A new seismotectonic model approach to Nicaragua

Un nuevo enfoque de modelo sismotectónico para Nicaragua

M.O. Cotilla-Rodríguez, L. Álvarez-Gómez, D. Córdoba-Barba and A. Muñoz-Guerrero

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FOREWORD

This book is one of some results obtained by the authors as part of the Scientific Research Project **KUK-AHPAN RTI2018-094827-B-C21**. The authors are a multidisciplinary team with extensive experience in Earth Sciences, and have collaborated for several years in other scientific publications.

The title perfectly describes the content and purpose of the book. The language used in the presentation is appropriate and conforms to contemporary scientific terminology. The structure of the text is harmoniously justified and includes 54 figures, 33 tables and 199 references, in 99 pages. Authors sustain the idea of St. Francis of Assisi (Italy, ¿?-1226): ***"La verdadera enseñanza que transmitimos es lo que vivimos; y somos buenos predicadores cuando ponemos en práctica lo que decimos".***

For the first time, a seismotectonic model for Central America is proposed and argued, subdividing it into two Seismotectonic Provinces: America Central I (El Salvador, Guatemala, Honduras and Nicaragua) and America Central II (Costa Rica and Panama). Significant differences appear in these regions with respect to the existing models in Chile, México and Peru; where Central America's lower hazard is highlighted. This is very important at the time of making hazard and risk estimates, especially when the limited monetary resources of Central American countries are known.

The authors undertook an extensive review of all the materials available to them, and the use of several bibliography (in different languages) reflected in the book demonstrates it. An element of consideration has been the argumentation about the fragmentation of active structures, the transmission of stresses and the corresponding deformations; as well as the hierarchy of all tectonic elements. Highlights the novel proposal of a set of active tectonic knots in Central America, and Nicaragua in particular. In this sense, in the vicinity of the Managua City, a knot is defined that justifies its unique seismic activity. It is hoped, mainly, in Nicaragua, and that it will allow them to question, with critical eyes and minds, the dogmas and models that are accepted by the majority of the scientific community. In this regard, the following reasoning is given: ***"Cualquier ayuda innecesaria es un obstáculo para el desarrollo"*** (María Tecla Artemisa Montessori/ Italy, 1870-Netherlands, 1952).

Finally, the use of several languages for the presentation of the work and the different covers is commendable. This should be an incentive for the new generations [***"The limits of my language are the limits of my world"*** (Ludwig Josef Johann Wittgensteine/ Austria, 1889-United Kingdom, 1951)].

DEDICATORY

This work is a deep and sincere recognition to the Nicaraguan people who have been affected throughout their history by strong and damaging earthquakes, tsunamis and volcanic eruptions.

"…Desde acá mis bendiciones
a esa hermosa población
la bella Nicaragua
que respeta la vida,
y pide paz en su nación."

Oda a Nicaragua (Renny Krieger)

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"Nada en el mundo es más peligroso que la ignorancia sincera y la estupidez concienzuda".

Martin Luther King, Jr. (U.S.A., 1929-1968)

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ABSTRACT: Nicaragua is a seismic-active structure of Central America in the Caribbean Plate. Central America has two well-differentiated types of seismicity (intraplate and interplate). In this geodynamic context there are some plates interacting (Caribbean, Cocos, Nazca, Northamerican, and Southamerican) and transferring efforts. The determined regionalization shows that El Salvador, Guatemala, Honduras and Nicaragua constitute a Seismotectonic Province, AC-I. Central America has another Province (AC-II) that includes Costa Rica and Panama. In Northern Province, AC-I, there is a set of Seismotectonic Units of lower order, with associated linear and knot structures. AC-I's main seismogenic source is the Mesoamerican Trench-Fore Volcanic Arc-Volcanic Arc parallel system (M_{max}=8,1). Many important cities are located in this active band. Nicaragua has two active knots on its borders with El Salvador and Costa Rica. The applied seismotectonic method of Russian origin, with modifications of the authors, allows to sustain that AC-I has the largest seismic hazard with more than 60.000 deaths. Managua is located in an active seismic knot of less category.

Keywords: Central America, morphotectonic, neotectonics, seismicity, tectonic knot

RESUMEN: *Nicaragua es una estructura sismo activa de América Central en la Placa Caribe. América Central tiene dos tipos de sismicidad (interior de placa y entre placas). En este marco geodinámico hay algunas placas interactuando (Caribe, Cocos, Nazca, Norteamericana y Suramericana) y transfiriendo esfuerzos. La regionalización determinada muestra que El Salvador, Guatemala, Honduras y Nicaragua constituyen una Provincia Sismotectónica, AC-I. Se argumenta que América Central tiene otra Provincia, AC-II, que incluye a Costa Rica y Panamá. En la Provincia Septentrional, AC-I, existe un conjunto de Unidades Sismotectónicas de menor orden, con estructuras lineales y de nudos asociados. La principal fuente sismogénica de AC-I es el sistema paralelo de Fosa Mesoamericana-Ante Arco Volcánico-Arco Volcánico ($M_{máx}$=8,1). En esa banda activa están localizadas muchas ciudades importantes. Nicaragua tiene dos nudos activos en sus fronteras con El Salvador y Costa Rica. El método sismotectónico aplicado de origen ruso con modificaciones de los autores permite definir la zona AC-I como la de mayor peligro sísmico* *con más de 60.000 muertos. Managua está localizada en un nudo de articulación sismoactivo de menor nivel.*

Palabras clave: *América Central, morfotectónica, neotectónica, sismicidad, nudo tectónico*

INTRODUCTION

"Me gusta la gente que vibra, que no hay que empujarla, que no hay que decirle que haga las cosas, sino que sabe lo que hay que hacer y que lo hace".

Mario Benedetti (Uruguay, 1920-2009)

INTRODUCTION

Nicaragua [**NI**] our interest area is a country in Central America [**CA**] that has physical borders with Costa Rica [**CR**], El Salvador [**ES**] and Honduras [**H**] (**Figure 1**). Acknowledging its proximity and spatial-temporal location, a brief comparative presentation is made to facilitate reading (**Table 1**). NI and ES are the largest and smallest area, respectively. All they are characterized by marine influences (from Pacific Ocean (155.557.000 km^2) and Caribbean Sea (2.515.914 km^2)) and phenomena associated. In these countries exist historical and contemporary knowledge about earthquakes, volcanoes and tsunamis effects. These data facilitate the development of a seismotectonic model.

Table 1. Some data on the study region.

Country (Capital)/ Independence (year)	Population/ Area (km^2)	P.I.B. 10^6 $ /I.D.H.	Maximum height (m)/ Largest river (km)/ Coastline (km)
CR (San José)/ 1821	5.137.000/ 51.100	99.146/ 0,810	Cerro Chirripó (3.820)/ Grande de Terralba (186)/ 1.412
ES (San Salvador)/ 1841	6.427.000/ 21.041	22.064/ 0,674	Cerro El Pital (2.730)/ Lempa (260)/ 307 (Pacific Ocean)
Guatemala (Ciudad de Guatemala)/ 1839	8.045.000/ 108.899	66.436/ 0,650	Tajumulco Volcano (4.222)/ Motagua (486,5)/ 255 km (Pacific Ocean) and ~148 km (Caribbean Sea)
H (Tegucigalpa)/ 1821	9.005.000/ 112.492	20.155/ 0,617	Cerro Las Minas (2.870)/ Comalí-Tapacalí (680)/ ~670 km (Pacific Ocean) and ~150 km (Caribbean Sea)
NI (Managua)/ 1821	5.359.000/ 130.373	12.612/ 0,658	El Mogotón (2.107)/ Coco (680)/ ~350 km (Pacific Ocean) and ~540 km (Caribbean Sea)
Panamá (Ciudad de Panamá)/ 1821	4.170.607/ 75.990	29.558/ 0,815	Barú Volcano 3.475/ Caribbean and Pacific 2.988,3 km
Total	**42.140.607/ 499.895**		

The study of active faults is an initial phase of seismotectonic researches. They are structures, relatively, linear that have seismic activity [**S-A**] at present, and appreciable sources of earthquakes characterized by the M_{max} and T (years) of strongest earthquakes recurrence, which not always can be possible to establish. These mainly depend on the regional tectonic regime. The active faults are located in the Seismotectonic Units [**SEU**]. They belong to Seismotectonic Province [**SPR**], and incorporate in a Seismotectonic Map [**SMP**]. Developing of a SMP requires an exhaustive and in-depth study of the results (geology, geomorphology, tectonics and seismicity). All these implies time, effort and at first use of published results, correctly referenced, to avoid duplication. Thus geological researches, in broad sense of the term, allow to configure a stable base to face the Seismotectonics. SMP is not an eclectic or static entity. The main utility of the SMP is the seismic hazard; therefore it is necessary to value, in depth, the seismotectonic structures. These are subject to complex processes of accumulation and release of energy, which do not always conform to perfect cycles. These processes are independent; therefore it is quite important to consider that: **1)** political-administrative limits always reduce the scope of research; **2)** the SMP of a region implies knowledge of the: **2.1)** crustal structure; **2.2)** neotectonics; **2.3)** seismicity; **2.4)** experience of specialists from other countries in tasks of this type. Obviously, the SMP must be improved periodically with the accuracy of new data. That scientific material is our main goal for NI and a first step about seismotectonic knowledge in the region, because there are great connections between each and all components.

