence/ local tsunamis) of the Septentrional fault and its unrelatedness to the faults in Cuba.

The Cuban territory has historical and instrumental seismic events with M<8,0. Of the known earthquakes 23 were selected and 22 of their characteristics were given for each one. We emphasize that the zone of greatest seismic hazard in Cuba is in Santiago de Cuba and the diagnosis carried out for strong earthquakes in ten localities indicated, again, Santiago de Cuba. This is in the Southeastern Seismotectonic Unit. In addition, a comparison of strong earthquakes in the Northern Caribbean was made and the non-exceptional nature of the disastrous action of the earthquake-hurricane pair was exposed. However, it is pointed out that this combination is the result of chance, since there is no causal relationship between them. Cuba was found to have a lower seismic hazard compared to Hispaniola, Puerto Rico and Jamaica.

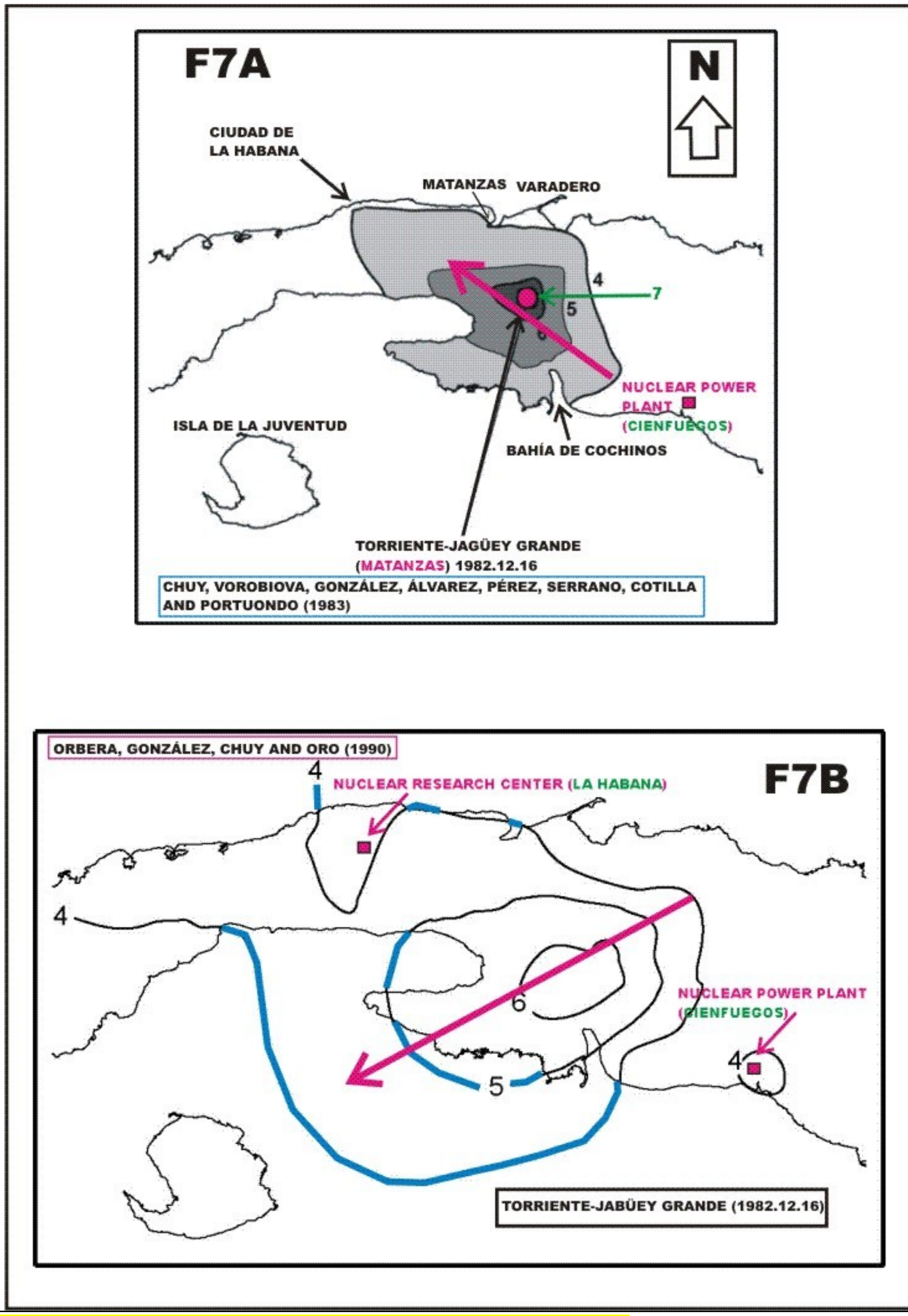

Figure 7. Two isoseismal models of the 1982 Torriente-Jagüey Grande earthquake. **7A)** Published in 1983 by Chuy, Vorobiova, González, Álvarez, Pérez, Serrano, Cotilla and Portuondo [24]. Appear: **1)** Red square (Nuclear Power Plant of Cienfuegos); **2)** We have indicated in red the direction of energy propagation (red arrow); **7B)** Published in 1990 by Orbera, González, Chuy and Oro [93]. Appear: **1)** Red squares (Nuclear Power Plant of Cienfuegos and Nuclear Research Center); **2)** We have indicated in: **2.1)** blue the stretches of isosists over the sea; **2.2)** red the direction of energy propagation (red arrow).

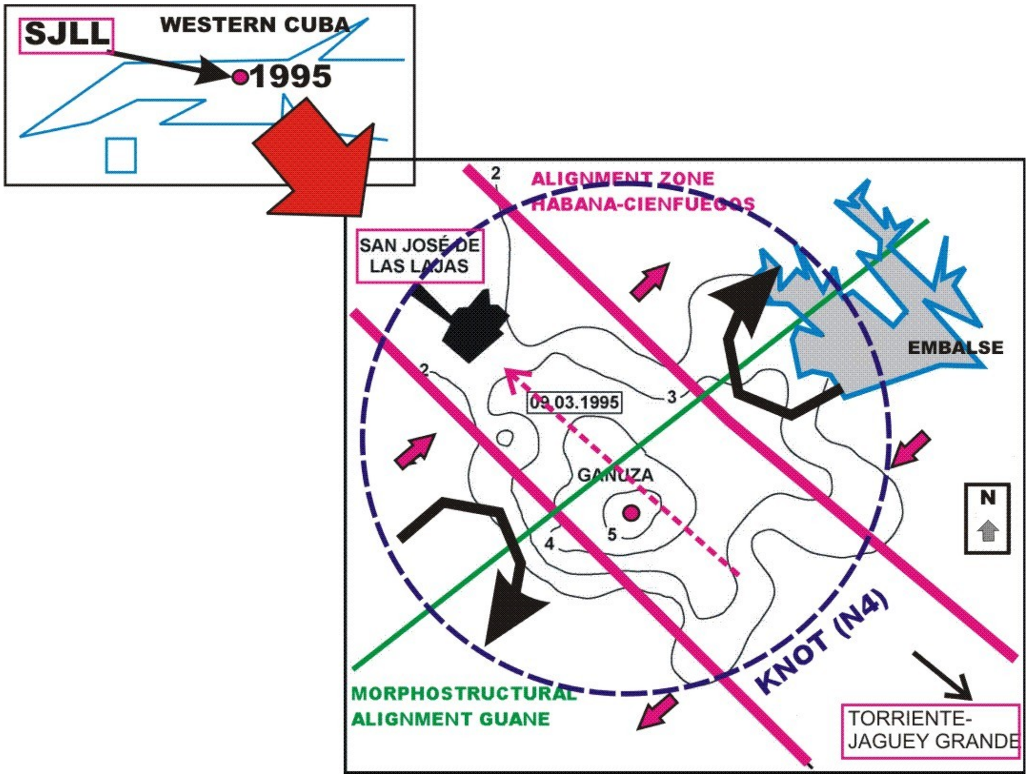

Figure 8. Morphotectonic surroundings of San José de Las Lajas (Cotilla [28]). Appear: 1) Morphostructural alignment Guane (green line); 2) Isoseismals of the 1995 earthquake of González *et al*. [71]; 3) Alignment knot (N4=San José de Las Lajas, purple dashed circle); 4) Sense of relative movement of the blocks (red arrows)); 5) Sense of rotational movement (black curved arrows); 6) Direction of energy propagation (dashed red arrow)); 7) Alignment zone Habana-Cienfuegos (red lines).

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Max PLANCK (Alemania, 1858-1947):"La ciencia es la progresiva aproximación del hombre al mundo real."

4-Cuba-Venezuela Earthquakes of 1766: Part I- General Historic Data Review and Treatment

4-Cuba-Venezuela Earthquakes of 1766: Part I- General Historic Data Review and Treatment
{*Terremotos de Cuba-Venezuela de 1766: Parte I- Revisión y tratamiento de datos históricos generales*}

Abstract- The two strongest documented historic earthquakes in Cuba and Venezuela are studied from the historical and seismic point of view. These territories, as colonies of Spain, had different economic level, being more weighted in Cuba. Both colonies were the main ports of the royal monopoly and where the conquest of the mainland began. Earthquakes occurred in 1766 in two different plate boundary zones: (a) North American-Caribbean (11.06 in Santiago de Cuba), (b) South American-Caribbean (21.10 in Cumana). No tsunami occurred with them. The Orient fault was responsible for the earthquake in Cuba. The epicenter of the second earthquake is a seismic active area (NVA knot) in the vicinity of Trinidad, where the faults El Pilar-El Soldado-Los Bajos' system are combined in the subduction zone of the Lesser Antilles.

Keywords: Caribbean, Cuba, earthquake, historical seismicity, Venezuela

Introduction

The study area, Caribbean region, has two large island arches (Antilles: Greatest (E-W) and Lesser (N-S), with 7.020 islands and area ~300.000 km^2) (**Figure 1**). The first one in the northern zone is composed by Cuba [**C**], Jamaica, Hispaniola (Haiti and Dominican Republic) and Puerto Rico. The Lesser Antilles at E link Puerto Rico and Venezuela [**V**]. These islands separate Caribbean Sea of Atlantic Ocean. In the S are V and Colombia in South America. The Lesser Antilles and V have a complex geodynamic interaction with earthquakes and tsunamis. A proven scientific source, Alexander von Humboldt (1769-1859), was used to compare the historical context of the 1766 earthquakes in Cuba (11.06) and Venezuela (21.10). It is our proposal. The naturalist visited (1799-1804) Colombia, C, Ecuador, Mexico, Peru and V and carried out the task with different means and many privations. He is recognized: (**a**) as Father of Universal Modern Geography; (**b**) like second discoverer of C; (**c**) been more useful for America than all conquerors. Also, he assured that: (**a**) agriculture and not just mining is a source of prosperity; (b) existed a real differentiation of agriculture in terms of variety of products and production type of Mexico and from slavery-monopoly in C and Jamaica; (**c**) scientific knowledge requires experimentation. This extraordinary scientist: (**a**) lived and valued the earthquake of Cumana (04.11.1799) and related it with that one of Quito; (**b**) also survived earthquakes in Colombia, Ecuador, Mexico and Peru; (**c**) described the earthquakes` characteristics using the types of ground movement, sound, time and duration time; (**d**) related faults and earthquakes; (**e**) showed that the natives were excellent geographers; (**f**) located Juan de la Cosa's world map in 1832.

Humboldt about: (**a**) Cuba (19.12.1800-15.03.1801/ 1804) assured that: (**a.1**) "…we find the noblest and most generous hospitality…"; (**a.2**) it has tradition as a settlement place, strong national identity and being the most European; (**a.3**) the increase of slaves from 1763 (32.000) to 1791-1823 (260.000) was related with the sugar cane; (**a.4**) earthquakes are stronger and more frequent in the East Region than in the Center-West one; (a.5) there is a new large geological formation. It was denominated Güines; (**b**) V argued that: (**b.1**) "I came by accident and was shocked (…for a long time our eyes were fixed on this earth where we have not had to complain about men…)"; (**b.2**) "…the Orinoco River is one of the most majestic…"; (**b.3**) Bourbon flexibility was advantageous ("…after the time when the neutrals have been admitted from time to time in the colonies ports. Actually, they has been allowed to climb to Caracas more easily…"); (**b.4**) "…the colonies, in the period of greatest activity, had a gross income of 180.10^{6} francs but internal administration absorbed ~145.10^{6}, while ~40.10^{6} flowed to Madrid…"; (**b.5**) "…the Jesuits had 20-30 thousand head of cattle…today is cultivated some yucca and bananas… horses and cows have disappeared…"

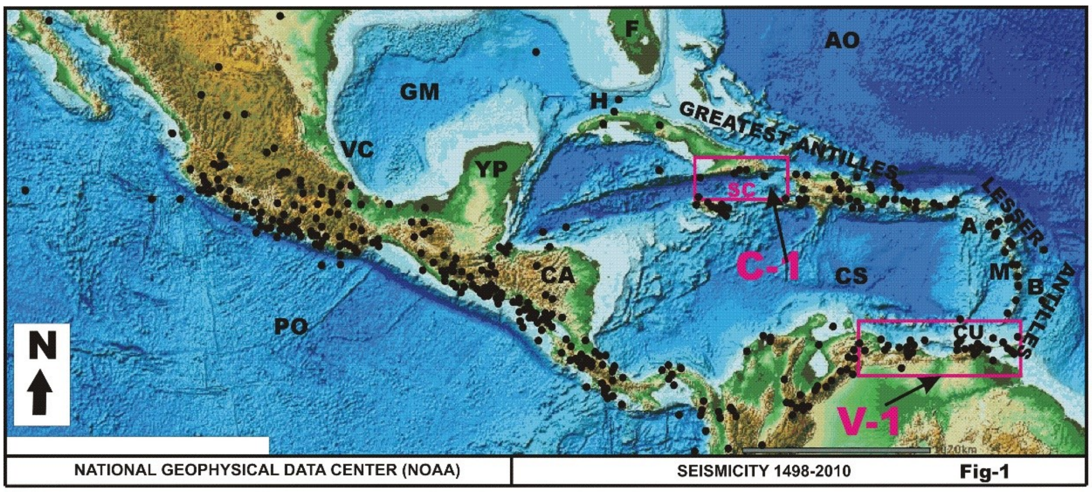

Figure 1. The study areas and their seismicity (NGDC). (**a**) epicenters (black circles); (**b**) study areas (red rectangles: C-1=Cuba/ V-1=Venezuela); (**c**) A=Antigua, B=Barbados, CA=Central America, CS=Caribbean Sea, CU=Cumana, F=Florida, GM=Gulf of Mexico, H=La Habana, M=Martinica, Ocean (AO=Atlantic, PO=Pacific), SC=Santiago de Cuba, VC=Veracruz; YP=Yucatan.

4.1 Historic Framework

The following references were used for this section [3, 4, 6-9, 12-14, 16, 32, 35, 37, 39, 41, 42, 48, 49, 51, 54-56, 60, 62, 67, 68, 76, 77, 79, 80, 91, 95, 97, 98, 99, 100, 107, 109-112, 114, 115, 118, 119, 123, 142, 154-156, 161-164, 167, 173, 177, 178, 186, 188, 193]. From them it can be argued that: (**a**) the Europeans arrived to America at the end of the XV century; (**b**) Admiral Columbus came in 1492 followed by Portugal in 1500, France in 1607, England in 1608 and Netherlands in 1625; (**c**) at the beginning Spain-Portugal (**Figure 2A**) were situated in the south of North America and Central America, and northern of the Andean zone; (**d**) Spain had the largest presence and dominance in the Caribbean islands and the Florida Peninsula, and spread Spanish and the Catholic religion (**Table 1**); (**e**) the expeditions came out of Santo Domingo and C; (**f**) they explored, mapped and colonized (**Table 2**); (g) the West Indies is called New Spain. Some relevant facts are related with the Spanish colonies: (**a**) Cuba's Bishopric established in Baracoa; (**b**)

King Felipe II (1527-1598) annexed Portugal (1580-1640) and constituted the Iberian Union. The relation was broken by Felipe IV (1605-1665); (**c**) C was separated from the Santo Domingo Viceroyalty (1537) and the King appointed its governors; (**d**) Juan de Pimentel in 1578 made a plane of Caracas; (**e**) C imposed (1607) two governorates (La Habana and Santiago de Cuba); (**f**) Athanasius Kircher S.J. [17] published a South America map (1664) and included Venezuela and Lesser Antilles; (**g**) C significantly increased tobacco exports (1740); (**h**) The Royal General Inspectorate of the Army and the Treasury was established in Santiago de Cuba; (**i**) Spain forced to leave Jamaica for England (1670); (**j**) in 1726, the province of Cumana was created, consisting of the territories of Cumana, Guayana, Barcelona, Maturin and the island of Trinidad; (**k**) Mejía and Badaraco [122] published a scheme of S. Domingo and its surroundings; (**l**) England (1762) occupied one year La Habana and increased from 3 to 96 trading ships; (**m**) economic income in Cuba (1764-1774) increased (316.029 to 532.029 strongest pesos); (**n**) Cuba was significantly fortified (La Habana (Atares, El Morro, El Principe, La Cabaña, La Fuerza, La Punta), Matanzas (San Sobrino), Cienfuegos (Jagua)); (**o**) Spain defeated England in Tolon (1744); (**p**) the movement of fleets (1766-1776) was 8.176 trading ships with a value of ~44 million francs; (**q**) Thomas Jeffreys (1719-1771) published in 1760 maps and plans of Havana and Cuba; (**r**) the last fleet was in 1776; (**s**) Cramer and Mañeras [68] published a map of Cumana; (**t**) took place the independence of Venezuela (1811) and Cuba (1898); (**u**) Spain abandoned Florida in favor of USA (1821).

Table 1. Main data of Cuba and Venezuela.

Characteristic	Cuba	Venezuela
Arrival Europeans/ capital city	27.10.1492/ La Habana (San Cristobal de La Habana)	2.08.1498/ Caracas (Santiago de Leon de Caracas)
Language/ religion (%)	Spanish/ catholic (40)	Spanish/ catholic (96)
Area (km^2)/ highest altitude (m)	110.922/ Pico Turquino (1.974)	912.050/ Pico Bolivar (5.007)
Main River (Longitude km)	Cauto (343)	Orinoco (2.140)
Inhabitants	11.338.138	28.870.195
Rate of development Consumer prices	0,777 (high) 84,69	0,726 (high) 87,50

The conquest and colonization of Venezuela (**Figure 2B**): (**a**) took more than a century and population was irregular over time, but with an increasing tendency. **Tables 3-7** prove it and the estimation data of Humboldt (late 18th century ~900.000 inhabitants) in the General Captaincy of V confirms it; (**b**) promoted the development of agriculture, livestock, mining (gold and silver) and trade. This was a real monopoly that executed with the Indian fleets (the Spanish treasury) and under the House of Contracting of Cadiz control (1503). The Indies Council (1524) was in charge of the government; (**c**) the colonies of the mainland, in terms of the economy, were not important to compare with the islands; (**d**) the provinces of V depended first of Santo Domingo (1717) and after of Santa Fe of Bogota; (**e**) in 1742 Felipe V (1683-1746) signed independence of that viceroyalty. They did not possess gold or silver, so they focused since 1620 on agriculture (cocoa and tobacco plantation and trade) and livestock; (f) the economy stood out (1750-1786) when: (f.1) the Guipuzcoana Company was modified; (f.2) Carlos III (1759-1788) created the Caracas Intendancy (8.12.1776) and the General Captaincy of V (8.09.1777). Humboldt annotated that Venezuela at the beginning of 19th century imported ~35.10[6] francs and most of the products were European. Data showed that port-cities (La Habana and Veracruz, Mexico) were control points of the Spain economy (Table 8). Thus, the Caribbean Sea was known as the Mediterranean of America.

Table 2. Selection of period data 1492-1766.

Year	Event	Year	Event
1492	Columbus arrived to Cuba and S. Domingo	1513	J.Ponce set up in La Florida V.Nuñez Balboa reached to Pacific Ocean
1493	Columbus arrived to Puerto Rico		
1494	Columbus arrived to Jamaica	1515	D. Velazquez conquered Cuba J.Diaz de Solis reached La Plata River
1498	Columbus arrived to Granada and Venezuela		
1499	A.de Ojeda reached Cabo de la Vela	1519	H.Cortes conquered Mexico
1500	P.Alvares Cabral arrived to Brasil	1531	F. Pizarro conquered Peru
1502	A.de Ojeda founded Santa Cruz	1534	P.Alvares founded San Francisco de Quito
1512	J.Ponce de Leon landed La Florida	1591	Cumana acquired the status of city

Table 3. Foundation of cities in Cuba and Venezuela.

Cuba		Venezuela	
Year	**City (Founder)**	**Year**	**City (Founder)**
1511	Nuestra Señora de la Asuncion de Baracoa (a)	1500	Puerto de las Perlas (Cumana) (g)
1513	San Salvador de Bayamo (a)	1502	Santa Cruz (La Guajira) (h)
1514	Sancti Spiritus, Santisima Trinidad (a)	1510	Nueva de Toledo
1515	Santiago de Cuba (b)	1528-1544	Nueva Cadiz
1519	San Cristobal de La Habana (c)	1529	Nueva Zamora de la Laguna de Maracaibo, Santa Ana de Coro (**i**)
1528	Sta. Mª de Puerto Principe (d)	1545	Isla Margarita**,** Nuestra Señora de la Pura y Limpia Concepción de El Tocuyo
1539	Baitiquiri	1548	Nuestra Señora de la Concepción de la Borburata
1545	San Juan de los Remedios (e)	1552	Nueva Segovia
1689	Gloriosa Santa Clara	1555	Nueva Valencia del Rey
1735	Sagua de Tanamo (f)	1557	Nuestra Señora de la Paz de Trujillo
1751	San Isidro de Holguin	1558	Santiago de los Caballeros de Mérida

Notes: (a) Diego Velazquez, (b) Hernan Cortes, (c) Panfilo de Narvaez, (d) Diego de Ovando, (e) Vasco Porcallo, (f) Hilario Frometa, (g) Gonzalo de Ocampo, (h) Alfonso de Ojeda, (i) Antonio Ehinger.

Spain under Carlos III had an economic recovery period. In the governments of Esquilache and Grimaldi (1759-1766) there were opposition to the reforms; and provoked the "Esquilache Mutiny" and the Jesuits deportation in 1767. The King (11.09.1766) accepted the indigenous people in the religious communities and for civil positions. At the beginning Felipe V and later on Simón Bolívar (1783-1830) promoted the Colombia, Ecuador, Panama and Venezuela union (~2.403.145 km^2). They had in common culture and economy). It was in the so called century of "The Lights" (*La Razón*) (step of tradition-revolution equilibrium (society was the enlightened and protectionist economy)).

Table 4. First religious (catholic) buildings of Cuba and Venezuela.

CUBA		VENEZUELA	
Year	**Enclosure**	**Year**	**Enclosure**
1512	Nuestra Señora de la Asuncion de Baracoa	1568	La Basilica Menor Santa Capel
1513	San Salvador de Bayamo	1614	Nuestra Señora de Las Mercedes
	San Juan de los Remedios	1621	Dulce Nombre de Jesus
1514	Santa Catalina	1665	Caracas Cathedral
1638	Santa Clara Convent	1696	Santa Rosalia
	Espiritu Santo	1708	La Candelaria
1644	Santiago de Cuba Cathedral	1769	San Jose de Chacao
1702	Belen Convent	1781	Santisima Trinidad
1722	San Basilio Magno	1788	Parroquial San Juan Bautista
1730	San Francisco de Asis Convent		
1748	La Habana Cathedral		
1767	San Carlos Seminar		
1789	Santo Angel Custodio		

Table 5. Population in Cuba and Venezuela.

Cuba				Venezuela			
Year	**Population**	**Year**	**Population**	**Year**	**Population**	**Year**	**Population**
1552	~3.000	1810	600.000	1783	580.000	1873	1.784.194
1608-1616	20.000	1827	704.487	1800	785.000	1920	2.479.525
1655	~40.000	1841	1.007.624	1810	800.000	1941	3.850.771
1757	149.000	1842	1.037.624	1822	766.000	1950	5.094.000
1774	171.620	1852	984.042	1825	785.000		
1792	205.000	1862	1.179.713	1839	887.000		
1804	432.000	1953	5.829.029	1847	1.267.962		

Table 6. Growth index.

Year	Cuba	Venezuela	Year	Cuba	Venezuela
1845	0 *	0 *	1877	59	18
1860	34	20	1895	118	50

* Initial reference

Table 7. First universities.

Year	Denomination/ country	Year	Denomination/ country
1538	Santo Tomas de Aquino/ Dominican Republic	1675	San Carlos/ Guatemala
1551	San Marcos/ Lima, Peru	1677	San Cristóbal de Huamanga/ Perú
1551	Real y Pontificia U. de México/ México	1721	Real y Pontificia U. de San Jerónimo/ Cuba
1580	Pontificia U. Santo Tomaá de Aquino/ Colombia	1721	Real y Pontificia U. de Caracas/ Venezuela
1603	Pontificia U. de San Fulgencio/ Ecuador		

Table 8. Economic data (import-export) of Cuba (1824-1831).

City	Currency (Cuban pesos)
La Habana	Import= 13.374.343/ Export = 9.609.858/ Total amount= 22.984.201
Santiago de Cuba	Import= 1.278.697/ Export= 1.412.358/ Total amount= 2.690.955
Cuba	**Import= 14.653.040/ Export= 11.025.216/ Total amount= 25.675.156**

4.2 Tectonics

The following bibliography was used for the chapter [2, 10, 22, 23, 26, 30, 38, 43, 50, 52, 63-66, 69, 70, 75, 94, 102, 104, 105, 113, 121, 124, 129, 140, 143-147, 157-159, 168-171, 179, 183, 187, 190, 191, 194, 195]. Figures 1 and 6 of Cotilla and Udias [62] show a block model of the Caribbean contemporary dynamic and deformation zones, where C and V are located. Tectonics and seismicity are due to the interaction of different plates (Caribbean, Cocos, Nazca, North and South American) (**Figures 1 and 3**). Caribbean is a microplate that has different speeds, 20-80 mm/year, and the northern margin is characterized by a fault system with left lateral displacement (Motagua fault (in Guatemala), the Septentrional and Plantain Garden-Enriquillo faults (in Jamaica-Hispaniola) and Oriente (southern C)). All they demonstrate seismic activity [**S-A**]. There is an oceanic crust spreading center (Mid Cayman). The microplate is subdued by the North American plate with S-A and volcanism at the E. The subduction is oblique (Puerto Rico, -8.340 m). In the Pacific Ocean area (Mexico-Panama) another convergence of plates is known with a more active subduction process, ~81 mm/year, and a greater angle than the above mentioned. On that edge are located the subduction process (Cocos-Rivera-Nazca under Caribbean). Much of the S-A is associated with that process and produces earthquakes up to 300 km deep and there is also volcanic activity.

Cuba is an emerged microplate of the southern of North American plate and has a differential uplift structure. It is associated with a set of active faults (Oriente, Nortecubana, Cauto-Nipe and Baconao) that make up a system of morpho-structures and seismic active knots. It interacts directly with active faults and where the dominant structure is the Orient trench (-7.646 m). This belongs to a larger underwater structure of pull-apart (longitude ~1.000 km/ wide ~110 km) that initiate at Cayman Islands. That center is active from the Middle Eocene (expansion rate ~15 mm/year). These elements are framed in a plate boundary zone [PBZ] where there are frequent earthquakes. A second significant S-A zone, also in the maritime area, is Cabo Cruz (**Figure 4B**). In that area there is an active intersection (knot) of the Oriente and Cauto-Nipe faults with six strong earthquakes (18.10.1551 (M6,6)/ 7.07.1852(M7,7)/ 26.08.1990 (M5,1)/ 25.05.1992 (M6,9)/ 4.02.2007 (M6,2)/ 28.01.2018 (M7,7)) that affected Cabo Cruz and Bayamo city). The fractal dimension estimates [**FD**] of strong earthquakes occurrence show differences for Cabo Cruz {0,89}, S. de Cuba {0,97}, Puerto Principe {1,28} and the northern Puerto Rico {1,35}. The values of Puerto Principe- Puerto Rico are similar to those obtained by Toro-Salas *et al.* [186] in the SW Colombia {1, 27-1,40}. Also the seismic potentials of the N Caribbean [65] show that the large values are in the E. It is relevant that there are tsunami data in Hispaniola-Puerto Rico but no to southeastern Cuba.

Subduction of the North and South American plates under the Caribbean produces volcanic activity and S-A. In V the movement of the Caribbean plate is right lateral and there are important faults (El Pilar (Serrania del Interior), San Sebastian (Cordillera de la

Costa), Oca-Ancon and Boconó (Los Andes)) with earthquakes (26.03.1812(M8,0)/ 29.10.1900(M7,7)/ 30.07.1967(M6,6)) (**Figure 5B**). They are the ones with the most activity and sliding course displacements oriented to the E-W, 100-150 km, and produces another PBZ (width of ~100 km) in South American-Caribbean. Associated with this system is another of lesser category and activity (faults: Valera/ La Victoria/ Tacagua-El Avila/ Urica). The entire coastal environment (4.000 km/ >200 islands/ 16 cities (with more than 100.000 inhabitants each one)/ ~50 inhabitants/km^2) has a high level of S-A. In western zone (V-Central Colombia) are located the Caribbean and Nazca plates that converge, ~65 mm/year, and produces important S-A (quantity and magnitude) and affect V. The structures segmentation has been verified in Cuba also discussed in Venezuela [22, 23, 86] and Mexico-Panama [64, 66]. It is known that (**a**) the fragmentation favors the deformation and transmission of regional and local efforts and blocks configuration; (**b**) northern PBZ (in Cuba) is less fragmented than the southern one at Venezuela; (**c**) the PBZ sinuosity coefficient value is different around the southeastern Cuba (0,91) and Venezuela (0,72); (**d**) the distances of SE Cuba to the Pacific and Virgin Islands is similar (~2.500 km). Thus, by observing the location of the two study areas (C-1/ V-1) (**Figure 1**) it can be assured that Venezuela receives a greater influence from the converging of Pacific and Atlantic oceanic plates. This is also reflected in the **figure 3**.