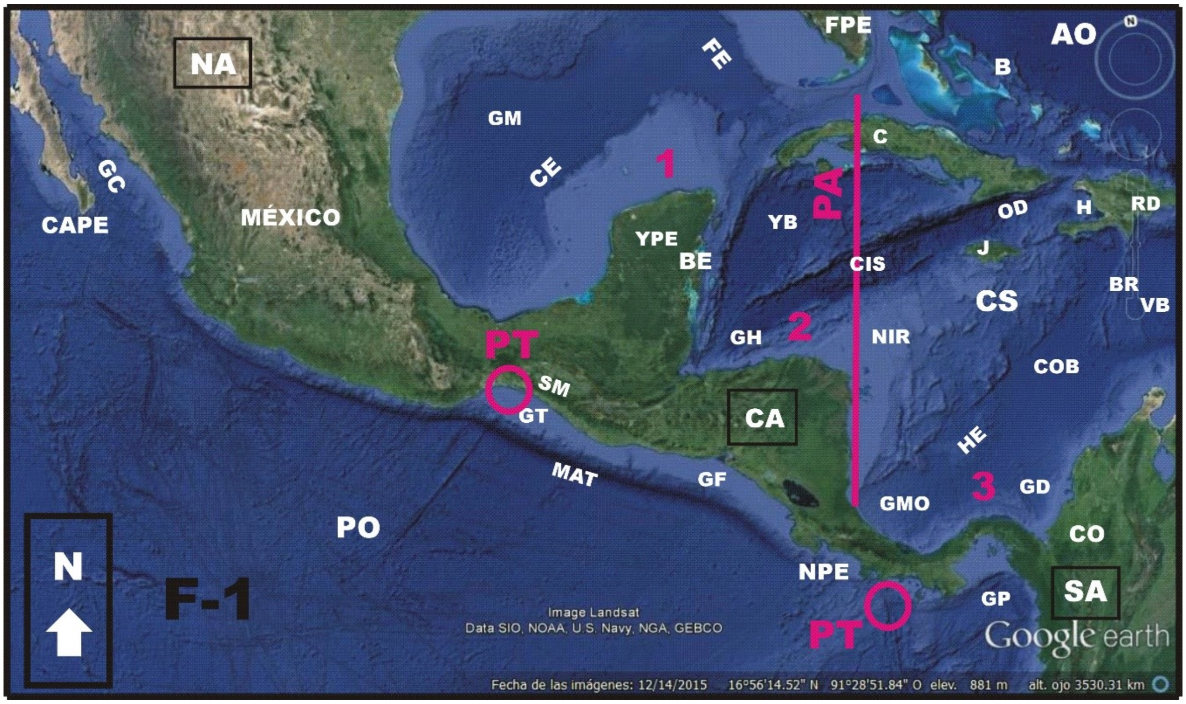


Figure 1. Basic scheme of Central America and its surroundings.

Appear: **1)** Basins (COB=Colombia, VB=Venezuela, YB=Yucatán); **2)** CA=Central America stages or steps (number in red); **3)** CS=Caribbean; **4)** Countries (B=Bahamas, BE=Belice, C=Cuba, CO=Colombia, H=Haití, CIS=Cayman Islands, J=Jamaica, RD=Dominican Republic); **5)** Deeps (OD=Oriente, Pacific (MAT=Mesoamerican)); **6)** Escarpments (CE=Campeche, FE=Florida, HE=Hess); **7)** Gulf of (GC=California, GD=Darién, GF=Fonseca, GH=Honduras, GM=Mexico, GMO=Mosquito, GP=Panama, GT=Tehuantepec); **8)** Mainland (America: **8.1)** of the North [NA]; **8.2)** of the South [SA]; **8.3)** Middle [CA]); **9)** Peninsulas (CAPE=California, FPE=Florida, NPE=Nicoya, YPE=Yucatán); **10)** Rises of (BR=Beata, NIR=Nicaragua); **11)** Oceans (AO=Atlantic, PO=Pacific); **12)** PA=predominant alignment (red line), SM=Sierra Madre, TP=Triple Tectonic Point (circle and acronym red).

1-NEOTECTONICS

"Lo que hace falta es someter a las circunstancias no someterse a ellas".

Quinto Horacio Flaco (Italia, 65 a.C.-8 a.C.)

1-NEOTECTONICS

In the Caribbean-CA region (**Figure 2**), where NI is located, there are well-defined tectonic alignments: **1)** two of them are extensive and approximately transversal, and related to the seismicity: **1.1)** E-NW to NE-SW (associated with the plate boundary fault system, Caribbean-Northamerican); **1.2)** NW-SE (from the southern border of Mexico to Panama, related to the convergence of the Caribbean-Cocos and Caribbean-Cocos-Nazca Plates). This group determines the location of ES, Guatemala, H and NI. These countries are in the mountainous area of the Sierra Madre del Norte (which extends south from Mexico to the vicinity of Guatemala City, NW-SE) and the Andes at south, where the main directions of the relief are N-S; **2)** at least two other quasi-parallel zones extend from the mainland to the Caribbean Sea area (the Guayape Fault and the Hess Escarpment).

The following reference were used: Alvarado *et al.* (2011); Álvarez-Gómez (2010); Álvarez *et al*. (2018); Anderson and Schmidt (1983); Aurger *et al*. (2004); Bergoing and Protti (2009); Brown Jr. *et al*. (1973); Burbach *et al*. (1984); Burkart and Self (1985); Calix-Matute (2011); Cheal and Steward (1982); Christesen *et al*. (1999); Correa *et al*. (2009); Corti *et al.* (2005); Cotilla *et al*. (2017, 2019); Cowan *et al*. (2002); Cruz (1999); Deaton and Bukart (1984); DeMets (2001); DeMets *et al*. (2010); Dengo (1968, 1969, 1973); Dengo *et al*. (1970); Dewey and Algermissen (1974); Donnelly *et al*. (1990); Ellis *et al*. (2018, 2019); Finch and Ritchie (1991); Fisher *et al*. (2003); Franco *et al*. (2012); French *et al*. (2010); Frez and Gámez (2008); Frischbutter (2002); Giunta *et al*. (2002); Gordon (1987); Gordon and Muehlberger (1994); Guzmán-Speziale (2001); Harlow and White (1985); Hey (1977); Hodgson (1978); INETER (1995, 2004, 2015); James (2015); Kobayashi *et al*. (2014); Kolarsky and Mann (1995); Kolarsky *et al*. (1995); La Femina *et al*. (2002, 2009); Lilljequist and Hodson (1983); Luna *et al.* (2008); Malfait and Dinkelman (1972); Mann (2007); Mann *et al*. (1990, 2002); Marshall and Vannuchi (2007); Martínez (1993); Martínez and Noguera (1992); McBirney and Williams (1965); McIntoch *et al*. (1993, 2007); Meschede and Backhausen (2000); Meyer-Abich (1955); Molina *et al*. (2009); Monterroso and Kulhánek (2003); Montan (1987); Muehlberg and Ritchie (1975); Pindell and Kennan (2001); Plafker and Brown Jr. (1975); Plank *et al*. (2002); Protti *et al*. (1995); Ritchie (1976); Rogers (2000); Rubí-Tellez (2006); Satake *et al*. (1994); Sthaler-Vásquez (2014); Simkin and Siebert (1994); Stoiber and Carr (1973); Strauch (2005); Suárez (1991); Turner *et al*., 2007; Vela-Velázquez (2009); von Huene *et al*. (2000); Walther *et al*. (2000); Ward *et al*. (1974); Weinberg (1992); Weyl (1980); White (1991); White and Harlow (1993); Wiesemann (1975); Williams (1955); Williams and Meyer-Abich (1955) and World Stress Map (2016) in order to develop the epigraph. We assure that in CA: **1)** geological formations have Paleozoic-Holocene age, but the Tertiary-Quaternary age prevails. The oldest are metamorphic types (Paleozoic-Mesozoic); **2)** mountains are of three types: tectonic, volcano-tectonic and volcanic. The tectonic ones are located in the center of Guatemala, the West of Belice, the NW and center of H, and the north of NI. They constitute the oldest geological nucleus in the region. While the volcano-tectonic reliefs are: **1)** in SE of Guatemala, south of H, and center and north of ES; **2)** located widely in the center and south of NI; **3)** in the west and south of CR; **4)** form the mountains of Panama. **Table 2** shows the highest altitudes in Belice, CR, ES, H and NI; **5)** NI is characterized by oblique subduction (~60º) of the Cocos Plate under the Caribbean Plate, through the Mesoamerican Oceanic Trench [**MAT**]. Subduction gave rise to the Volcanic Arc that parallels the MAT. This process produces: **5.1)** a general clockwise rotation; **5.2)** fragmentation of the Volcanic Arc; **5.3)** short transverse faults and small blocks; **6)** the oblique collision is not exclusive to CA but also to the NE Caribbean; **7)** the Volcanic Chain (Guatemala-Panama) has approximately 1.500 km long; **8)** the Volcanic Chain in ES has a width of 15-30 km/ direction WNW-ESE; **9)** ES is located in the fourth tectonic segment of CA, which has a length of approximately 230 km; **10)** the structural interpretation of this tectonic segment allowed to define three fault systems: WNW-ESE, NNW-SSE, and NE-SW; **11)** Eastern ES has three active Quaternary volcanic zones (Berlin-Usulután, Pacayal and San Miguel, and Gulf of Fonseca). San Miguel volcano is one of the most active in CA.