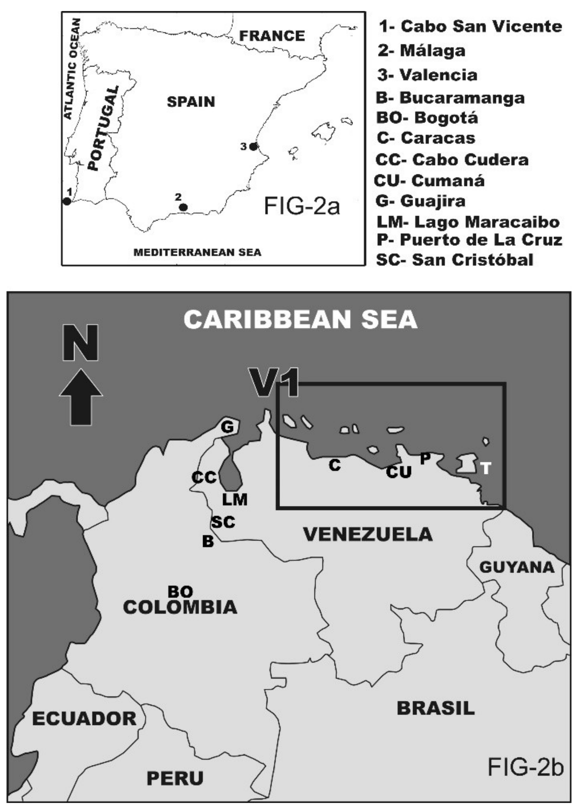

Figure 2. Schemes of the Iberian Peninsula (2A) and Venezuela (2B).

4.3 Seismicity

The following results have been used in the section [1, 4, 5, 11, 18-22, 24, 25, 27, 31, 32, 34, 45, 46, 53-59, 69, 71-74, 76, 79, 82-89, 96, 101, 106, 108, 112, 116, 117, 120, 125-128, 130-133, 135, 137-139, 141, 142, 144, 148-151, 153-157, 160, 165, 166, 172, 174, 176, 178, 180-182, 185, 189, 192, 197]. With these, it can argued that: (a) in 1766 five strong earthquakes occurred in the world, three of them in America (Table 9); (b) since the arrival of the Spaniards to America in October 1492 they faced tropical cyclones. It is nowadays known that these natural organisms are common on those dates; (c) early tested the strength and frequency of earthquakes and tsunamis. Although they were not new to them (Table 10). In the Spanish Cortes, news (or studies) of American earthquakes were relatively frequent (examples: 1502=Santo Domingo/ 1516=Panama/ 1524=El Salvador/ 1526 and 1541=Guatemala/ 1528=Cuba and Nicaragua); as well as requests to repair the damage and also appeared some compilations and catalogues (Table 11). After that, Spanish governors had information about earthquakes and procedures.

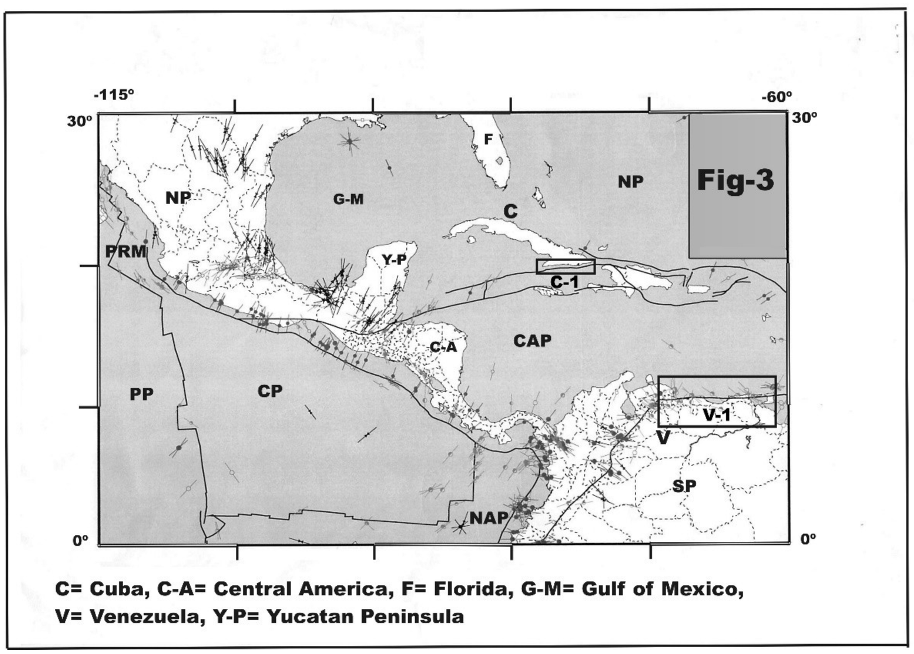

Figure 3. Simplified tectonic scheme with the World Stress Map-2000. (a) plates (CP=Cocos, CAP=Caribbean, NP=North American, NAP=Nazca, PP=Pacific, PRM=Rivera, SP=South American); (b) stress symbols.

Table 9. **Earthquakes of 1766 on the World.**

Nº	Date	Locality	M/I	Characteristics
1	.03.8	Homori, Japan	7,3/ 9	?
2	.05.22	Istanbul, Turquois	7,1/ 9	4.500 deaths
3	.06.11	Santiago de Cuba, Cuba	6,8/ 9	~40 deaths
4	.07.9	Santiago de Cali, Colombia	/ 8	Several aftershocks (until 07.19)
5	.10.21	Cumana, Venezuela	8,0/ 9	No significant damage in Caracas

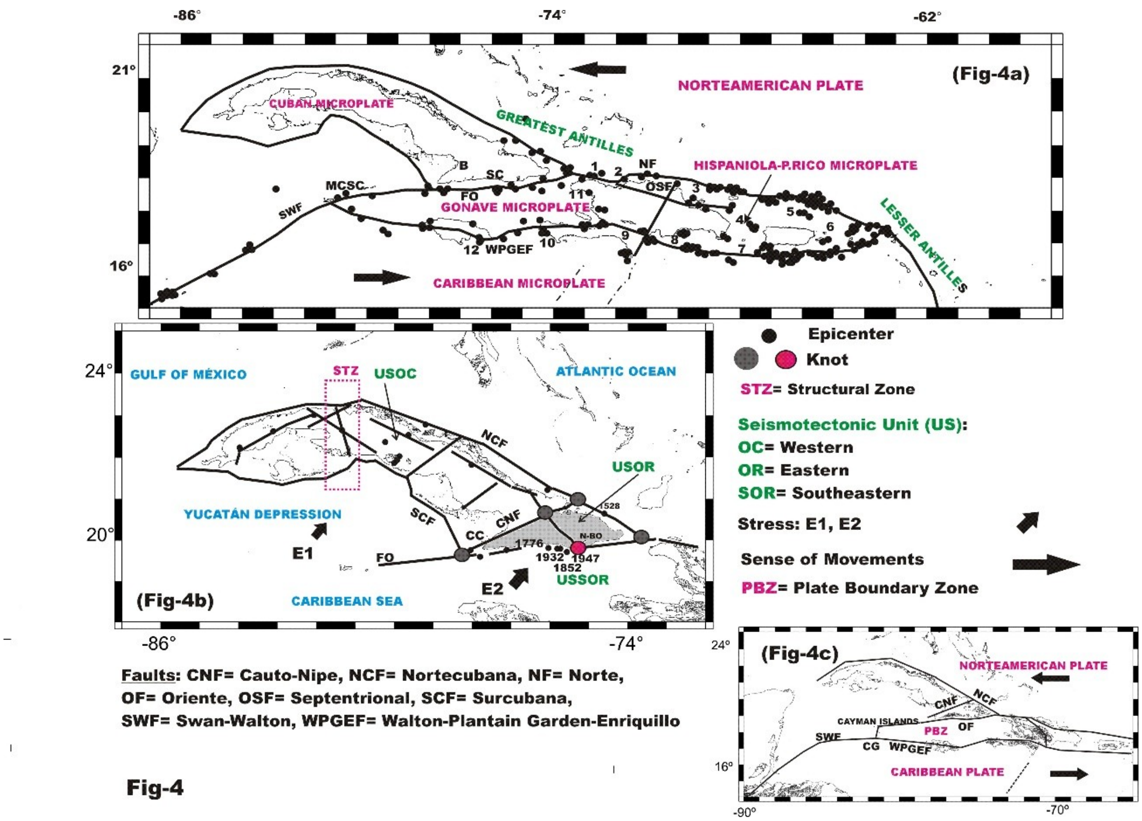

Figure 4. Seismotectonic of the northern Caribbean. Figure 4A. Earthquakes (year (M)) (a) 1842(6,2), (b) 1897(7,5), (c) 1946(7,8), (d) 1943(7,5), (e) 1787(8,0), (f) 1867(7,3), (g) 1918 (7,3), (h) 1673(7,5), (i) 2010(7,0), (j) 1770(7,8), (k) 1887(7,9), (l) 1692(7,5)); Localities: B=Bayamo, CC=Cabo Cruz, SC=Santiago de Cuba. Figure 4B. Four earthquakes around Santiago de Cuba (black circles-year (Table 18)). Figure 4C. Mid Cayman Center (CG).

Table 10. **Some strong earthquakes around Spain and Portugal.**

Date	Characteristic	Date	Characteristic
1169.02.4	Italia, Sicilia/ 15.000 deaths	1428.02.2	Spain, Girona (M9,0)/ 800 deaths
1693.01.11	Italia y Malta/ 60.000 deaths	1531.09.30	Baza/ 400 deaths
1755.11.1	Portugal/ (M_w8,7)/ ~100.000 deaths	1680.10.9	Malaga/ (M6,8)/ 70 deaths
1761.03.31	Cabo San Vicente/ (M6,7)	1748.03.23	Valencia/ (M6,2)/ 38 deaths

Capel [46] and Ortiz-Gallardo [136] provide information on the earthquakes knowledge in the 18th century. In 1732 earthquake was defined as: "Violent and impetuous movement of the earth. Regularly it gets from exhalations, and thick winds in concavities of it, that cracking with humidity, prevents them from coming out, or sprout; and looking for the exit cause with its impetus the tremor. Which is more often the case in ports, or places near the sea" [152]. We highlight two results of "seismic regionalization" surprising for that time: (a) Benito Viñes-Martorell, SJ distinguished in 1880 the differential S-A of the Western and Eastern Cuba; (b) Montessus de Ballore [132] used its catalogue to publish the first map with the seismic areas of the northern Venezuela indicating the most dangerous sites;

(c) Table 12 has 18 earthquakes' analyses and their historic-social-seismogenetic comparative. They are similar to our work.

Table 11. **First earthquakes' catalogues of Cuba and Venezuela.**

Year	Author	Text
1855 and 1857 [148-150]	A.Poey y Aguirre	Cuba - Caribbean (3 catalogues)
1940 [45]	M.Centeno	Venezuela catalogue

Table 12. **Authors with similar papers.**

Author (s)	Year	Author (s)	Year	Author (s)	Year
Humboldt	1819	Christl and Altez	2000	Sarabia-Gomez *et al.*	2010
Brito-Figueroa	1961	Astroza *et al.*	2002	Ros-Magán	2011
Ambraseys	1971, 2001	Altez	2003, 2005, 2014, 2017	Ruiz and Madariaga	2012
Lopez-Marinas	1977	Amodio	2005	Udias *et al.*	2012
Guidoboni and Stucchi	1993	Campos *et al.*	2005	Buforn *et al.*	2017
Christl	1993	Cisternas and Valera	2008	Allier-Montaño	2018

The first two earthquakes, well documented in Cuba and Venezuela (Table 13) occurred after the arrival of the Spaniards (C=36 years/ V=32 years). The strong and perceptible S-A in the surroundings of C (Figs. 4a-b) and V (Figure 5B) is quite known. In table 14 is showed the strongest earthquakes in America before 1766; none of them has affected C or V. Table 15 contains several of the heavy and dangerous earthquakes that have occurred in the southeastern Cuba within the S. de Cuba tectonic segment. All of them are of surface type and without tsunamis. The most important local tsunamis of V are in table 16. A tsunami (1.11.1755) from far away source (Portugal) was slightly perceived in S. de Cuba, Antigua, Barbados and Martinica (Figure 1, Table 16). Figure 2 of Fukuoka *et al.* [74] shows the 1492-2000 tsunamis in the Caribbean. Table 17 has the strongest events in Venezuela.

Table 13. **First earthquakes in Cuba and Venezuela.**

Year	Country	Location and description
1528	Cuba	(Figure 4B) Nuestra Señora de la Asunción de Baracoa was the locality where the arrival of Columbus is supposed. The epicenter was in the surrounding marine zone, associated with the Nortecubana fault. People went out in procession with the Virgin
1530	Venezuela	(Figure 5A) The coastal town of Cumana (Nueva Toledo) of eastern V was destroyed by an earthquake (10:30/ M_b7,3). It affected Cariaco Gulf and the land opened and sprouted salt water mixed with asphalt. The sea suddenly withdrew leaving the beach dry and when returning it exceeded the limits in height ~500 m

Audemard [22] presented several arguments about the strong seismicity of the northern Venezuela. He maintained that: (a) the events of 1530 and 1853 had tsunamis and were spatially related to those of 1797 and 1929. They took place to the E of Cumana in Punta Baja-El Peñon; (b) six earthquakes (1530, 1629, 1684, 1766, 1787 and 1853) destroyed Cumana, where soil conditions are quite different; (c) the 1684 and 1997 earthquakes are related to Cariaco town (between Cariaco and Paria Gulfs); (**d**) there are two main zones of S-A in the subduction zone of the Greater Antilles and the El Pilar fault; (**e**) the earthquake of 1766 is similar to that of 29.07.1967 (**Tables 16-17**); (**f**) the 1766 event happened to 60-200 km depth and more to the E of the El Pilar fault; (**g**) no tsunamis in 1766 occurred. From Perez and Mendoza [144] figures we can see that: (**a**) figures 1 and 3 have two major epicenter concentrations with: (**a.1**) an intersection of active faults occurs where h~160 km (Bucaramanga, Colombia vicinity); (**a.2**) in the NW edge (close to Trinidad) h>40 km where are active faults (El Pilar, Los Bajos and El Soldado); (**b**) figure 2 indicates the 18.05.1875 earthquake epicenter in Cucuta (near Bucaramanga); (**c**) figure 4 includes 21 focal mechanisms (1983-1995) of the right-hand type movement; (**d**) figure 5 has four mechanisms of compressive type with right lateral displacement. Four earthquakes (1967-2018) recorded by the USGS were located in the Caribbean-South American PBZ (**Figure 1**) and three of them around Sucre, where the NVA knot. Several authors [15, 28, 29, 33, 58, 61, 65, 81, 90, 92, 93, 134, 198] have related earthquakes to faults intersection (or knot); while Audermard [18, 24], Jouanne *et al.* [103] and VanDecar *et al.* [191] indicated the significant S-A of the center-north and NE of Venezuela. Bonive *et al.* [34] used the seismic data (1995-2001) of the Venezuelan Northeastern Seismological Network and determined different fault systems (Pedernales thrust- El Soldado-Los Bajos) where there are changes from shallow to deep, and assured a transition tectonic regimen. From this area there is information which confirms the known data [78, 116, 127, 184].

Altez [8] used in his table 1 four strong earthquakes of Caracas (**Table 17**) and indicated that: (a) the fatalities were 2.221; (b) their percentage values of deaths from earthquakes in relation to the population varies from 0,035 % to 10 %.

Table 14. Some strong earthquakes (before 1766) in America.

Date	Location/ description	Date	Location/ description
1575.12.16	Chile, Valdivia/ (M_w8,5)/1.200 deaths	1700.01.26	California-British Columbia/ (M_L8,7)
1730.07.8	Valparaiso/ (M_w8,7)/ 300 deaths	1701.11.9	Haiti/ (M6,1)/ 7/ several deaths
1615.09.7	Puerto Rico/ (M_w8,7)/ 300 deaths	1751.09.16	Haiti/ (M6,8)/ 9/
1687.10.20	Peru/ (M_w8,5)/ 5.000 deaths	1751.10.18	Haiti/ (M7,8)/ 9/ ~200 deaths
1746.10.28	Peru/ (M_w9,0)/ ~10.000 deaths	1751.11.21	Haiti/ (M6,5)/ 8/
1692.06.7	Jamaica/ -3.000 deaths	1770.06.3	Haiti/ (M7,5)/ 10/ ~300 deaths

Table 15. Strong earthquakes of Southeastern Cuba.

Date	Brief description	Date	Brief description	Date	Brief description
1578.08.	I=8/ (M6,75)	1766.06.11	I=9/ (M6,8)/ 40 deaths	1842.07.7	I=8/ (M6,8)
1678.02.11	I=8/ (M6,75)	1800.10.14	I=8/ (M6,4)/ 5 deaths	1852.08.20	I=8/ (M6,4)/ 2 deaths
1760.07.11	I=8/ (M6,75)	1826.09.18	I=8/ (M6,4)/ 1 death	1932.02.3	I=8/ (M6,75)/ 25 deaths

Note: I (MSK-1978 scale)

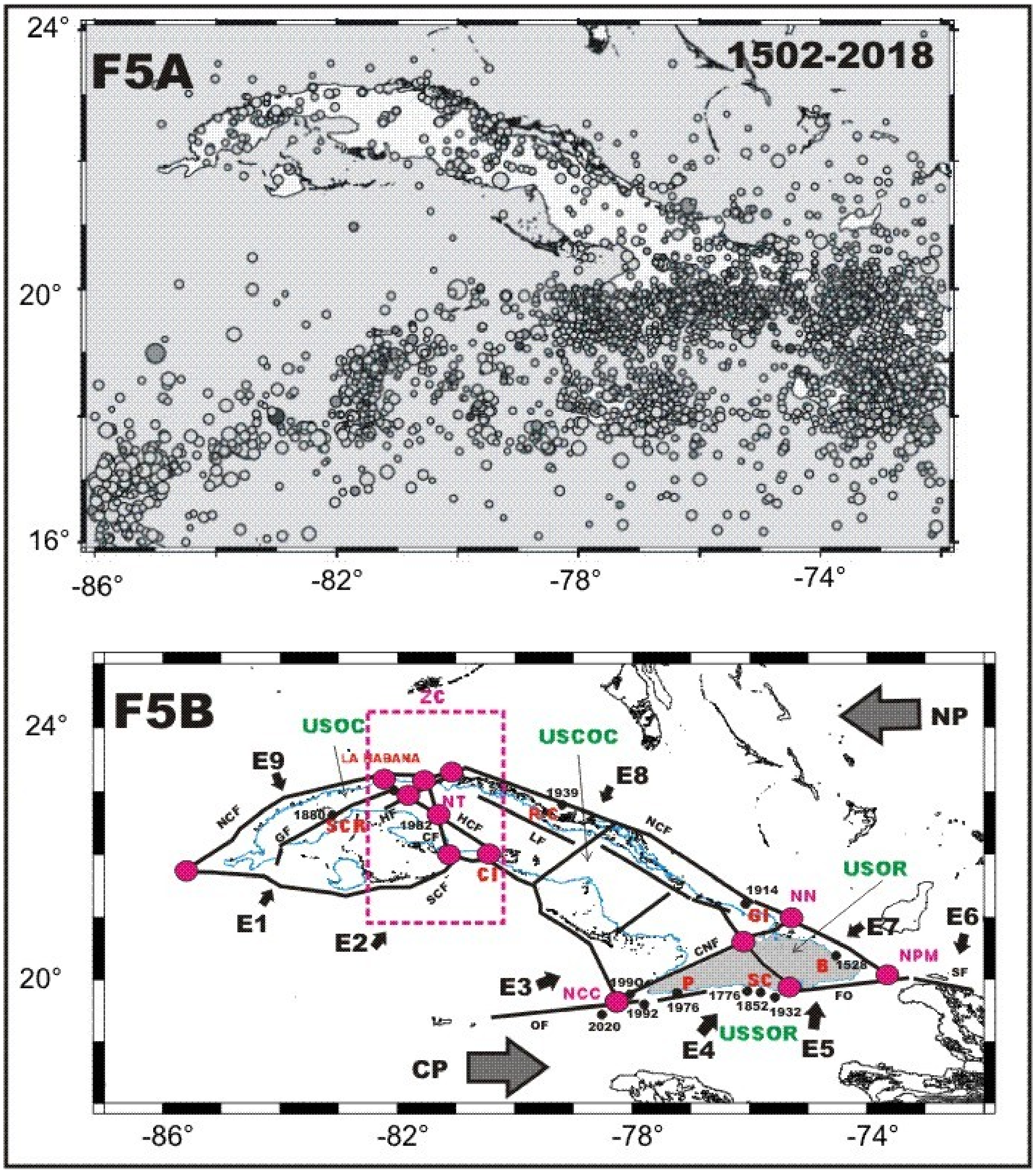

Figure 5. Seismotectonics of Cuba. **A)** Seismicity map of CENAIS [14]; **B)** Seismotectonic province of Cuba. Appear: **1)** Seismotectonic Units (green leteers: USOC=Western, USCOC=Centre-Western, USOR=Eastern, USSOR=Southeastern); **2)** Fault (black lines: CF, CNF, GF=Guane. HF=Hicacos, HCF=Habana-Cienfuegos, LF=Las Villas, NCF, OF, SF=Septentrional, SCF); **3)** Epicenters (black circle with year (see **Table 3**)); **4)** Stress axis $\sigma_{hmáx}$ (heavy black arrow with letter and number (E1-5)); **5)** localities (orange letters); **6)** Knots (red circles and letters (NCC=Cabo Cruz, NN=Nipe, NPM=Punta de Maisí, NT=Torriente-Jagüey Grande)); **7)** Plates; **8)** Sense of movement of the plates (heavy grain arrows); **9)** ZC=Zone of structural change (discontinue red rectangle).

Table 16. Tsunamis.

Date	Event	Date	Event	Date	Event	Date	Event
1530.09.1	Cumana	1906.01.31	Cumana	1541.12.25	Nueva Cadiz	1867.11.18	Margarita
1853.07.15	Cumana	1929.01.17	Cumana	1802.05.5	Orinoco River	1997.07.9	Margarita
						1900.10.29	Macuto

Table 17. **Significant earthquakes for Venezuela.**

Date	(M) I/ Location	Date	(M) I/ Location	Date	(M) I/ Location
1641.06.11	7/ Caracas	1766.10.21	(8,0)/ Cumana	1874.08.17	(7,1) 8/ El Pilar
1812.03.26	(7,7) 9/	1797.12.14	(6,5-6,6) 9/	1986.06.11	7/
1900.10.29	(7,7) 7/	1853.07.16	(6,2-6,3) 9/	1875.05.18	(6,9-7,1)/Cucuta, Colombia
1967.07.29	(6,5-6,7) 6/	1927.01.17	9/	1878.12.4	(6,4-6,5)/ Cua
1823.08.	(6,0-6,3)/Cariaco	1610.02.3	(7,3)/ Merida	1888.11.17	(6,0-6,3)/ Guanare
1997.07.9	(7,0)/	1812.03.26	(6,5-6,7)/	1900.10.29	(7,6-7,8)/ Cabo Codera
1530.09.1	(7,3)/ Cumana	1834.12.8	(6,2-6,3)/	1932.03.14	(6,75)/ Southern Andes
1684.05.4	8/	1894.04.28	(7,1-7,3)/	1541.12.25	8/ Nueva Cadiz
				2018.08.21	(7,3)8/ 24 km ENE Caribe River

4.3.1 *Data from the 1766 Earthquake in Cuba*

The design of Santiago de Cuba city until end of the 18^{th} century corresponds to the urban planning of the Conquest period. It was distinguished by the similarity to the military camps in Spain. The design was made of ruler-twine with a grid figure. The predominant constructions were of straw and boards of cedar, and fenced by *cañabrava* (*bambusa vulgaris Schrad arundo donax*). The majority furniture was very rudimentary with sebum candle lighting. Quarry buildings were very rare and only associated to religious and military entities. The vast majority of roads were dirt, embankments and few paved with rounded river pebbles, wooden pavements. Santiago's urban design responded to its complex topography until 1947. In this sense the streets were narrow and most houses had one or two levels. Outside of downtown had few buildings.

On 11.06.1766 (00:00 h) there was an earthquake in Santiago de Cuba (Ms6,8 - from Cotilla and Udías [63]; M_s7,5 from Álvarez *et al*. [11] (Figure 4). It was perceptible in La Habana (~800 km), Bayamo (~100 km), Haiti and Jamaica. There were 34-40 deaths and 700 injured; and more than 60 perceptible aftershocks, but no tsunami. The epicenter, estimated at (19,9 N 76,1 W) is on the Oriente fault, depth (25 km from Cotilla and Udías [62] and 30 km from Álvarez *et al*. [11] and maximum seismic intensity (MSK) 9 degree was reported.

Their main buildings: (**a**) destroyed: Morro Castle and Socapa Fortress (both at the bay entrance), San Francisco Castle, Hospital, Governor House, and a large number of warehouses, the port dock and small houses; (**b**) affected: the Cathedral. In the new collected information Cotilla [53]: (**b.1**) it is ensured that the dock of eastern platform collapsed; (**b.2**) the flames consumed the carriages, wagons, warehouses and goods, and caused the beasts stampede; (**b.3**) on the port shore was mud and sand that flooded all; (**b.4**) the Indies Council sent 2.10^6 Cuban pesos; (**b.5**) decreased the sugar production; (**b.6**) destruction of the Ermita Virgen del Cobre; (**b.7**) very affected postal mail on horseback S. de Cuba-La Habana; (**b.8**) miscellaneous impacts on Copper Mines; (**b.9**) there was widespread hysteria and panic in the population; (**c**) Bayamo city was severely affected, without dead. The destroyed and affected buildings were: churches (Santo Domingo, Parroquial), Padre Serafico San Francisco Convent, Parishes (San Juan, Santo Cristo del

Buen Viaje, Nuestra Señora de la Luz, Nuestra Señora de Regla and Santa Ana), San Roque Hospital, houses of stones (263), adobe (487), woods (71); (**d**) Jamaica (Montego Bay, Port Antonio) and Haiti (Puerto Principe) reported this earthquake; (**e**) the King Carlos III gave 10.000 gold pieces; (**f**) the foreign press [78] wrote about it.

It is now possible to indicate that: (a) At southern of S. de Cuba (1528-1932) other strong earthquakes occurred (**Figure 4**, **Table 14**); (**b**) in **Table 18A** there is a comparison of three well studied earthquakes; (**c**) data made possible to estimate two periods for strong earthquakes in Santiago de Cuba: (**c.1**) 96 years (16th-18th centuries); (**c.2**) 93 years (16th-20th centuries); (**d**) the design of Santiago de Cuba city and the time of occurrence of the 1766 earthquake explains the low number of deaths in relation to the total inhabitants.

Table 18A. Comparison of three strong earthquakes in Santiago de Cuba (Cotilla [56]).

	Date		
Characteristic	**1766.06.11**	**1852.08.20**	**1932.02.3**
Foreshocks/ aftershocks (days)	Few/ 50 (66)	4/ 60 (1.095)	4/ 122 (365)
Duration of the main event (s)	Few	4	4
Time of origin (hh:mm)/ tsunami	00:00/ No	14:05/ No	12:35/ No
Intensity (MSK)/ magnitude	9/ 6,8	8/ 6,4	8/ 6,75
Area of perceptibility (10^3 km^2)/ isoseismics	1/ Yes	0,8/ Yes	0,9/ Yes
Coordinates (N W)/ depth (km)	19,9 76,1/ 30	19,75 75,32/ 30	19,75 75,58/ 35
Population/ Deaths/ Injured	5.149/ 40/ 700	41.230/ 2/ 200	500.000/ 25/ 350
Loos (millions of pesos/ economic aids)	10/ Yes (Spain)	20/ Yes (Spain)	20/ Yes (some)
Destruction of Morro Castle	Yes	No	No
Destruction of religious buildings	Yes	Yes	Yes
Civil buildings affected (%)	75	85	80
Perceived at La Habana/ Jamaica/ Haiti	Yes/ Yes/ Yes	No/ Yes/ Yes	No/ Yes/ Yes
Sense of seismic wave perceptibility	E-W	SE-NW	E-W
Coverage of the international press/ source	Yes/ GAI	Yes/ GAI	Yes/Committee C-USA
Political system	Colony	Colony	Republic
Period between two earthquakes (years)		1852-1766 (86)	1932-1852 (80)

There were published some intensity data from this earthquake [47, 53]. The last one is very complete (**Table 18B**). It has a discussion of the sources of original data available and the evaluation of felt intensities in different settlements. When original intensities has the kind "I - I + 1", there were substituted by "I + 0.5".

There are different methods of tracing isolines over a felt intensity map from a simple eye`s trace to statistical interpolation. Now, we present an isoseismal map (**Figure 6**) made by using the set of intensity values of **table 18B**. It was used the Delaunay triangulation method [175] included in GMT`s software package [196]. This method considers that a set of points on a plane is processed under the rule that no point appear inside of the circumcircle of any formed triangle.

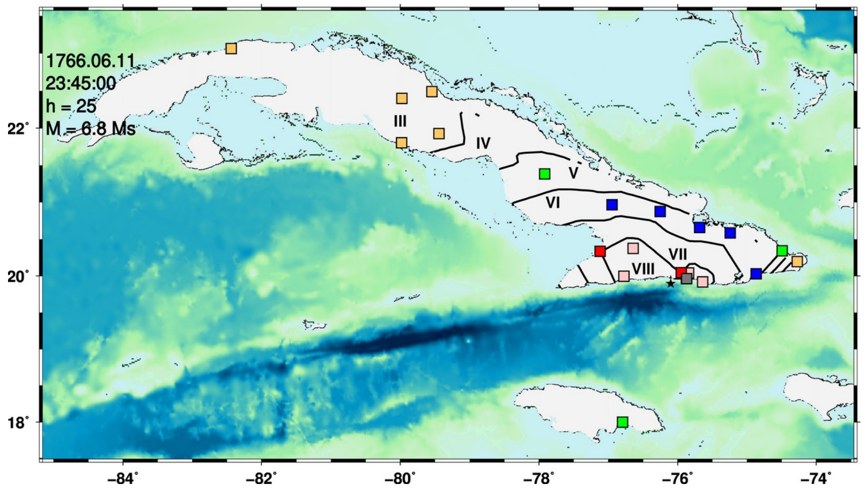

Figure 6. New isoseismal map of 1766 in Santiago de Cuba: Rectangles in color and isolines of felt intensity points (MSK scale) and epicenter (black star).

4.3.2 *Data from the 1766 Earthquake in Venezuela*

After 127 days of the Cuban earthquake occurred another strongest one in Venezuela. In the literature appears: "…On 21.10.1766 the city of Cumana was completely destroyed…" (figures 1-3 of Grases [86]) "…within a few minutes all the houses were sunk and the shaking repeated for 14 months in hours…" It is known that since 1638 the Saint Patron of Cocoa in Venezuela, is "Our Lady of Mercy`s". The image was taken out in procession to implore the sick with smallpox plague, which two years before affected them, and which in 1766 reappeared. At the end of the procession stood the Virgin in the Cathedral. Then the day mentioned (4:30 a.m.) all the South America coast shook. People heard a thunder and saw a lightning bolt. In Cumana there were flames on the bank of the Manzanares River and serious damages in churches and forts. An islet near the Peña Aranacoto of Orinoco River disappeared. Houses sank and temples were heavily damaged. People spent months on the streets. It was felt at different localities as Barcelona, Caniagua, Caracas, Cariaco, Cayanea, Ciudad Bolivar, El Cumanaco, El Pilar, Guarenas, Isles (Barbados, Guadalupe, Margarita, Martinica and Trinidad), La Guaira, Pao, Puerto Cabello, Macuro, Maracaibo, Maturín, N Colombia, Petare, Surinam, Taguay and Yaguaparo. Panic took hold of Caracas but no one was killed or wounded. Some large buildings suffered from the tremors and the houses were practically intact. Therefore, the devotees assured that "Mercy`s" was the "Protective Virgin of Venezuela".