In two figures (F-1 and F-2 by Pindell and Kennan, 2001) a set of structures and tectonic elements of the region around Gulf of Mexico (15º-35º N 75º-105º W) (F-1) and Caribbean Sea (5º-25º N 55º-90º W) (F-2) can be seen. They assured that CA is in the western part of Caribbean Plate and is affected by differential movements of Cocos, Nazca, Northamerican and Southamerican Plates (**Figure 2**). In that setting there is a subduction process with S-A and volcanism, where the Cocos Plate undergone Caribbean Microplate in MAT. The convergence is N25º-30º and with a relative speed of 10,2+/-0,5 to 7,2+/-0,3 cm/year.

Table 2. Maximum altitudes.

Country	Mountain range/ Altitude (m)	Country	Mountain range/ Altitude (m)
CR	Cordillera de Talamanca/ Cerro Chirripó (3.820)	H	Cordillera de Celaque/ Pico Celaque (2.730)
ES	Cinturón Volcánico/ Volcán Santa Ana (2.362)	NI	Sierra de Dipilto/ Mogotón (2.107)

The general consensus among specialists about CA is the existence of four large tectonic blocks (**Figure 2**): **1)** Maya (on the Northamerican Plateau); **2)** Chortis; **3)** Chorotega (bordering the Hess Escarpment); **4)** Choco (to the east and south of Panama)). But much of it belongs to two blocks: Chortis and Chorotega. Chortis was active in Cr_{Early} and is located to west and limits with the active Motagua Fault and to SW with MAT. The south is covered by Cenozoic volcanic products; and east limit is not well defined. Figures of Sthaler-Vázquez (2014) for CA: **1)** No. 2.2 shows main tectonic elements where mentioned blocks are located and a very heterogeneous fault system; **2)** No. 2.4 (Conceptual model of forces and displacements) presents a tectonic interpretation for Chortis Block and its immediate surrounding. Thus, there are three main interaction zones (boundaries) in the plates: **1)** Caribbean-Northamerican (active fault system, Polochic-Motagua). Both sides of the structure had a same past in the Mesozoic. The system is also in the Caribbean Sea and related to Swan Fault. They have left lateral movement. In it, a pull-apart basin was formed, called Cayman, which extends to the east up to Eastern Cuba); **2)** Caribbean-Cocos (El

Salvador and Guayape Faults); **3)** Caribbean-Cocos-Northamerican forming a Triple Tectonic Point [**PTT**] on the Pacific side. In Dengo (1973) there are delimited, for CA, various Morphotectonic Units: **1)** Pacific Volcanic Chain and Nicaraguan Depression (NW-SE trending (wide~75 km/ longitude~600/ km h of 35-50 m)); **2)** Costera Planicie of: **2.1)** Gulf of Mexico, **2.2)** Caribbean, **2.3)** Pacific; **3)** Ranges of the North of CA; **4)** Range and Volcanic Plateau; **5)** Mountain System of South of CA; **6)** Peten Lowlands and Yucatan Peninsula.

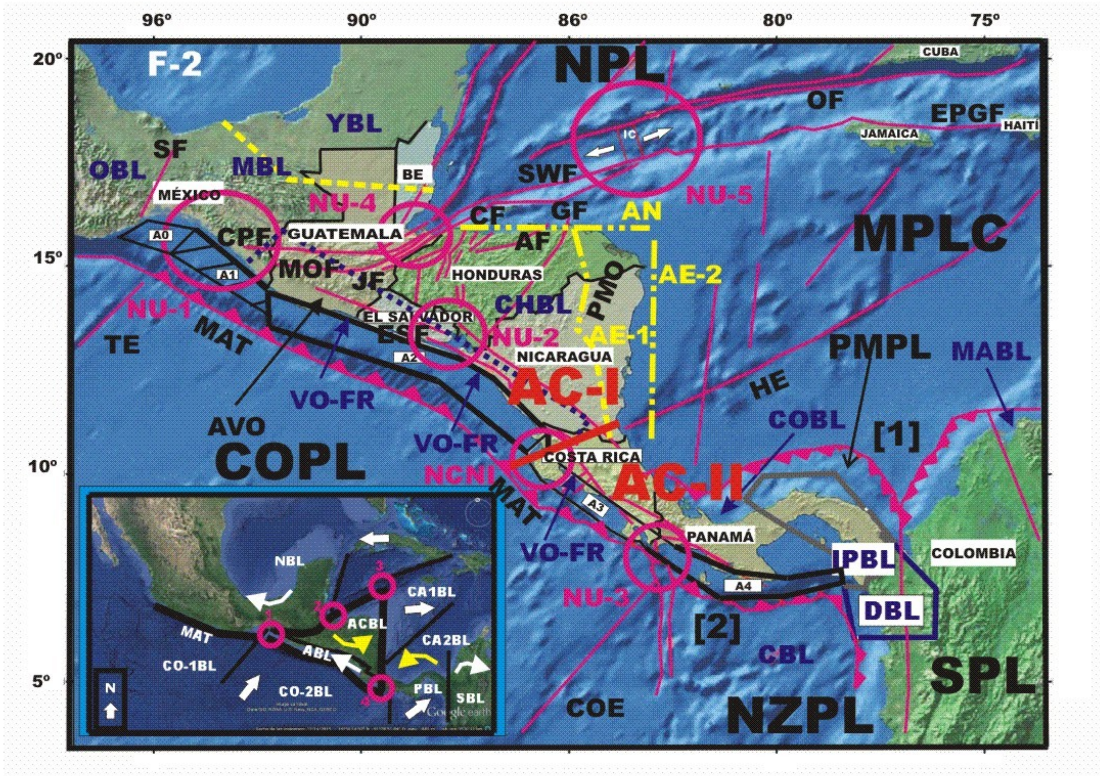


Figure 2. Simplified tectonic representation.

Appear: **1)** Alignments (dashed yellow lines with two interleaved points: AN=North, AE-1=East-1, AE-2=East-2); **2)** Alignment intersections (knots (circle with acronym in red, NU-1); **3)** Blocks (purple with acronym: CBL=Choco, CHBL=Chortis, COBL=Choroteca, DBL=Darién, MABL=Maracaibo, MBL=Maya, OBL=Oaxaca, IPBL=Planicie-Istmo de Panama, YBL=Yucatán); **4)** Deformed of Panama (lines with black triangles (North [1], South [2])); **5)** Countries (BE=Belice); **6)** Escarpment of (CE=Cocos, HE=Hess, TE=Tehuantepec); **7)** Fore-arc [A0-A4]; **8)** Faults (red line (AF=Aguán, AAF=Atrato-Aruba, CF=Ceiba, CHAF=Chamelecón, CPF=Chixoy-Polochic, ESF=El Salvador, EPGF=Enriquillo-Plantain Garden, GF=Guayape, JF=Jocotán-Chamalecón, PAF=Panama, MOF=Motagua, OF=Oriente, SF=Cruz-Salina, SWF=Swan); **9)** MAT=Mesoamerican Trench; **10)** Microplates (CMPL=Caribbean, PMPL=Panama); **11)** Plates (NPL=Northamerican, SPL=Southamerican, COPL=Cocos, NZPL=Nazca); **12)** Territorial Units (orange thick line, AC-I); **13)** AVO=Volcanic Arc; **14)** Volcanic Front [indicated by purple arrow, VO-FR].

Box of the **Figure 2.** Morphotectonic regionalization: Appear: **1)** Block limits (black continuous line); **2)** Block rotation (curved arrows: **2.1)** white=clockwise, **2.2)** yellow=counterclockwise); **3)** Main blocks (White letters: ABL=Fore-arc; ACBL=Central America, CO-1BL=Cocos-1, CO-2BL=Cocos-2, CA-1BL=Caribbean-1, CA-2BL=Caribbean-2, NBL=North America, PBL=Panama, SBL=South America); **4)** Main knots (circles with number in red); **5)** sense of movement of blocks (white thick arrow).

On the other hand there are two results on the structural segmentation in American region: **1)** Luna *et al.* (2008) propose in their figure 5 a seismotectonic model for the surroundings of Tehuantepec Fracture Zone and its relation with MAT and Polochic-Motagua Faults, in Cocos subduction area. The proposal considers that there is reactivation of structures by gravitational processes associated with subduction; **2)** Vela-Velásquez (2009) holds that the Nazca Plate is divided into three parts (North, Central and South). These divisions produce the plate segmentation and are associated with two active transverse fault systems to the trench (Gulf of Guayaquil and Paracas). This obviously gives to the mentioned faults a less seismogenic category.

The location analysis, geological characteristics and geodynamic position of the region in actual plate system, allows to support for the mentioned Blocks (Maya (southern Mexico), Chortis (Guatemala, ES, NI and H), Chorotega (CR and Northern Panama) and Choco (Panama and Northern Colombia)) a coherent kinematics with seismicity. Thus movement of Maya Block could be clockwise.

For CA the limit of Caribbean Plate by the west is: **1**) located at Cocos Plate, in the Pacific Ocean; **2)** convergent and mainly characterized by subduction process; **3)** where it configures an active Volcanic Chain (L~1.100 km), arranged approximately parallel to the coast and at a distance of ~110 km and associated with MAT. Here the subduction is oblique with respect to the collision line and there are variations of: **1)** angle of 25º-85º; **2)** depth of 100-200 km; **3)** speed of 70-80 mm/year. There are segments 100-300 km long and with differences in direction and dip in subduction. Focal mechanisms indicate three types of faulting: **1)** normal (h~10 km from subduction zone, from MAT to the coast); **2)** reverse (h=15-50 km); **3)** normal with sub-vertical planes (h=50-280 km). The earthquakes in this latter zone are of the intra-plate type. All these data justify the segmentation of Volcanic Chain.

NI is limited by three large tectonic units of the: **1)** Pacific Ocean (the Continental Shelf, MAT, and Cocos and Nazca Plates); **2)** Caribbean Sea (Caribbean Plate and the Rise (or Bank) of NI); **3)** inland (Nicaraguan Graben and Highlands). This Graben is a young regional tectonic structure (Quaternary) that extends parallel to the Pacific (Gulf of Fonseca-CR). It is wedged between: the Rivas Anticline to the west and Interior Highlands to east. There exist a set of volcanoes from Circum-Pacific Ring of Fire (Example: San Francisco/ 1.745 m). It is considered to be an elongated structure, under a tectonic regime of the transpressive type, of NW-SE direction (L~300 km/ A~70 km). It is arranged parallel to Pacific coast, and has two fault systems: **1)** normal and open directional fractures N-S; **2)** left side displacement and direction NE-NNE. Comparison of faults and fractures (NW direction with right lateral displacement and NE direction of left lateral displacement) of Volcanic Chain in NI with those of CR, ES and Guatemala shows that, only in NI the NE are active. It has been assured a set of minor blocks in rotation (clockwise) with left lateral failure that obeys to the system of oblique stresses by the action of the subduction process. Nevertheless, the authors has other point of view.

The location of Volcanic Chain includes a greater surface extension (ES- northern CR) and conforms a NW basin that widens ~40 km in ES and -75 km in the SE of NI. In Managua the Depression is 50 km wide and is occupied by the Managua and Nicaragua Lakes. It has two main faults: **1)** Mateare (parallel to the Depression/ 900 m high escarpment); **2)** Tiscapa (perpendicular to the graben/ fault, NE-SW direction/ 3 km of displacement/ associated to the 1972 earthquake, in

Managua). SW limit of the depression is the above mentioned Mateare Fault escarpment. A displacement of 3 km was estimated for this one. Hess Escarpment is an alignment (L~1.000 km) in Caribbean Sea that divides two regions with opposing tectonic regimes: **1)** compression to the north (Nicaragua Rise); **2)** distension to the south (Colombia Basin). It extends between the Caribbean Coast of NI and southern Jamaica, and it is the eastern limit of Chortis Block. This area of the Caribbean Sea has a triangular shape and is situated to the south of Jamaica. Towards the continent (to SW) the alignment is in Lowlands of Caribbean coast of NI at southern of Nicaraguan Depression.

There is in CA a set of results from GPS measurements. Among them are: **1)** Correa-Mora *et al.* (2009) that for ES-H-NI proposed: **1.1)** in Pacific zone convergence speeds of 72-79 mm/year and a defined displacement of volcanic arc to NW from NI to ES (their figure 1); **1.2)** for 1964-2006 period the existence of reverse and normal faults from MAT to the coast line (their figure 2); **2)** Alvarado *et al.* (2011) argued that: **2.1)** Cocos-Caribbean Plates have convergence speeds of 78-84 mm/year; **2.2)** tendency of displacement of the volcanic arc is to NW with 15 mm/year; **2.3)** a possible tectonic deformation at Gulf of Fonseca and develop a pull-apart basin model with right-hand movements; **3)** Ellis *et al.* (2018, 2019) in two extensive works argue that: **3.1)** convergence speeds are 75-76 mm/year; **3.2)** there is displacement to the NW parallel to Pacific coast of the volcanic arc; **3.3)** there is a block in Gulf of Fonseca; **3.4)** a total of eight internal blocks are deformed by plates action.

It is very important to consider that the authorship of volcanic arc displacement to NW and parallel to Pacific coast by GPS measurements, ~14 mm/year, belong to Lyon-Caen *et al*. (2006) Turner *et al*. (2007) and Alvarado (2008). The authors have some doubts about this model of activity with displacement from volcanic arc to NW.

From another part it is interesting and significant for the development of our exposition indicate that: **1)** the majority of the focal mechanism solutions at Nicaraguan Depression are left lateral; **2)** in this region, some earthquakes have occurred with normal type solutions associated with transverse faults (NE-SW). These facts gave way to two different neotectonic models based on Frischbutter (2002) tectonic model proposal in the surrounding of Managua Lake. Such model argues for transverse displacement with a system of short faults that establish a turning cell. They are: **1)** bookshelf faulting (LaFemina *et al*., 2002); **2)** card game (Álvarez *et al*., 2018). The main difference between these models is in the definition of internal blocks and strong earthquakes occurrence. Furthermore, it must be considered that both models lead to the gradual and progressive closure of the Depression and the configuration of a main fault system parallel to Pacific coast. At this point it is necessary consider crust anisotropy and the lateral and transversal differentiation of Nicaraguan region. Also, fault kinematics is of great importance in these cases. When two fault systems intersect or intercept each other, it is necessary to decide which of them is the youngest. The field tasks can help to establish the seismicity pattern associated with these systems and especially the active and inactive (i.e., Bankwitz *et al.,* 2003; Cotilla, 1988; Cotilla and

Álvarez, 2001; Cotilla *et al*., 1993, 1998; Cosgrove and Hudson, 2016; Gokhale, 2011; Machette, 2000; Scholz, 2019). On these elements we consider that it is not feasible to assume the presence of small blocks and a perfect internal rotation, when the linking faults are inactive. We maintain that there is a succession of differential movements that produce the clockwise rotation, but as a regional tendency. For the successive and differential rotation (as spin) several elements must be considered, such as: **1)** the difference in velocity from G-CR of the Cocos Plate; **2)** the different collision-contact zone between the Nicaraguan Depression and the large northern block. A fuller discussion of the matter is given below.