The bishop indicated to make a painting with the title of "Our Lady of Venezuela" in homage to Mary and according with Carlos III decree. The King named her as the patroness of all his kingdoms. A plaque with the inscription was placed at the foot of the *Servatrici Nostrae* image (Our Savior). Humboldt commented: "…that the earthquake was once, the most fatal for the settlers and the most remarkable for the physical history of the country…” With the data Grases: (a) Assured it was the beginning of historic seismicity in V (240 years); (b) said it’s probably the strongest (Ms~8,0); (c) drew the isoseismics (63 localities) with ~$3,6.10^6$ km^2 perceptibility area; (d) estimated the speed of Caribbean and South American plates (14 mm/year); (e) indicated that from the N of Cucuta to La Güira was affected; (f) determined the dimension of the active fault zone (longitude=1.200 km/ wide=80-100 km/ depth=4 km); (g) included a set of strong earthquakes in the interaction area (Table 17). Also, Perez *et al*. [147] indicated in its figure 9 this earthquake associated with El Pilar fault. In this area there is ~$2,0.10^6$ people.

Table 18B. Felt intensities of 1766.06.11 earthquake in Cuba (modified from Cotilla [2003]).

Longitude	Latitude	Intensity MSK-78	Settlement	Longitude	Latitude	Intensity MSK-78	Settlement
-75,8750	19,9730	9	La Socapa	-75,2410	20,5850	6	Sagua de Tánamo
-75,8700	19,9660	9	El Morro	-76,2520	20,8780	6	Holguín
-75,8410	20,0430	8	S. de Cuba	-74,550	20,3440	5,5	Baracoa
-76,7750	19,9980	8	Mar Verde	-77,9190	21,3860	5	Camagüey
-76,6430	20,3780	8	Bayamo	-76,7940	17,9970	5	Kingston
-75,6410	19,9210	8	Playa Daiquirí	-79,9830	21,8050	3	Trinidad
-75,9480	20,0450	7,5	El Cobre	-79,4450	21,9270	3	Sancti Spíritus
-77,1170	20,3380	7,5	Manzanillo	-79,5450	22,4910	3	Remedios
-74,8670	20,0310	6	Baitiquirí	-74,2760	20,1980	3	Vertientes
-76,9480	20,9680	6	Las Tunas	-79,9760	22,4000	3	Santa Clara
-75,6810	20,6590	6	Mayarí	-82,4400	23,0680	3	La Habana

Although there are a lot of studies or reports about this earthquake, some of them with isoseismal maps, intensity data are present only in two of them: in the on-line catalogue of felt earthquakes in South America [44] and by Mocquet [127]. In the first case, the author of the report for Venezuela was Grases [83]. Nevertheless, they can be associated to J. Grases, the person that made the more detailed studies of historic earthquakes in Venezuela. In CERESIS [44] catalogue there are present 46 points with intensity evaluation. Mocquet [127] reevaluate the intensity for several of them and add 16 new points with intensities evaluated by him. For drawing an isoseismic map we took the CERESIS data and complemented them with additional Mocquet data. As these last data have in some cases not an unique value but an interval, we transformed them to unique values using the criteria: “I - I+1” is substituted by “I + 0,5”, “< I” is substituted by “I - 1”, “> I” is substituted by “I + 1” and “I - I +2” is substituted by “I + 1”. In table 19 there are presented the intensity values resulting for the combination of data from both sources. The isoseismal map prepared with these data is presented in figure 7. As in the case of Cuban earthquake the map was drown using the Delaunay triangulation method [175] included in GMT`s software package [196]. Figure 7 shows an intersection of two linear structures (NNE and W-E).

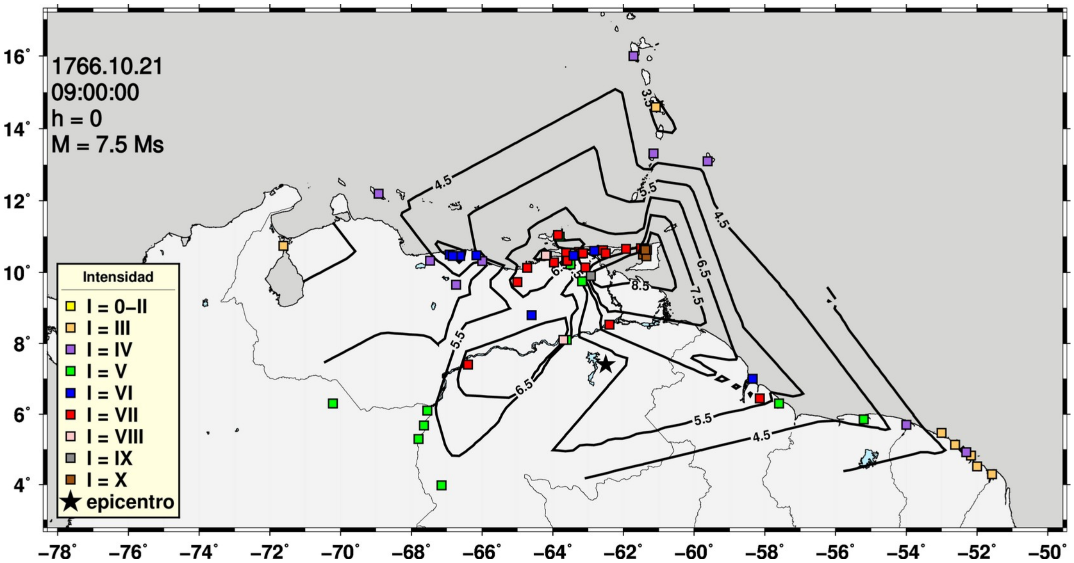

Figure 7. New isoseismal map of 21.10.1766 earthquake. It was prepared by combining data from CERESIS [44] and Mocquet [127].

There were published different interpretations about the source of this earthquake, between them: (a) Grases [84] considers a Ms7,9, intermediate depth at epicentral coordinates (10,7 N -62,5 W); (b) CERESIS considers a Ms7,5 at 0 km depth and epicentral coordinates (7,4 N -62.5 W); (c) Mocquet [127] considers a magnitude range Ms6,5-7,5, at depth 85±20 km and epicentral coordinates (11,0 N -62,5 W); (d) Audemard [22] considers that is incorrect to associate this earthquake to El Pilar fault due to the fact that it was not observed liquefaction in Cumaná, and no tsunamis was detected. He agrees with coordinates of Grases and estimates a magnitude close to 7,5.

We don't agree with the hypothesis of an intermediate earthquake. Instead of that, we consider that high isolated intensities in Trinidad, together with long elongated isoseismal of intensity VII toward the west, are characteristic of a low depth strike-slip earthquake with an epicenter more to the east, close to Trinidad, and magnitude M≥ 7,5 (which explain the big felt area). By the other hand, we agree with Grases [84] and Mocquet [127] that high intensities along Orinoco River should respond to soil conditions. The argument that no tsunami implies an intermediate depth earthquake can't be sustained, because strike-slip earthquakes in general do not generate tsunamis.

It was prepared **table 19** using on-line intensity data from CERESIS and Mocquet [127]. CERESIS data [**CE**] are in MMI and Mocquet data [**MO**] are in EMS. As the differences between these scales are not very appreciable, there are processed together as a single intensity scale. In the original CE data was a place named as "Surinam" without coordinates. As in Surinam at this time only Paramaribo has importance, this intensity was assigned to it.

Table 19. **Intensity data from CERESIS [44] and Mocquet [22].**

Source= CE							
Longitude	**Latitude**	**Intensity**	**Settlement**	**Longitude**	**Latitude**	**Intensity**	**Settlement**
-64,2000	10,4800	8	Altos Marina de Cumaná	-62.8300	10.6000	6	Yaguaraparo
-64,1700	10,4700	8	Cumaná	-63,5000	10,2200	5	Caripe
-63,6200	10,5500	7	Cariaco	-67,6400	5,6800	5	Atures
-63,9700	10,2800	7	Cumanacoa	-63,6000	8,1000	5	Ciudad Bolívar
-63,2500	10,5700	7	El Rincón	-67,5500	6,1000	5	Macuco
-66,4000	7,4000	7	La Encaramada	-67,8000	5,3000	5	Raudal Maipures
-63,6200	10,3200	7	Cocuisas	-63,8000	11,0000	5	Margarita
-61,9300	10,6600	7	Macuro	-63.1700	9.7500	5	Maturín
-65,0000	9,7300	7	San Lorenzo	-57.6000	6.3000	5	Berbice
-63,2000	10,5300	7	San Pablo De Coicu	-55.2040	5.8520	5	Paramaribo
-63,5800	10,3300	7	Santa Clara de Payacu	-66,0000	10,3200	4	Caucagua
-63,8500	11,0500	7	Pampatar	-67,4700	10,3300	4	Maracay
-62,5800	10,6200	7	Irapa	-61.7200	16.0000	4	Guadalupe
-63.0800	10.1400	7	Teresén	-59.6200	13.1000	4	Barbados
-62.5000	10.5400	7	Soro	-52.3000	4.9200	4	Cayena
-63.1400	10.5400	7	N.S. de El Pilar	-54.0000	5.7000	4	Marony
-62.4000	8.5300	7	Antigua Guayana	-71,6200	10,7400	3	Maracaibo
-64.7200	10.1300	7	Barcelona	-52.1700	4.8300	3	Oyac
-61.5100	10.6800	7	Port of Spain	-52.6200	5.1300	3	Couron
-66,9200	10,5000	6	Caracas	-52.0000	4.5200	3	Kaw
-64,6000	8,8000	6	El Pao	-61.0800	14.6000	3	Martinica
-66,6200	10,4600	6	Guarenas	-51.5800	4.3000	3	Oyapoc
-63.4100	10.4700	6	Tierra Hueca	-53.0000	5.4700	3	Sinnamary
Source= MO							
-61,4500	10,5000	9,5	Guairía	-58,3500	7,0000	6	Essequebo
-61,3500	10,4500	9,5	N.S. de Monserrate	-66,1600	10,4800	5,5	Higuerote
-61,3300	10,6300	9,5	San Agustín Arauca	-66,8300	10,4600	5,5	Petare
-61,4200	10,6500	9,5	San Joseph Oruña	-70,2200	6,3000	5	Río Casanare
-61,3800	10,6300	9,5	San Pablo Tacarigua	-67,1500	3,9800	5	Río Ventuari
-62,9200	9,9000	9	Río Guarapiche	-68,9300	1,2000	4	Curacoa
-63,7000	8,1000	7,5	Buena Vista	-61,1500	13,3200	4	Saint Vincent
-58,1500	6,4500	6,5	Temerari River	-66,7300	9,6500	4	Taguay

Some macro-seismic estimates were made, based on statistical suggestions by Prof. Dr. G. Grünthal, some applied in Cotilla *et al*. [67]. They indicate that: (**a**) the latitude / longitude range (higher - lower) of the intensity values (III-VIII) gives a perceptibility grid of 4,5º-16º N / 50º-72º W; (**b**) the weights of each intensity are: III=0,152; IV=0,130; V=0,196; VI=0,109; VII=0,370; VIII=0,043; (**c**) the reliability of the perceptibility area is quite sure (~90 %) in the range VII-VIII; (**d**) the asymmetry of the axes of the zones varies significantly: III-VIII=0,35; VII-VIII=0,58; $I_{average}$=0,70; (**e**) the deformation rate of the isolines is also different: III=0,17; VII-VIII=0,55; $I_{average}$=0,38; (**f**) there are two main axes of propagation: N-S and E-W. The second one is the main axis. So the source can be an intersection of structures.

Conclusions

The authors consider that the retrospective study of strong earthquakes is very important for a reliable modeling of the seismic danger. In this sense, the comparative analysis obtained for the case of the 1766 seismic events in two different areas of the Caribbean, Cuba and Venezuela, confirms it.

Our main results are the following:

(1) The 1766.06.11 Santiago de Cuba earthquake was the greatest tragedy to date (75 deaths/ 700 injured/ 75 % buildings affected) in Cuba (Mw7,2/ I= IX/ h= 30 km/ 19,9 N -76,1 W/ perceptible up to La Habana city [~800 km]). The epicenter is associated to the Oriente fault zone

(2) The 1766.10.21 Venezuelan earthquake is characterized by Mw7,5/ I= X/ h= 30 km/ 10,7 N -62,5 W/ ~3,6.106 km^2 perceptibility area/ the seismic source can be an intersection of two active structures (NVA knot)

(3) The NVA knot is defined for the first time

(4) New isoseismal maps were drawn up for these earthquakes

(5) The isosists made, from the original data, for Cuba and Venezuela are very different as expected

(6) These earthquakes produced panic but did not local tsunami

(7) The 1766 Cuban earthquake occurred in the area of greatest seismic activity

(8) There are different recurrence periods of strong earthquakes (Cuba [1766-1852= 86 years]/ Venezuela [1766-1797= 31 years])

(9) The strongest earthquakes in Venezuela are associated with Caracas

(10) Spaniard Crown aided to Cuba but no Venezuela.

We confirm that Venezuela related to Cuba have: (**a**) larger population; (**b**) greatest magnitude of earthquakes; (**c**) much greater number of strong earthquakes; (d) larger number of fatalities and affected by earthquakes; (**e**) more quantity of local tsunami reports; (**f**) the largest linear extension of seismic activity in the Caribbean plate contact; (**g**) greater seismic hazard; (**h**) much less economic development in 1766; (**i**) taken its first catalog of earthquakes in 1940 and Cuba in 1855; (j) had the first earthquake report in approximately the same year.

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aac NEWTON (Inglaterra, 1643-1727): "Lo que conocemos es una gota, lo que no conocemos es un océano."

5-Cuba-Venezuela Earthquakes of 1766: Part II- Modeling the Macroseismic Field and Final Results

5-Cuba-Venezuela Earthquakes of 1766: Part II- Modeling the Macroseismic Field and Final Results

Terremotos de Cuba-Venezuela de 1766: Parte II- Modelado del campo macrosísmico y resultados finales}

Abstract- The macroseismic field, of the two strongest earthquakes of Cuba and Venezuela in 1766, was processed with an elliptical isoseismals model in order to get more reliable estimations of their coordinates and magnitude. Several possible adjustments (varying model or initial parameters) were done for each earthquake. The process included a statistical analysis of the residuals of adjustment to select the better one, in combination with tracing of theoretical isoseismals over felt intensity data. The results reinforced our seismotectonic analysis made in the Part I of this paper set. Also a general discussion of isoseismals' model applied is provided.

Keywords: Caribbean, Cuba, earthquake, historical seismicity, macroseismic field, Venezuela

Introduction

This is a second part of our study. Part I is specially committed to the tectonic and historic seismicity. Also, we comprehend a lively evaluation of two sturdy earthquakes in Cuba and Venezuela. They occurred at the same year, 1766 in two colonies of Spain. The first part includes all information consulted and reviewed, as well as the processing of data on seismicity. It permits to gain exceptional seismotectonic models and to confirm, for the primary time, that Cuba received crucial aid from the Spanish Crown, and none Venezuela. There are 21 tables and 7 figures in Part I some of them are quoted here. We will refer in present paper to some of them.