We consider that the fault intersections are active structures. They are junctions between normal (or reverse) faults and either transversely oriented strike-slip or oblique-slip faults. In that areas there are subsurface fluid movement enhanced by some minor faults connecting the major intersecting structures, forming highly fractured zones or extension quadrants with increased permeability. In **figure 2A** we present a simplified model of this type of structure to Nicaragua Depression.

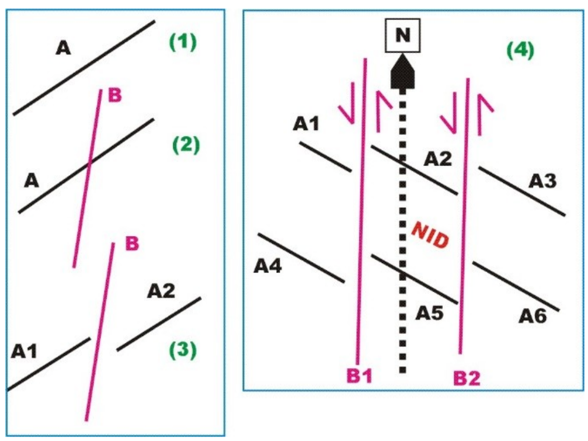


Figure 2A. Structural models to faults interception.
Appear: **1)** stages ((1) (2) (3) (4) in green color); **2)** faults (black (A) and red (B) lines); **3)** B1-B2= transcurrent fault (actives: red arrows)/ A1-A6= fault segments (the majority no actives); **4)** applied to Nicaragua Depression [NID, in orange color].

Álvarez *et al*. (2018) assured that Nicaraguan Depression is plenty of quasi parallel faults with normal faulting of N-S direction at its borders and left lateral strike-slip of NE-SW direction at its centre. The driven mechanism is the inclined subduction of Cocos Plate under Caribbean one that makes Central America Forearc sliver to move toward NW. In it M_{max} would be: **1)** 6,5 for strike-slip faults; **2)** 5,5 for inner border normal faults; **3)** 5,0 outer border normal faults. There are two hazardous sectors in the Nicaraguan Depression ($M_{max} \geq 6,0$): **1)** Zapatera-Ometepe Island that threats Rivas and Granada cities; **2)** Rota volcano-Tonala that threats Chinandega and Leon cities.

Alignments, fractures and geometrical arrangement

"Dejaría en este libro toda mi alma".
Federico García Lorca (España, 1896-1936)

Alignments, fractures and geometrical arrangement

The processing and analysis of published materials (Ward *et al*., 1974; Weyl, 1980; INETER, 1995, 2004, 2015; Frischbutter, 2002; Rubí-Tellez, 2006) allowed to obtain for NI a fracture statistical differentiation. This is a stage that has demonstrated usefulness in the cases of Cuba, Mexico and Spain to distinguish areas of greater weakness of the crust. The process execution was very simple: **1)** capture, arrangement, adjustment and transformation at the same scale and digitalization; **2)** classification. All it was made using a GIS (Cotilla and Córdoba, 2004). The result of classification process in the third iteration (85% confidence) shows five zones: NE (35%), NW (29%), N-S (19%), E-W (10%), and mixture (7%). The NW direction is mostly associated with Pacific coast line, Volcanic Depression and east band of it. The NE fracture zone is practically concentrated in north and associated with H structures. The N-S and E-W zones are located east of Nicaraguan Depression. The interpretation of this result allows us to consider the primacy of the NW structures that are related to the process of push and pull from Pacific to Caribbean. The rest of structures correspond to secondary fracturing processes. These data will be contrasted with those of seismicity and morphotectonics in order to determine the most active areas and delimit the main seismic sources. In an analogous way it was established for Managua Lake (12º-13ºN/ 86º-87ºW) there are four sectors differentiated in quadrants with the following data of fractures: First=40%, Second=12%, Third=24%, and Fourth=34%. It is observed that the greatest number of fractures are in first and fourth quadrants. That is, in eastern part of Managua Lake.

The studies derived from the 1972 Managua earthquake have supported among other things that: **1)** the earthquake is related to Tiscapa Fault; **2)** the fault has left lateral movement; **3)** the fault is linked to right lateral displacement of Volcanic Chain and consequently would be of a transformative type; **4)** the main maximum stress in CA are: N-S and N-NW; **5)** the existence of grabens and depressions similar to Managua in CA suggest the influence on them of Cocos-Caribbean Plates; **6)** Tiscapa Fault and their parallel system and parallel to Managua Depression are conjugated faults; **7)** Cofradía Fault south (L~37 km N-S) of normal type, constitute the eastern limit of Managua Graben. Frischbutter (2002) presented in its figure 4 a principal stress model that differs from Rubí-Tellez (2006) in figure 1-20. The first one has a couple of perpendicular stress sets with N-S compression and E-W extension, in the vicinity of Managua Lake.

Other specialists like the mentioned above with local studies defined the seismic-active zone of Managua. Nevertheless, the authors consider that delimitation of seismogenic structures have a regional approach (macro and meso order). With these data is possible to get the local level (micro). All it is in a geodynamic frame with the plates interaction, mainly, Caribbean-Cocos. The stress transmission, and rupture-strain distribution in the relief allows a hierarchical classification of seismic-active zones. That's the path used here.

It is known that Managua Lake (1.025 km^2/ Longitude=65 km/ Wide=58 km/ Depth$_{max}$=20 m/ Altitude$_{max}$=38 m/ Perimeter=135 km) and Nicaragua Lake (8.624 km^2/ Longitude=148 km/

Wide=90/ $Depth_{max}$=45 m/ $Altitude_{max}$=33 m/ Perimeter=250 km/ 2 volcanoes) are depressed volcanic structures within Nicaraguan Graben. Similar volcanic structures are recognized in ES and CR. Despite its immediate proximity, the same genesis and arrangement in the neotectonic plane has a different shape and dimension. We determined shape index and sinuosity coefficients, Ks, of both lakes (**Table 3**). Also, we determined the different values of the Ks north of the Nicaragua Depression for two segments: **1)** Río Grande de Matagalpa-Managua Lake (0,77); **2)** Nicaragua Lake-Costa Rica (0,93). All these data allow us to sustain that there is significant anisotropic lateral variation of the crust under the influence of plates' interaction.

Table 3. Data from the Lakes.

Lake	Ks (N)	Ks (S)	IS
Managua	0,63	0,68	0,45
Nicaragua	0,96	0,54	0,72

Notes: **1)** Ks=Sinuosity coefficient; **2)** IS=Shape index.

Figure 3 shows the main macro and meso elements of the region bordering the Nicaraguan Pacific. In this neotectonic plane, Nicaraguan Depression stands out with two distinctive meso elements: Managua and Nicaragua Lakes. The diagonal transverse deformation of Managua Lake is related to deformations and rupture processes. The areas of volcanic and coastline alignments with their lateral displacements are quite relevant as well as the presence toward northern Managua Lake of an area of strong neotectonic uplifts. According to Annex XXV of CAPRA (2008), Masaya-Gulf of Fonseca segment is the one with most volcanic activity. The arrangement of drainage surface and hypsometric differentiation of the relief in four parts: mountains, two pairs of plains and a tectonic depression confirm the importance of the mentioned plate interaction. A SW-NE ellipse has been plotted in the vicinity of Managua. It represents the area of the maximum common seismic intensities of the 1931 and 1972 earthquakes.