5.1-Statistical Treatment of the Earthquakes of 1766

Here, we are going to use the seismic information of the two strong earthquakes of 1766 produced in the Caribbean region. They were presented and analyzed in the Part I of this paper. Our proposal is to apply a recognized statistical methods set.

5.1.1-*About treatment of historic earthquakes*

The rough material of historic earthquake is a collection of descriptions about how were felt the earthquakes in different locations. Elementary process that is to be done is an evaluation of intensities using a scale. At first we take into account the intrinsic subjective character of evaluation of intensities, not only for judgment criteria. All effects should be evaluated for assigning an intensity value. Also, we know that in some cases the intensity has a fuzzy character [44].

The need of extracting the maximum information from felt data of earthquakes conducted to the first attempt to model the isoseismals: at the beginning of 20th Century Kövesligethy [52] proposed a model of the kind $I_i=I_0 – f(\Delta, h)$ [where: Δ= epicentral distance; h= the depth of focus]. Later on, with the introduction of the concept of magnitude the term I_0 was substituted by a function of M, and the general formula was transformed into $I= f(M, \Delta, h)$. The most common is called attenuation formula of "Kövesligethian type":

$$I = b \cdot M - k \cdot \lg(r) - p \cdot r + d \qquad (1)$$

Where: (**a**) b, k, p, d = coefficients to be evaluated; (**b**) $r = (\Delta^2 + h^2)^{1/2}$, [Δ+constant or a function of (Δ, h)]. The formula describes a field of I in the 2D space and is called "macroseismic field". But, when the problem is to assess the main parameters of a historic earthquake (coordinates and magnitude) it is necessary to process its observed macroseismic field. There are different methods that process: (**a**) only maximum intensity values; (**b**) several isoseismals; (**c**) rely in the adjustment of a theoretical model of isoseismals. All of them are subjective, but in last time there has been done attempts to introduce statistical procedures to diminish such subjectivism. See Musson and Cecić [56] for the general case and Bakun *et al*. [9] for the use of statistics in macroseismic data processing. The availability of macroseismic data is of several kinds that sometimes appear mixed: (**a**) descriptive documents where all the data of felt earthquakes are presented; (**b**) a summary of data with evaluation of intensities; (**c**) post-processing of data (isoseismal maps, estimation of coordinates and magnitudes).

The drawing of isoseismals in the majority of cases is by eye fitting. Nevertheless, some authors use geostatistical methods to do so [30, 52] or other statistical interpolation procedures (see part I of this paper for an example).

The statistical methods of for assessing main parameters of earthquakes rely on the existence of a dense pattern of felt intensities, as was the case in the preparation of European earthquake catalog [63] and they are based manly in the analysis to close of epicenter macroseismic field. But in the case of Cuba and Northwestern Venezuela, with low density of population in the 18th Century, were it should be drown isoseismals through long sea areas, these methods are difficult to apply. For these cases it seems more reasonable to adjust an isoseismal model that take into account the whole macroseismic field, giving equal weight to close to epicenter and long away from it felt intensities.

The macroseismic field created by formula (1) has circular symmetry and this is not the common behaviour of real isoseismals. There in general are elongated following tectonic features and many scientists prefer to model them as ellipses, using as main characteristics the ratio of major axis to minor axis (A/B) or the area of isoseismals.

With the objective to include it in seismic risk assessment [6] develop a model of elliptical isoseismals characterized by an equation of the type:

$$\lg [Q_I(M)] = a(I) + b(I) \cdot M + \sigma_Q \xi \qquad (2)$$

Where: (**a**) $Q_I(M)$= the area of degree I isoseismal; (**b**) $\sigma_Q \xi$= a random variable. Another parameter is the geographic orientation of major axis. This model was tested in several regions of former Soviet Union and Italy.

For the use in deterministic seismic zoning in the former USSR it was developed a model of empirical elliptical isoseismals [11].

Later on, Álvarez [2] develop a model of elliptical isoseismals that was tested in Greater Antilles [4]. Its objective was dual: (**a**) to use in parameter estimation of historic earthquakes; (**b**) to include it in seismic hazard estimation program [3]. The characteristics are: (**a**) a geometric estimation of distance to be used in attenuation formula considering A/B and orientation of major axis; (**b**) a formula of Kovesligethian type for attenuation description, with three forms of evaluating "r" (along minor axis, major axis or average radius of the ellipse); (**c**) possibility of considering a regular variation of ellipticity from inner to outer isoseismals.

The contributions for modeling macroseismic field in elliptical isoseismals continued with time. In China [12, 65] followed a procedure of adjusting a Koveslighetian type formula for major and minor axes of ellipses independently. In New Zealand, Dowrick and Rhoades [31] developed a model with empirical shape of elliptical isoseismals and an attenuation law more complicated that formula (1).

In this paper the model of Álvarez [2] was used (**see ANNEX 1**) for assessing main parameters of the 1766 earthquakes in Cuba and Venezuela.

5.1.2-*Adjusting an Isoseismal Model to Felt Intensities*

As is discussed in **ANNEX 1**, the model of elliptical isoseismal is highly dependent of the attenuation formula that is applied. The formulas have a regional dependency. To select one from literature (or develop it from felt intensities) that fits the intensity data under analysis is not an easy job.

An adjustment of isoseismal model can be done: (**a**) from visual inspection of the fit of calculated isolines to already existing isoseismal map [4]; (**b**) with a map of felt intensities. But visual inspection adds more subjectivism to an already intrinsically subjective material. In this paper we decided to analyze the residuals I_{calc} - I_{obs} for taking a decision. Due to the continuous character of I_{calc}, an ideal fit of the data requires that all the residuals be placed in a range [-0,5 – 0,5]. Then, the adjustment should be best as short as the points separate from this condition. The other aspect to take into account is the behavior of the residuals > 0,5 and < 0,5 with distance that gives information about overall fit of attenuation formula (1).

5.1.3-*Earthquake of 11.06.1766 in Cuba*

In the case of Cuba there we tested two different variants of Koveslıgethian formula: (**a**) Fedotov and Shumilina [32] [**FE-1971**] {b= 1,5/ k= 2,63/ p= 0,0087/ d= 2,5} developed for Kamchatka Peninsula, that fits Greater Antilles data with well accuracy [4]; (**b**) Gómez *et al*. [34] [**GO-2003**] {b= 1,4/ k= 3,17/ p= 0,0017/ d= 3,11} by adjusting data of felt intensities in Eastern Cuba.

The earthquake of 11.06.1766, as was discussed before, has two different magnitude estimation: M_S6,8 from Cotilla and Udías [26] and M_W7,5 from Álvarez *et al.* [5]. Then it was decided to test three values of magnitude M_W (6,8/ 7,2/ 7,5). From observed intensity data it was possible to identify a ratio A/B= 1,4. The tests were done for two directions of r_e: A and Δ_m, and both attenuation laws independently, for a total of 12 different adjustments. In each case there were calculated the average and standard dispersion (μ, σ) of residuals and a least square fit of “y= a + b·x” [where: x= distance and y= residual]. The felt intensities data was taken from **table 18B** (Part I) and results presented in **table 20**.

Table 20. **Analysis of residuals $I_{calc} - I_{obs}$ for the mentioned combinations for earthquake in Cuba.**

F	r_e	M_W	μ	σ	a	b	F	r_e	M_W	μ	σ	a	b
FS	A	6,8	-0,95	1,633	0,21	-0,0049	GO	A	6,8	-0,55	0,993	-0,79	0,0010
FS	Δ_m	6,8	-0,46	1,196	0,35	-0,0041	GO	Δ_m	6,8	-0,27	0,903	-0,62	0,0017
FS	A	7,2	-0,34	1,373	0,81	-0,0049	GO	A	7,2	0,01	0,829	-0,23	0,0010
FS	Δ_m	7,2	0,15	1,116	0,96	-0,0041	GO	Δ_m	7,2	0,29	0,907	-0,06	0,0017
FS	A	7,5	0,11	1,335	1,27	-0,0049	GO	A	7,5	0,43	0,935	0,18	0,0010
FS	Δ_m	7,5	0,60	1,260	1,41	-0,0041	GO	Δ_m	7,5	0,71	1,113	0,35	0,0017

Notes: (a) F= formula; (b) (μ, σ) average and standard deviation; (c) (a, b) least squares adjustment of "y= a + b·x" [x= distance and y= residual]; (d) FS = Fedotov and Shumilina [32], GO = Gomez *et al.* [34]; (e) Δ_m – average radius.

The selection of the best fit will corresponds to (μ, σ) closer to (0, 0,5) and (a, b) closer to (0, 0), The best approximations to them are for M_W= 7,2 in the case of FE-1971 formula for r_e= Δ_m and GO-2003 formula for r_e= A. The final selection is done after visual inspections of the corresponding maps (**Figure 8**).

In those maps, it is clear a different behavior of both models. Due to the less value of parameter k in Kovesligethian kind formula for GO-2003, the isoseismal calculated with this model have bigger values at great distances than with FE-1971 model. Any of the model fits well I= VI and behave more of less the same for I≥ VII. For I= III at distances bigger that 400 km the FE-1971 models adjusts better. We use this adjustment. In the **figure 9** are presented the graphics of statistical analysis of the selected solution.

Then, we can estimate that earthquake has more probable parameters [19,9 N -76,1 W/ h= 25 km/ M_W= 7,2]. The isoseismals′ map is described by: A/B=1,4 ; $r_e = \Delta_m$; η = 0, isoseismals ′ orientation = 0° in polar coordinates and FE-1971 coefficients of Kovesligethian formula.

5.1.4-*Earthquake of 21.10.1766 in Venezuela*

In the case of Venezuela there are not any formula of Kovesligethian type tested before. There exist some studies made for Colombia, Bolivia and Ecuador. Nevertheless, they use attenuation formulas not of the type (1) but of the kind I= f (I_0, Δ, h). These are not applicable to use with the isoseismal model. The only one equation of the kind (1) found for South America, correspond to Brazil [59] [QU-2019] {b= 0,995/ k= 1,505/ p= 0,00116/ d= 2,08} for intraplate earthquakes with M≤ 6,2 m_b. We decided test the two ones used with Cuban earthquake: (**a**) Chen *et al*. [13] [CH-2002] developed for Central America [b= 1,5/ k= 2,7/ p= 0,00106/ d= 1,7] for m_b; (**b**) QU-2019. As in the previous case, the felt intensities data was took from **table 19** (Part I).

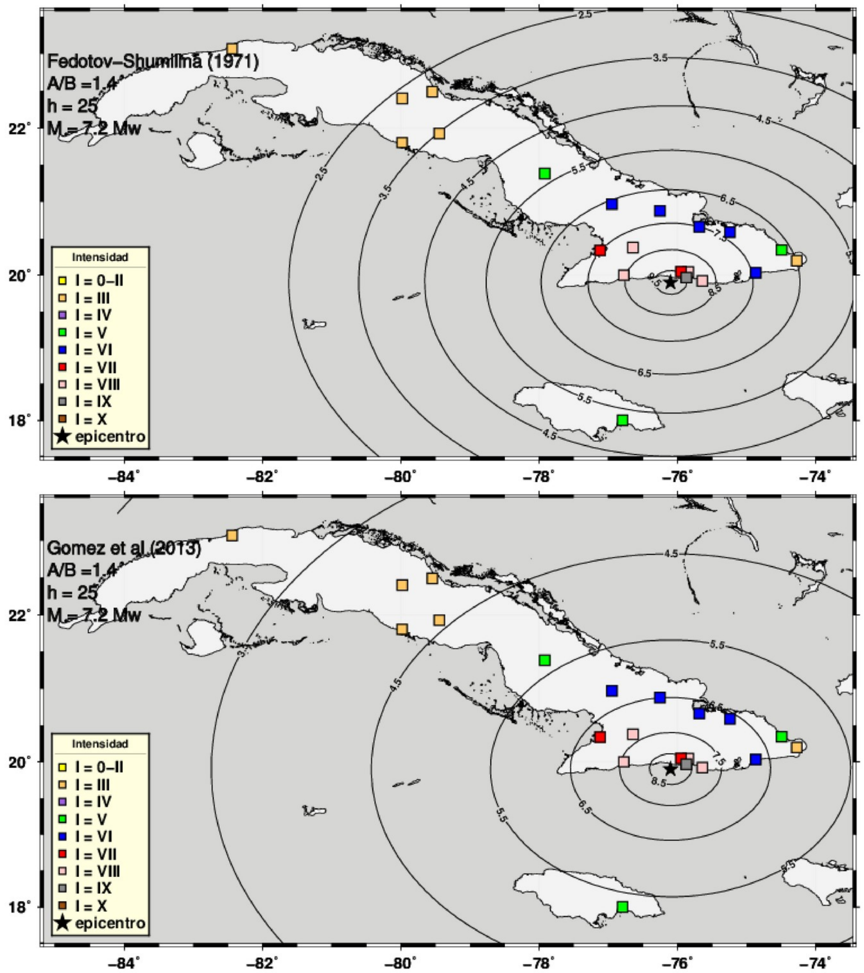

Figure 8. Comparison of the maps with theoretical isoseismals for booth cases.

A preliminary test on the applicability of these formulas determined that the formula of: (**a**) FE-1971 fail in fitting the intensities of points placed far away from epicenter; (**b**) GO-2003 gives worst results than the remainder two; (**c**) CH-2002 and QU-2009 fit the data with acceptable behavior and can be used for the final test. All these formulas were obtained for m_b and we are evaluating an earthquake with possible $M_W \geq 7,5$, where m_b is not defined. Then, we are doing an extrapolation of the formulas. An inspection of real intensity data reflects that isoseismals should have an A/B not very large. A test performed using the CH-2002`s formula for a range of A/B [1,0 1,6] determined that the best fit is with A/B= 1,2. From the data discussed before we will test a magnitude in the 7,5-7,9 interval [three values (7,5/ 7,7/ 7,9) and also three depth values (10/ 20/ 30) km]. Also there will be tested two direction of r_e (A, Δ_m). It gives a total of 36 possible combinations. Results are in **table 21.**

As it can be seen from this table, the best adjustment is obtained by CH-2002 formula with h= 10 km and $r_e = \Delta_m$. The second one is for the same formula and r_e, but for depth 30 km. Then, we estimate that earthquake has probably parameters [10,4 N -61,5 W/ h= 30 km/ M_W= 7,5]. The isoseismal′s map is described by: A/B= 1,2, $r_e = \Delta_m$, η= 0, isoseismals′ orientation= 0° in polar coordinates and CH-2002 coefficients of Kovesligethian formula. In **figure 10** are the graphics of statistical analysis of the selected solution and in figure 11 the map of the theoretical isoseismal for the selected adjustment.

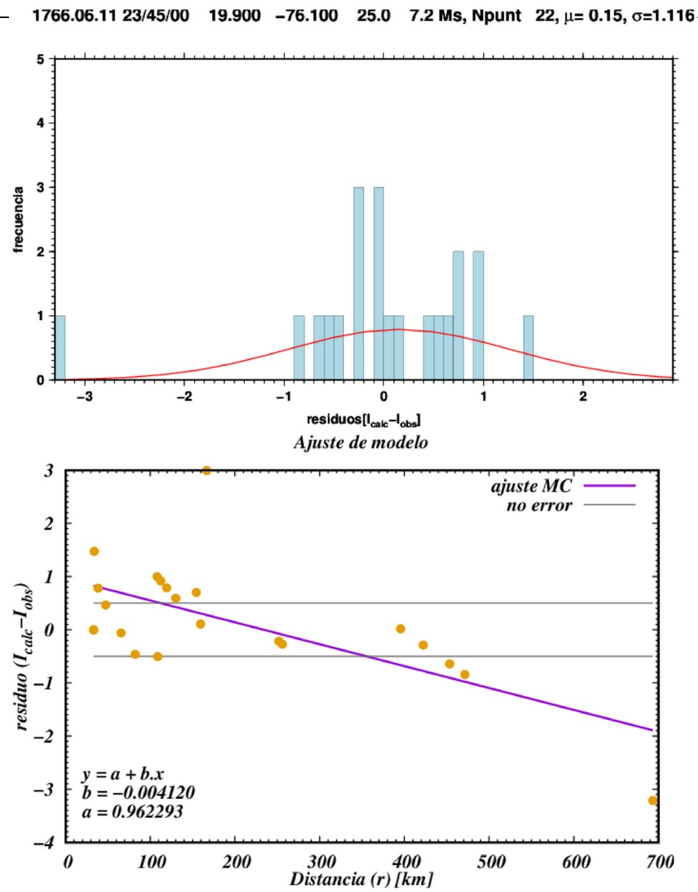

Figure 9. Statistics of residuals for selected adjustment of theoretical model for Cuban earthquake of 11.06.1766. (a) Upper: histogram of residuals, red line represents the normal distribution for values of (μ, σ); (b) lower: dependence of residuals upon distance, gray lines represents the zone in which adjust is correct.

5.2-Discussion

Review of the historical seismicity of the Caribbean, including Cuba and Venezuela, demonstrates the increase in publications since the 20th century where previous data are modified. It indicated that there is a temporal coincidence in terms of the historical seismicity of Cuba (1528) and Venezuela (1530) [5, 54]. They are the initial settlement sites of the Spaniards. They have not volcanic activity but in the vicinity of: (a) Cuba has neither volcanoes: (b) Venezuela has volcanoes (**b.1**) Colombia (~25/ from [1528] in the Galeras [4.276 m]); (**b.2**) the Lesser Antilles (~24 strong earthquakes), near Venezuela has three active volcanoes in: (**b.2.1**) Granada (*Kick-en-Jenny* underwater volcano with 13 eruptions 1939-2001); (**b.2.2**) San Vicente and Granadinas (*La Soufriere* volcano); (**b.2.3**) Martinica (*Montagne Pelee*, year 1902 with ~32.200); (**b.2.4**) Trinidad-Tobago (Devil's Wood Yard mud volcano)). Volcanoes are associated with earthquakes and tsunamis, and can affect Venezuela. These countries are situated in two important zones of seismic activity [**S-A**] where the largest is Venezuela. Nevertheless, Martinica and Trinidad have suffered eight strong earthquakes (1690-1954).

Table 21. **Analysis of residuals I_{calc}-I_{obs} for the mentioned combinations.**

F	r_e	M_W	h	μ	σ	a	b	r_e	M_W	h	μ	σ	a	b
CH	A	7,5	10	-0,12	1,046	-0,023	0,00018	Δ_m	7,7	20	0,37	1,100	0,36	0
CH	Δ_m	7,5	10	0,04	1,038	0,081	0,00008	A	7,9	20	0,57	1,182	0,62	-0,00011
CH	A	7,7	10	0,24	1,066	0,32	-0,00018	Δ_m	7,9	20	0,72	1,262	0,72	0
CH	Δ_m	7,7	10	0,39	1,110	0,43	-0,00008	A	7,5	30	-0,17	1,052	-0,14	-0,00003
CH	A	7,9	10	0,59	1,165	0,68	-0,00018	Δ_m	7,5	30	-0,01	1,040	-0,05	0,00009
CH	Δ_m	7,9	10	0,75	1,128	0,78	-0,00008	A	7,7	30	0,19	1,055	0,20	0,00003
CH	A	7,5	20	-0,14	1,046	-0,082	-0,00011	Δ_m	7,7	30	0,34	1,094	0,29	0,00009
CH	Δ_m	7,5	20	0,01	1,036	0,014	0	A	7,9	30	0,54	1,171	0,55	0,00003
CH	A	7,7	20	0,21	1,059	0,27	-0,00011	Δ_m	7,9	30	0,69	1,249	0,64	0,00009
QU	A	7,5	10	-0,61	1,266	-1,11	0,00098	Δ_m	7,7	20	-0,28	1,171	-0,85	0,0012
QU	Δ_m	7,5	10	-0,50	1,229	-1,05	0,0012	A	7,9	20	-0,16	1,131	-0,67	0,0010
QU	A	7,7	10	-0,38	1,170	-0,87	0,00098	Δ_m	7,9	20	-0,05	1,138	-0,62	0,0012
QU	Δ_m	7,7	10	-0,27	1,154	-0,81	0,0012	A	7,5	30	-0,64	1,303	-1,18	0,0010
QU	A	7,9	10	-0,14	1,117	-0,64	0,00098	Δ_m	7,5	30	-0,53	1,269	-1,13	0,0013
QU	Δ_m	7,9	10	-0,03	1,123	-0,58	0,0012	A	7,7	30	-0,41	1,205	-0,95	0,0010
QU	A	7,5	20	-0,63	1,283	-1,14	0,0010	Δ_m	7,7	30	-0,30	1,191	-0,90	0,0013
QU	Δ_m	7,5	20	-0,51	1,248	-1,09	0,0012	A	7,9	30	-0,17	1,147	-0,71	0,0010
QU	A	7,7	20	-0,39	1,186	-0,91	0,0010	Δ_m	7,9	30	-0,06	1,155	-0,67	0,0013

Notes: (a) F=formula; (b) (μ, σ) average and standard deviation; (c) (a, b) least squares adjustment of "y = a + b·x", where x=distance and y=residual; (d) CH= Chen *et al*. [13], QU= Quadros *et al.* [59]; (e) Δ_m= average radius.

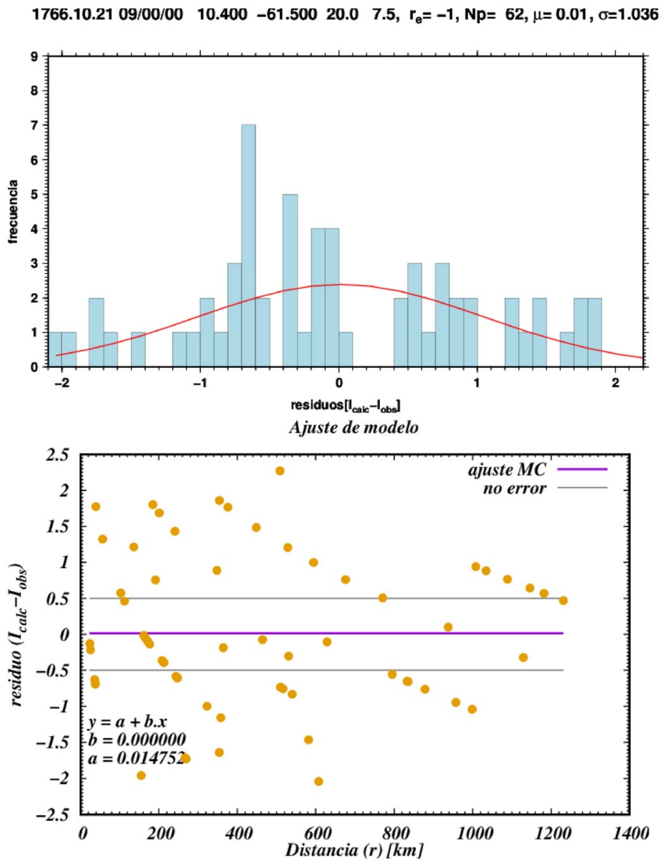

Figure 10. Statistics of residuals for selected adjustment of theoretical model for the 21.10.1766 earthquake in Venezuela. **(a)** Upper: histogram of residuals, red line represents the normal distribution for values of (μ, σ); **(b)** Lower: dependence of residuals upon distance, gray lines represents the zone in which the adjustment is correct**.**

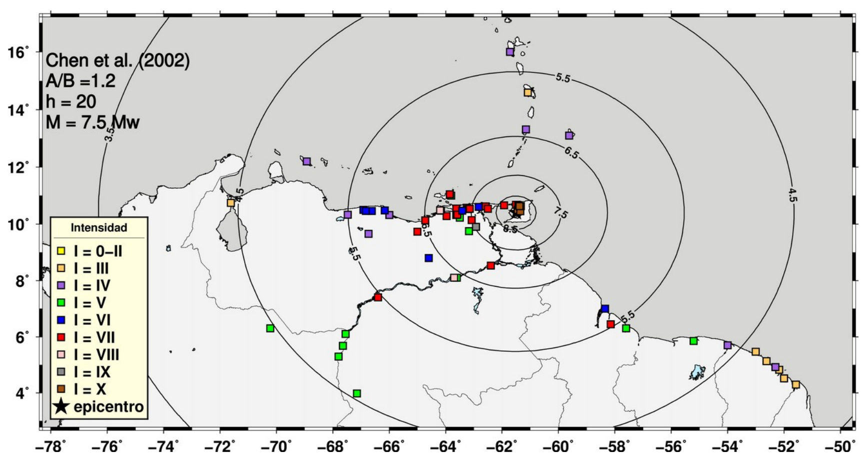

Figure 11. Map with theoretical isoseismals for the adjusted model.

S-A (amount of events and M) of Venezuela is higher than in Cuba (**Tables 15 and 17**). Venezuela has a source of local tsunamis (**Table 16**) and losses (economic, material and human) by earthquakes and tsunamis greater than Cuba. Also, the S-A is larger South American-Caribbean Plate Boundary Zone [**PBZ**] than of North American-Caribbean one. At 1766 two earthquakes occurred in different Caribbean regions: (**a**) Northern (Cuba: 11.06/ M6,8/ 50 [66 days] aftershocks/ 40 deaths/ 10^3 km^2) (**Figure 4**); (**b**) Southern (Venezuela: 21.10/ M8,0/ 14 months of aftershocks/ ? deaths/ $3,6.10^6$ km^2) (**Figure 5**); (**c**) epicenters were located for: (**c.1**) Cuba in the Oriente fault (**Figure 4**); (**c.2**) Venezuela in El Pilar fault-subduction zone of Lesser Antilles (El Soldado and Los Bajos faults). They are historically the largest (Cuba [M6,8] and Venezuela [M8,0]) in their respective zones. Other strong events have occurred in such areas. Both countries were colonies of Spain and the events occurred 74 and 78 years, respectively after the Spaniards arrived. There are different recurrence periods (Cuba [1766-1852= 86 years]/ Venezuela [1766-1797= 31 years]) and evidently different S-A.

Information on the historical context of these two earthquakes shows that: (**a**) Cuba and Venezuela had a very different economic situation. Cuba, as an island-port, enjoyed significant control over commercial and monetary traffic, while Venezuela did not; (**b**) the number of governmental and ecclesiastical buildings in Cuba was greater than in Venezuela (**Table 4**); (**c**) the Spaniards authorities of highest rank and category were the ones who described the earthquakes of 1766 and the effects produced. Then there have been not defect of form; (**d**) Cuba received an important economic contribution, from Spain, to repair the damage of the earthquake and Venezuela did not. It has been proven that destroyed and affected fortifications, such as the San Pedro de La Roca Castle (Morro, 1638) and the Lighthouse (1848) were well rebuilt. The 1852 and 1932 earthquakes did not damage them (**Table 17**); (**e**) the situation of Venezuela, regarding the less attention of the Crown, for the earthquakes effects are showed by Altez [1] when comparing what has been lived with: (**e.1**) the tsunami of 1.09.1530 that destroyed the Captain Jacome de Castellon fort in the Cumana River (Venezuela), with hardly any comments; (**e.2**) the 11.09.1541 multiple phenomenon of that devastated Santiago de los Caballeros, Guatemala (earthquake, eruption of the Fuego volcano and collapse of the Agua volcano). "Newspaper" exposed a "creep-able earthquake". That writing was the first for America; (**f**) there was a noticeable decline in population (~400.000 persons) in Venezuela (1810-1822) (**Tables 5-6**) which is justified with the 1812 earthquake and which affected the Growth index by -2 points. This earthquake is similar to that of 1766. The panic behavior of the population by these two earthquakes was similar. Since the earthquakes in the colonies some anti-seismic measures were considered.

We interpret S-A area in the Caribbean-South American PBZ (**Figures 3 and 6**) at the eastern end of Venezuela, near Trinidad as a knot (NVA knot). The sector has the highest epicenter density (1950-2000), while for Santiago de Cuba (1979-1999) is quite lower. The indicated area coincides with the mentioned fault zones intersection (El Pilar) and subduction area of the Lesser Antilles. Based mainly on [7, 8, 10, 46-48, 57, 61] this type of intersection is seismoactive. The NVA knot has spatial coincidence with the three isoseismals appearing in [33]. The tsunami occurrence with the 1812 earthquake of Venezuela allows to assume that the mechanism must be subduction (combined compressive - right lateral component [like the earthquake of 2018 (USGS)]). Three of the four recorded earthquakes are at the NVA knot (**Table 22**).

Table 22. Earthquakes in Venezuela recorded by the USGS.

Date/ time	M/ depth (km)	Coordinates (N W)	Focal mechanism	Location
1967.07.29/ 00:00:04	6,0/ 25	10,559 67,330		Vargas
1986.06.11/ 13:48:01	6,3/ 18,8	10,597 62,928	97,52 355,75	Sucre
1997.07.9/ 19:24:13	7,0/ 19,9	10,598 63,486	173,76 265,82	Sucre
2018.08.22/ 9:31:45	5,8/ 108	10,659 62,929	83,78 201,27	Yaguaraparo

Our proposal of a seismic knot is not new at all, since in other places there are several antecedents as in: (a) Alpes-Dinarides [38]; (b) Altai-Sayan-Baikal [41]; (c) Armenia [68]; (d) Bering Sea [53]; (e) Carpatos-Balcanes [37]; (f) Cuba: (f.1) Torriente-Jagüey Grande [14-16]; (f.2) San José de las Lajas [16]; (f.3) Cabo Cruz [15, 19]; (g) Himalaya [10, 35, 36]; (h) Greece [42]; (i) Hispaniola [27]; (j) Italy [38, 67]; (k) México [29]; (l) Mongolia [66]; (m) Romania [59]; (n) Russia [7, 8, 49, 50]; (o) Spain: (o.1) to the all territory [18, 40]; (o.2) Béticas [20-22, 28, 62]; (o.3) Galicia [17]; (o.4) Albacete [23]; (o.5) Guadalajara [24]; (o.6) Cantabria [25]; (p) USA: (p.1) New Madrid [64]; (p.2) California [45]. The effectiveness of some of these determinations is presented in table 23.

Figure 1 of Gitis *et al.* [33] shows, in the north-eastern-southern Caribbean band, the results of the GEO automatic system for the M_{max} determination. The highest values are located in the vicinity of Venezuela-Trinidad. For the entire Caribbean region (Figure 1 by Ruiz-Schulcloper *et al.* [62]) the absolute values M_{max} are in the Pacific area. Other areas with small maximus are in Hispaniola, Puerto Rico and Venezuela-Trinidad. The result was obtained by mathematical modeling using pattern recognition techniques. The two mentioned papers indicate that the most active area is on the southern edge, where Venezuela. Figure 1 of [55] shows the NE end of Venezuela as very active. There (Venezuela-Trinidad) in the vicinity of the S-edge of the Lesser Antilles (NVA knot) is a complex arrangement of seismic faults that accommodate deformations and justify the strong earthquakes and tsunamis occurrence. That area is much more active than Cuba.