From topographic and relief maps and satellite images it is possible to sustain that Managua Lake has a greater neotectonic deformation than that of Nicaragua as a whole due to the collision to the north with the higher elevations of the territory (**Figure 3A2**). The SW-NE transverse alignment -AT- to east of Managua Lake corresponds to the main alignment represented in figure 16 (Compiled outline of geological maps) of Lilljequist and Hodson (1983). In the Managua surroundings, there is an intersection of structures that constitutes an active knot. That is a structure equivalent to those indicated in **figure 2**. An analysis of surface fracturing have been done for three small regions (R1, R2 and R3 showed in **figure 3**) and corresponding rose diagrams are presented in **figure 3A1**. They are altimetrically different zones and have been delimited and are joined to Volcanic Arc. The figures generally follow the same pattern; however, there are quite a few differences between them. The R2 region has a marked N-S pattern that is not identified in the other two. The main directions of surface runoff indicate different tipping and in particular from Nicaragua Lake with respect to Managua one.

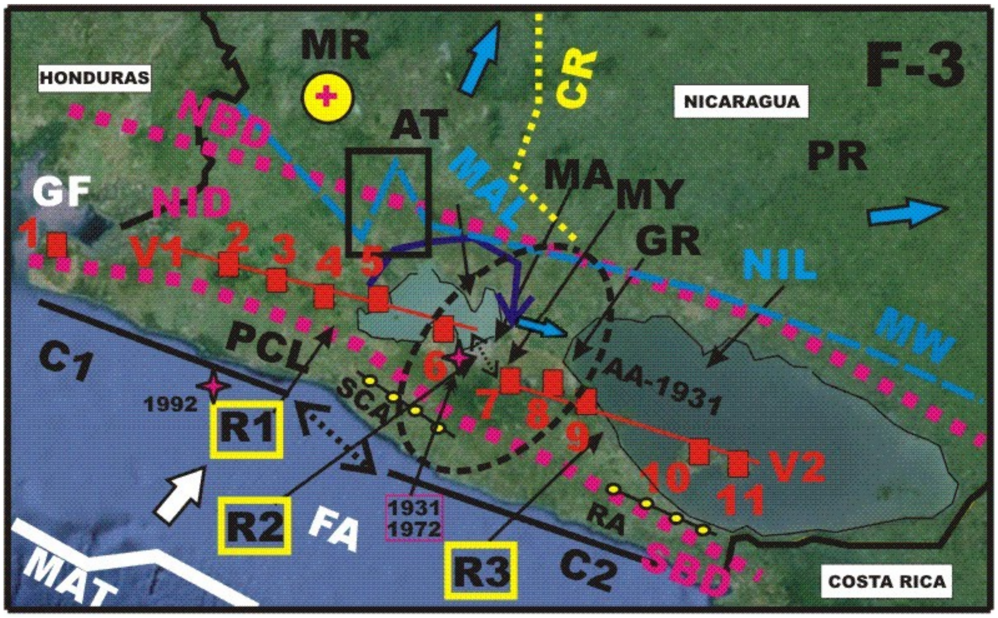


Figure 3. Neotectonic scheme of the Pacific and volcanic margins of Nicaragua.

Appear: **1)** AT=Abnormal turn of the main surface water divider (black rectangle); **2)** Anticline (SCA=San Cayetano, RA=Rivas (black line with yellow circle)); **3)** Black line with acronym (coast alignment), orange line with acronym (volcanoes alignment); **4)** Cities (GR=Granada, MA=Managua); **5)** Curve arrow (relative movement at Managua area, in purple); **6)** Discontinue line with acronym in red (NBD=Northern Boundary Depression, SBD=Southern Boundary Depression); **7)** Epicentres (red star with year: 1931 and 1972); **8)** Fractures regions (R1, R2, R3 (square in yellow). See figure 3A1); **9)** Lakes (MAL=Managua, NIL=Nicaragua); **10)** Localities (GF=Gulf of Fonseca); **11)** MW=Main surface water divider (blue dashed line); **12)** Neotectonic uplift area (yellow circle); **13)** Affected area by 1931 and 1972 earthquakes (discontinue black ellipse with acronym AA); **14)** Regions (MAT=Mesoamerican Trench, PCL=Pacific coastlands and sierras, MR=Mountain, MY=Masaya, PR=Plain, NID=Nicaraguan Depression; CR=Contact region (discontinues yellow line)); **15)** Skip indicator (double discontinuous arrow, red and black); **16)** Surface run-off (blue arrow); **17)** Volcano and Caldera with acronym (orange rectangle): 1=Consiguina, 2=San Cristóbal, 3=Telica, 4=Cerro Negro, 5=Momotobo, 6=Chiltepe, 7=Masaya, 8=Mombacho, 9=Zapatera, 10=Concepción, 11=La Madera; **18)** White arrow=Main stress strike.

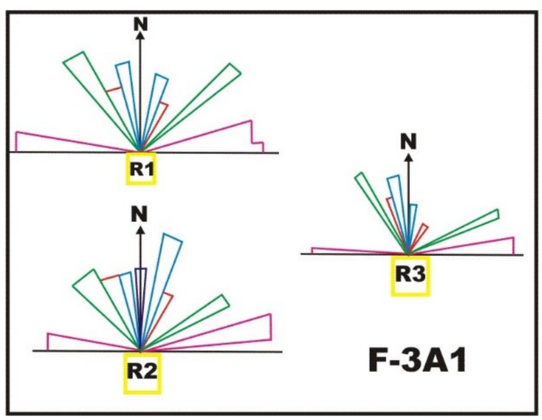


Figure 3A1. Directional diagrams (see Figure 3).

Appear: **1)** Fracture length (1-5 km); **2)** Representation rank (≥10 units); **3)** Sampling area (30 km^2).

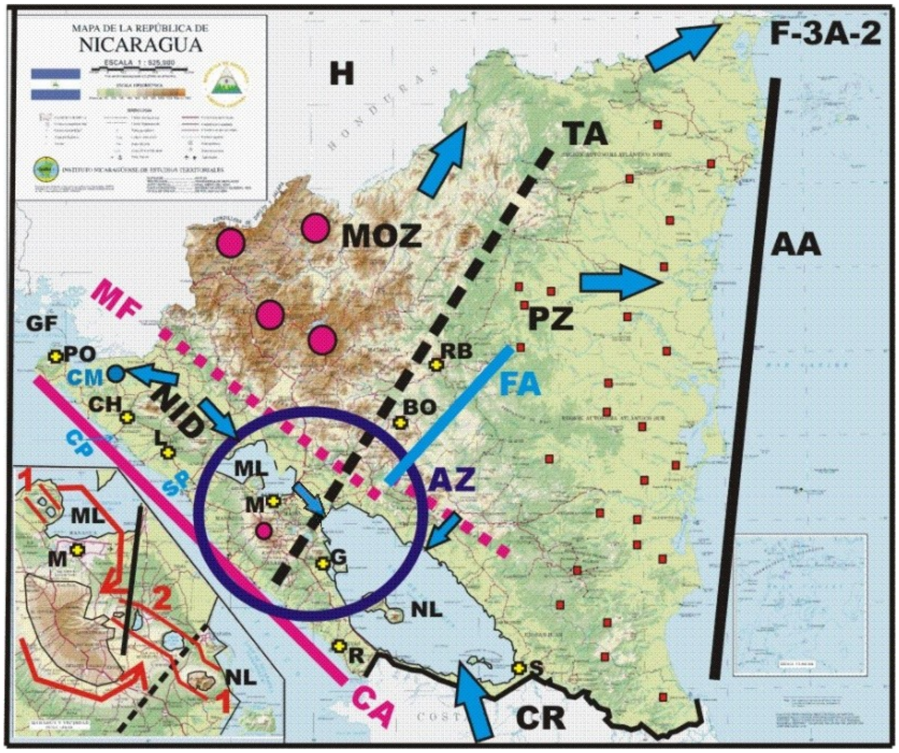


Figure 3A2. Representation of some neotectonic elements in Nicaragua.

Appear: **1)** Alignments (CA=Coast (continue line in red), FA=Fluvial (continue line in blue), MF=Mountain front (discontinue line in red), TA=Transversal (discontinue line in black), AA=Atlantic (continue black line): **2)** Anomalous fluvial intersection (CM=Puerto Morazán, blue circle); **3)** Areas with significant river deformation (rectangle in orange); **4)** AZ=Active area (circle with acronym in purple); **5)** Cities (BO=Boaco, PO=Potosí, CH=Chinandega, G=Granada, L=León, M=Managua, R=Rivas, RB=Río Blanco, S=San Carlos); **6)** Countries (CR=Costa Rica, H=Honduras; **7)** GF=Gulf of Fonseca; **8)** Lakes (ML=Managua, NL=Nicaragua); **9)** NID=Nicaraguan Depression; **10)** Neotectonic uplift (red circle); **11)** Zone (MOZ=Mountain, PZ=Plain); **12)** Ports (CP=Corinto, SP=Sandino, in blue).

Box of the **figure 3A2** is included in purple circle: **1)** Associated Secondary Depressions (orange line) 1 and 2; **2)** Curved arrow (relative movement in the vicinity of Managua in orange); **3)** Left lateral fault (black line).

It is the first time that a large knot is identified in NI (**Figura 3A2**). This structure is an area that reflects relief deformations and neotectonic activity from the perspective of a regional analysis. The spatial location of the knot corresponds to the lateral differentiation of the two large lakes and the existence of a transverse-diagonal NE alignment to them.

Figure 1, Chapter 6 of Segura (2018) presents the segmentation of the "volcanic front". This is composed of two 20 km long rectangular parts with a transverse displacement in the vicinity of Laguna de Tiscapa. Our proposal is shown in the **figure 3A3**. This **figure** complements **figure 3** with the aim of distinguishing neotectonic differentiation from the Nicaraguan territory. That figure presents interpretation of the relief and its main elements (blocks, alignments, tendency of movements, figures, and arrangement). It was decided to eliminate the representations of Managua and Nicaragua Lakes in order to distinguish the main regularities and deformations of the structures. In this case, two sets of seven blocks appear, generally rectangular, between coast line and mountainous region of interior. We highlight: **1)** the differences in distance between blocks and mountainous front; **2)** the arrangement of alignments set that fit the spaces between blocks; **3)** the evident rotations of some blocks; **4)** the blocks staggering; **5)** differentiation of the magnitude of convergence stresses.

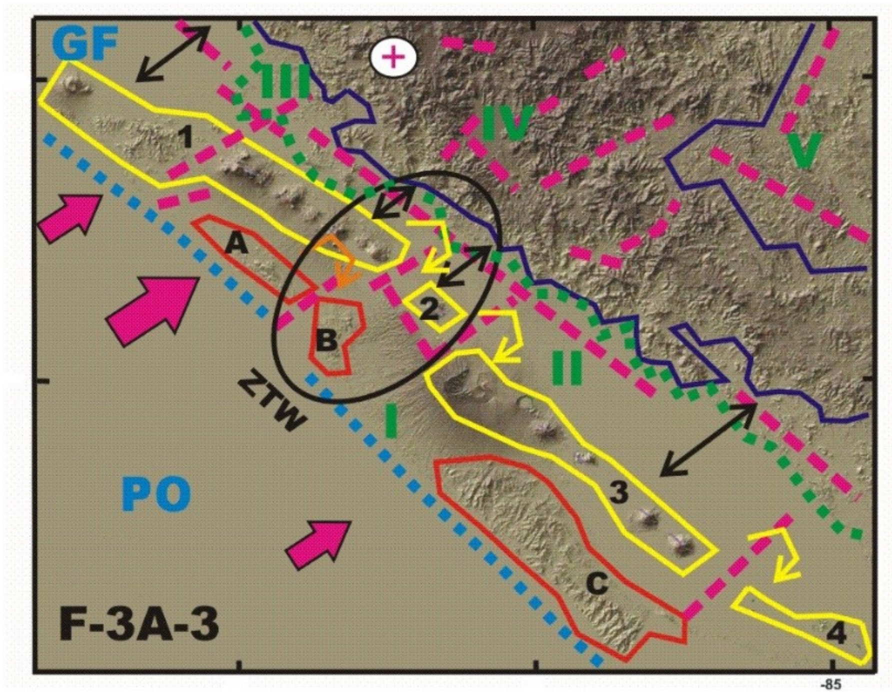


Figure 3A3. Structural analysis in the Central Nicaragua Depression.
Appear: **1)** Block movement with clockwise tendency (curve yellow arrows, curve orange arrow); **2)** Volcanic Blocks (yellow with numbers); **3)** Coastal Bolcks (orange with letters); **4)** Coastal alignments (discontinue blue line); **5)** GF=Gulf of Fonseca, PO=Pacific Ocean; **6)** Main alignments (discontinue red lines); **7)** Morphotectonic regions (Roman letters in green: discontinue green lines, purple lines); **8)** Stress (red arrows); **9)** Intense uplifting area (white circle with red cross); **10)** ZTW=Zone of tectonic weakness (black ellipse).

Between Lakes Nicaragua and Managua runs the Tipitapa River (SE-NW/ L~35 km) (**FigureS 3A4 and 3A4-1**). On its way it crosses the Tisma Lagoon (14,11 km^2). The river has a Ks=0.77 and has in its initial and final segments two bends to the north. We indicated for first time the Tisma alignment ([**ALT**] NW/ L~27 km) from N of Granada (Fortín II) to El Libano (to the W of the Tisma Lagoon, and which is parallel to the villages of Tisma, San Juan de Tipitapa and La Carbonera) (**Figure 3A4**). This structure is also parallel to: **1)** the deviation of the volcanic chain (at the distance of ~16 km); **2)** the Mateare Fault at a distance of ~33 km). In the surroundings of this natural fluvial transfer there is a set of hydrogeological indicators that allow us to sustain the existence of two areas of different dimensions: **1)** the zone of greater water deformation of the Lakes (indicated with a dashed ellipse in blue); **2)** the zone of the inner lagoons of the Depression (indicated with a red rectangle). We also distinguish the very different distance between the southern lakes and the Pacific coastline. We sustain that all these structures are under regional tectonic control and the proposal of a left lateral transverse fault is feasible.

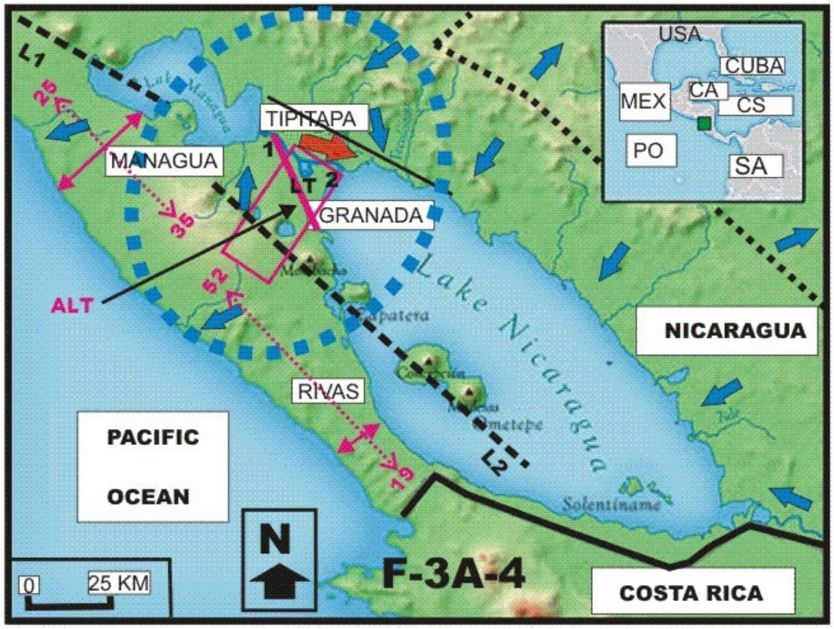


Figure 3A4. Morphotectonic scheme of the linking zone between the lakes.

Appear: **1)** Acronyms (ALT=Tisma alignment, LT=Tisma Lagoon, Mex=Mexico, SA=South America, USA=United States of America, PO=Pacific Ocean, CS=Caribbean Sea, CA=Central America); **2)** Curvatures to the N of the Tipitapa river (1=San Juan de Tipitapa-El Libano and 2=El Paso); **3)** Direction of runoff from Lake Managua to Lake Nicaragua (orange arrow); **4)** First Order Main Divide of the Fluvial Network (irregular line of black dots); **5)** Fluvial deformation area (blue dashed ellipse); **6)** Main affected area (red rectangle); **7)** Surface runoff direction (blue arrow); **8)** Volcanic alignments (black dashed lines with acronyms), L1 and L2); **9)** Width between the Pacific coastline and the Lakes (double pairs red arrows/ values in km: S of Managua Lake= 25/ 35 and S of Nicaragua Lake= 52/ 19).