Table 23. Some effective determinations.

Location	Date	First element		Tectonic environment
		Earthquake	Knot	
Armenia	7.12.1988		X	Plate boundary
USA	1988		X	Plate boundary
Cabo Cruz	26.08.1990		X	Plate boundary
Caucaso	2009		X	Plate boundary
Italy	Series of 2016	X		Plate boundary
Torriente-Jagüey Grande	16.12.1982	X		Plate interior
San José de las Lajas	9.03.1995		X	Plate interior
Galicia	23.05.1997	X		Plate interior
Murcia	11.05.2011		X	Plate interior
Albacete	23.02.2015		X	Plate interior
Guadalajara	Series of 2017		X	Plate interior

We assure that: (a) the two regions affected by the 1766 earthquakes in the Caribbean region were treated very differently by the Crown of Spain. Cuba received a significant economic aid; (b) the seismogenesis of Cuba and Venezuela is quite different; (c) the seismic hazard: (c.1) is real in southeastern Cuba and northeastern Venezuela territories; (c.2) can heavy affect inhabitants of Santiago de Cuba and Cumana; (d) also local tsunamis can be occurred in northeastern Venezuela;

(**e**) the 1766 Santiago de Cuba earthquake was the greatest tragedy to date (40 deaths/ 700 injured) in Cuba; (**f**) the most disastrous seismic events of Venezuela occurred in Caracas (~2.200 deaths); (**g**) Cuba and Venezuela have different percentage values of deaths from earthquakes in relation to the population. Cuba has <0,7 %, and Venezuela, up to 10 %.

Although the interpretation of macroseismic data is intrinsically a subjective matter, we obtained some results in point analysis of felt intensities and adjusting of a theoretic model of isoseismals. In the case of Cuban results, where distribution of felt intensities is somewhat smooth, we adjusted a model that allows to select a M_W7,2 intermediate value between previous estimates by other authors. In the case of Venezuelan earthquake, where the felt intensities pattern was more complex, our results indicate a magnitude M_W7,5 and a depth of 30 km. This depth contradicts the criteria of several researches that considers that this earthquake is of intermediate depth.

The location of Venezuelan epicenter of 1766 earthquake and the two main alignments or axis E-W and NNE-SSW are quite clear in **figure 7A**. In it there is defined the NVA knot.

The results of the adjustment of the isoseismal models show the difficult to fit a Kovesligethian type attenuation law using the macroseismic field. When adjusting isoseismal model for Greater Antillas, Álvarez and Chuy [4] found a good fit of [33] formula with r_e= A for some earthquakes and with r_e= Δ_m for others. With earthquake of 1766 in Cuba, the fit was with r_e= Δ_m also. This means that this formula doesn't fits very well the data. Trying to solve this problem, Gómez *et al*. [34] adjusted a new formula for Eastearn Cuba, but it doesn't fit well the macroseismic field at long distances of epicenter. The case of Venezuela is worst, because nobody tested before a formula of this kind. It seems that the formula of [13] for Central America is applicable, but the test was done with only one earthquake characterized by a very complex macroseismic field. Then the problem of finding adequate formulas of Kovesligethian type for describing the macroseismic field continues open.

The use of an isoseismals' model for assessing earthquake parameters, may look less precise than the use of the statistical criteria developed last time [9] for doing the same. Then, when the initial data produce several researchers to made divergent estimations, as the Venezuelan earthquake of 1766 case, it is possible to consider that, instead to reduce the analysis to closer distances, to use the complete macroseismic field. This should be the better option for assessing magnitude and depth of historic earthquakes. By the other hand, when observed intensities are in islands, separated for extensive sea areas, or a very irregular pattern of intensities, due to the sparse settlement' locations, we must be to analyze the whole observed macroseismic field to extract the maximum information

The model used is highly versatile. It does not depend of a particular attenuation formula, but for a kind of that. It is very common in seismology. Although, we used a Kovesligethian kind, any formula of the kind I= f (M,Δ,h) can be used. Additionally the facility of measuring Δ in three different directions in an ellipse (A, Δ_m, B) gives the possibility of using the same formula for fitting different attenuation behaviors. Finally, there is possible to consider the diminishing of ratio of major to minor axes (A/B) of ellipses as intensity value decreases, in a formula of the kind $A/B|_I$= f (I,I_0). This situation is frequent in continental earthquakes and we didn't encountered it in Caribbean or Central America earthquakes. In the annex is deduced, for the Kovesligethian kind of formula (with r= hypocenter distance) an expression of the kind $A/B|_I = f(I, r_e, h)$, but it can be deduced for other kind of attenuation formula.

Conclusions

The authors consider that the retrospective study of strong earthquakes is very important for a reliable modeling of the seismic danger. In this sense, the comparative analysis obtained for the case of the 1766 events in two different areas of the Caribbean, Cuba and Venezuela, confirms it.

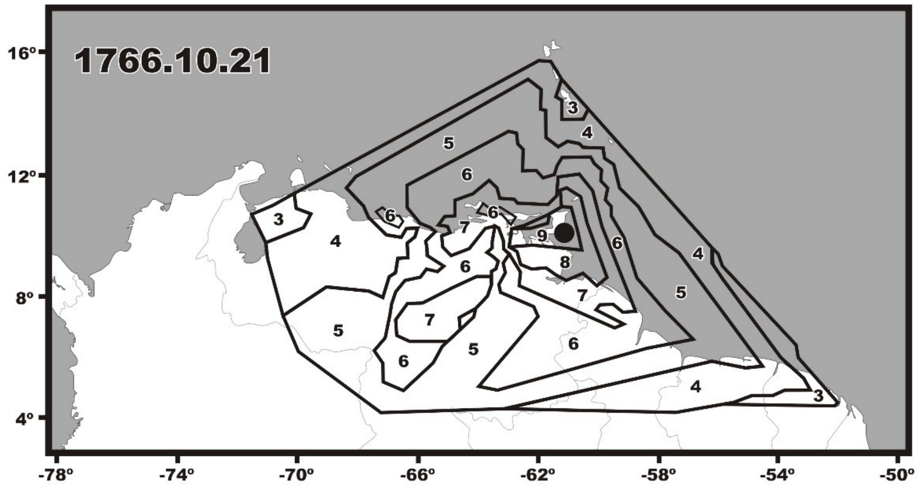

Figure 7A. Generalized isoseismal scheme of 1766 in Venezuela.

Our main results are the following:

(a) The 1766 earthquake is related in: (**a.1**) Cuba to the Oriente fault zone; (**a.**2) Venezuela with the NVA knot in the vicinity of western Venezuela-Trinidad

(b) The adjusted parameters of earthquakes are: (**b.1**) Cuban earthquake [19,9 N -76,1 W/ h= 25 km/ M_W= 7,2]; (**b.2**) Venezuelan earthquake [10,4 N -61,5 W/ h= 30 km/ M_W= 7,5]

(c) The Cuban and Venezuelan felt intensities pattern are quite different, that is reflected in the adjustment. The histogram of the residuals for the case of Venezuelan earthquake shows an appreciable number of earthquakes with values in the ranges (-1, -2) and (1, 2), while for the case of Cuban earthquake, the majority of residuals are in the range (-1, 1)

(d) The relative bigger complexity of macroseismic field of Venezuelan earthquake is explained for the location of his focus in the seismoactive NVA knot

(e) The best fit model for Cuban earthquake was obtained with the Kovesligethian type of attenuation formula made by Fedotov and Shumilina [33] for Kamchatka Peninsula (with distance measured along average radius Δ_m of the ellipses). This reinforce the results of Chuy and Álvarez [4], obtained by a try and error procedure of adjustment of model isoseismals to smoothed hand traced experimental isoseismals of Greater Antilles earthquakes

(f) The best fit model for Venezuelan earthquake was obtained with the model of Chen *et al*. [13] (with distance measured along major axis A of the ellipses). It has to be pointed out that this formula was obtained for m_b that is difficult to consider in a magnitude M_W7.5 earthquake.

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ANNEX 1
The Model of Elliptical Isoseismals

This model requires the existence of an attenuation law of Kovesligethian type [1] that allow to describe the macroseismic field. As was mentioned in the text, the value of “r” in this formula can be calculated in different ways. In the case of an elliptical isoseismal this value is not calculated as a generalized distance hypocenter-point, but a generalized distance hypocenter-ellipse that passes by the point. Present model determines how to calculate this distance, based on the ratio A/B of major to minor axis of the ellipses and, perhaps, a decrease of this ratio from inner to outer isoseismals.

For describing the shape of the ellipses there are used the parametric equations of an ellipse:

$$\Delta = A \cdot \left| \frac{\cos\theta}{\cos\alpha} \right| = B \cdot \left| \frac{sen\theta}{sen\alpha} \right|$$

Where: (a) Δ= the distance from the center of the ellipse to a point in its contour; (b) α= the polar angle of line joining both point; (c) θ= an auxiliary angle calculated as: θ = arctan [A/B·tan(α)] (Figure A.1):

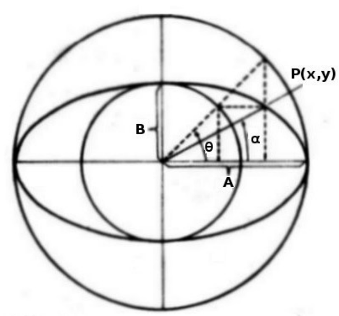

Figure A.1. Scheme of the meaning of the different parameters that describe the shape of isoseismals (modified from Álvarez and Chuy [4].

The attenuation is determined by the Kovesligethian formula evaluated in r= r_e

$$r_e = \left(\Delta_e^2 + h^2\right)^{1/2}$$

Where: (a) h= focal depth; (b) Δ_e= the distance epicenter-ellipse in a particular direction called “effective radius”. The limits are the directions of major axis (Δ_e= max) and minor one (Δ_e= min). In the last case the isoseismals are bigger and more separated

$$\Delta_m = 2/\pi \int \Delta \cdot d\alpha = B \cdot K(m)/2\pi$$

between them. Is convenient to consider and intermediate distance, say the average radius of the ellipse:

Where: (a) m= 1 - $B^2/A^2 \geq 0$; (b) K(m) is an elliptical integral of first kind, which values may be found in special tables. A comparison of isoseismal obtained in the different cases of estimation of r_e is presented in figure A.2.

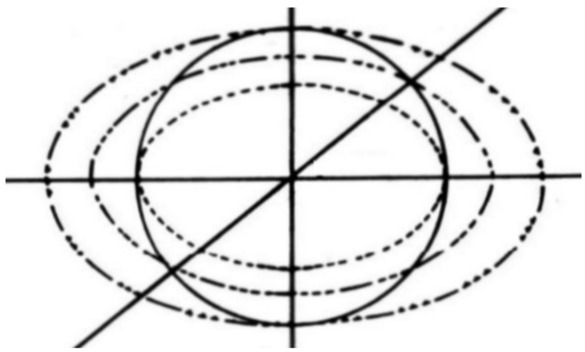

Figure A.2. Comparison of the ellipses obtained by selecting different directions for r_e. (a) Outer ellipse (B); (b) intermediate ellipse (Δ_m); (c) inner ellipse (A). The circle correspond to circular isoseismals. The possibility of selecting this directions increase the applicability of a particular Koveslighethian type formula (modified from Álvarez and Chuy [4].

Sometimes it is observed a behavior in macroseismic field that corresponds to a diminishing of ratio of major to minor axes (A/B) of ellipses as intensity value decreases:

$$A/B\big|_{I=I_i} = A/B\big|_{I=I_0} - \eta \cdot (I_0 - I_i)$$

For a Koveligethian type attenuation formula it is expressed as:

$$A/B\big|_{I=I_i} = A/B\big|_{I=I_0} - \eta \cdot \left[k/\lg(r_{e_i}/h) - p \cdot (r_{e_i} - h)\right]$$

Where: r_{e_i}= the effective radius of the isoseismal with I= I_i.

Then, the model is defined by: (a) parameters of the Kovesligethian kind formula; (b) focal depth; (c) ratio A/B; (d) direction of the effective radius; (e) parameter η of decreasing of A/B as a function of I_0 - I_i. It is added also geographical information on the orientation of major axis for a correct tracing of isoseismals in a map.

"…No hay que apagar la luz del otro para lograr que brille la nuestra…"
(Mahatma GANDHI, India, 1869-1948)

COMENTARIOS FINALES

Recorrida la Monografía quedan por resaltar algunos puntos comentados, y que consideramos importantes. Ellos son que:

1) las observaciones y los estudios de terremotos en Cuba se conocen desde prácticamente del arribo de los españoles y fueron completándose con el tiempo, en al menos 4 etapas temporales. Esto ha sido en el tiempo un proceso lento y con pulsos de diferente amplitud, y nunca lineal

2) Cuba es un megabloque con cuatro Unidades Sismotectónicas -o bloques- en el borde meridional de la placa norteamericana

3) las estructuras activas están segmentadas y categorizadas diferentemente

4) Cuba tiene tres tipos de actividad sísmica: **a)** entre placas; **b)** interior de placa; **c)** antrópica

5) la sismicidad se relaciona, directamente, con la interacción entre las placas de Norteamérica y del Caribe que genera y transmite esfuerzos

6) hay dos tipos de estructuras sismogénicas: **a)** fallas; **b)** nudos o intersecciones de fallas

7) las fallas Nortecubana y Surcubana, como bordes externos del megabloque, son activas, están segmentadas y deformadas

8) la falla Oriente es la más activa y de mayor peligro sísmico, en particular para la ciudad de Santiago de Cuba

9) la falla Nortecubana no tiene relación contemporánea alguna de continuidad geoespacial con la falla Septentrional de Haití. Esta última es un límite de placas y posee una mayor capacidad sismogenética.

Este resultado de conjunto consideramos debe permitir al lector interesado: **1)** usarle como una sólida plataforma para mejorar el conocimiento sismotectónico de Cuba en el contexto del Caribe; **2)** recopilar y analizar las Referencias utilizadas en los cinco Capítulos; **3)** alejarse de las especulaciones y la distorsión de datos. Además, recomiendan que: **1)** la base del conocimiento sobre la Sismotectónica de Cuba tiene que sustentarse en investigaciones y datos contrastados; **2)** siempre hay que indicar, adecuadamente, las fuentes empleadas; **3)** las críticas, de cualquier indóle, tienen que ajustarse a la ética y alejarse de las fantasias, y de apropiación indebida de ideas y resultados de otros autores.

En esa línea de razonamiento, exponemos por vez primera que los autores, primero y tercero, de la monografía han mantenido durante varios años correspondencia epistolar, y también por correo electrónico, con algunos jóvenes universitarios cubanos, de dentro y fuera de Cuba. Estos jóvenes han solicitado mantener, desde entonces, el anonimato. Hemos correspondido oportunamentre a su interés y remitido tanto nuestras publicaciones, como también algunas otras de otros autores sobre la temática sismotectónica, principalmente. Esto evidentemente ha sido y es con el único objetivo de ayudarles en su formación académica. En consecuencia se trae la siguiente idea de **Alexander GRAHAM BELL (Reino Unido, 1847-1922):** ***"Antes que todas otras cosas la preparación es la clave para el éxito"***,

Por último, el primer autor quiere dejar patente que se ha negado a cumplimentar solicitudes similares de otras personas del campo de la Sismología de Cuba. Las razones solo incumben a este autor, pero la siguiente idea del genio **Galileo GALILEI (Italia, 1564-1642)** debe permitir al lector entender las razones ***"…En cuestiones de ciencia, la autoridad de miles no vale el humilde razonamiento de un simple individuo…"***