Figure 3B shows a geological differentiation of NI territory where the majority area is of volcanic type. The youngest rocks are concentrated aligned as regular bands with Pacific coast line. This representation shows: **1)** the very great influence of plate convergence in NI; **2)** the location of Nicaraguan Depression between two large systems of quasi-parallel structures in relation to the Pacific coastline: **2.1)** Pacific Coastline and Sierras; **2.2)** Ignimbrite Province. Analyzing the spatial distribution of rock types, dimensions and configuration of Managua and Nicaragua Lakes, we maintain that the greatest deformation is associated with the first one.

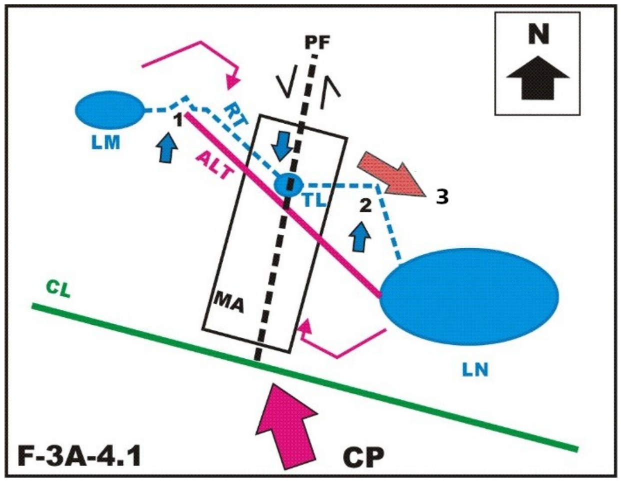


Figure 3A4-1. Detail of morphotectonic at Tisma area.
Appear: **1)** Acronyms (1= San Juan de Tipitapa-El Libano and 2=El Paso; ALT=Tisma alignment (red line); CL=Coastal line (green line); CP=Cocos Plate; LM=Managua Lake; MA=Main affected area (rectangle in black); NL=Nicaragua Lake; PF=Probable fault (discontinue black line with arrows); RT=Tipitapa River (dashed blue line); TL=Tisma Lagoon (lakes and lagoon circular figures in blue); **2)** Curve arrows=relative movements (in red); **3)** Direction of runoff from Lake Managua to Lake Nicaragua (orange arrow); **4)** Direction of plate convergence (red arrow); **5)** Surface runoff direction (blue arrow).

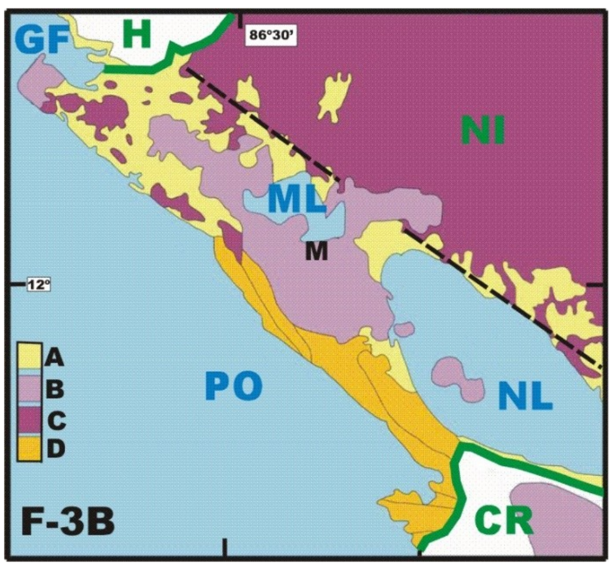


Figure 3B. Geological scheme of Nicaragua.
Appear: **1)** Rock types (see legend: A=Aluvial, B=Volcanic-Quaternary, C=Volcanic-Tertiary, D=Sedimentary-Marine); **2)** Countries (in green: CR=Costa Rica, H=Honduras, NI=Nicaragua); **3)** GF=Gulf of Fonseca, M=Managua, ML=Managua Lake, NL=Nicaragua Lake, PO=Pacific Ocean; **4)** Alignment (discontinue black line).

Cotilla (1984) determined from aerial photos and topographic maps analysis, in the vicinity of the Masaya volcano (h635 m/ last eruption 2015) and the Masaya and Apoyo calderas, the fractures pattern of predominant N-NNE direction. Taking it into account authors proposes a faults and alignments set (**Figure 3C**). They are an active family of short structures in lateral and quasi-parallel N-NNE arrangement. Specifically, Estadio and Tiscapa Faults are associated with strong earthquakes of 31.03.1931 (M6,0) and 23.12.1972 (M6,2), respectively. Other earthquakes (2014 series and 2000) are located over well differentiate and laterally displaced lineaments. The mentioned N-NNE faults set in Managua City area is framed by two largest faults: **1)** Mateare (N-NNW); **2)** Cofradía (N-NNE). These two fault arrangements is spatially related to volcanoes (Apoyeque and Masaya) and volcanic lagoons (Apoyo, Masaya and Tiscapa) in a segment beside to the Managua Lake. In this setting, several tectonic weakness lines of different categories converge, responding to Cocos-Caribbean Plates convergence. It is a very clear active volcanic area (**Figure 3C**) where exists a joint knot (with low and high seismicity (**Table 8**) and volcanism), Managua Knot. Such element is one of the three most active areas of NI. Figure 3, Chapter 6 of Segura (2018) represents that area as the Nicaragua Graben discontinuity.

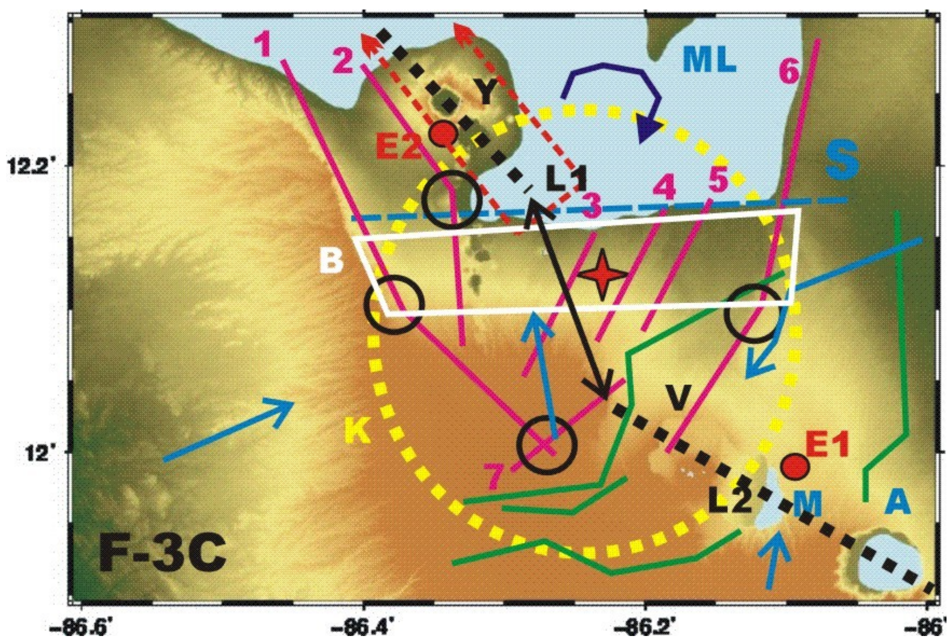


Figure 3C. Simplified neotectonic picture of Managua Lake (Block 2 yelow of **Figure 3A3**).
Appear: **1)** Alignment strike (blue arrow); **2)** A=Apoyo Lake, Y=Apoyeque Volcano, M=Masaya Lake, V=Masaya Volcano; **3)** Deformation fault areas (black circles); **4)** Deflection of volcanic lines (double black arrows); **5)** Epicentre of 1972 (red star); **6)** Epicentral area of 2014 serie [22.04.2014 (M5,2/ h=6 km), 10.04.2014 (M5,0/ h=6,4 km), 10.04.2014 (M5,0/ h=1,5 km), 10.04.2014 (M6,2/ h=1,1 km)] (orange rectangular figure); **6.1)** red circle 13.04.2014 (M5,6/ h=5,4 km); **6.2)** red circle 7.07.2000; **7)** Faults (lines and acronym in red: 1=Mateare, 2=Nejapa, 3=Tiscapa, 4=Escuela, 5=Aeropuerto, 6=Cofradía, 7=Nubes); **8)** K=Managua Knot (dashed circle and acronym in yellow); **9)** B=Managua Microblock (white rectangle); **10)** S=Managua step (discontinue blue line); **11)** Relief deformation (green lines); **12)** L=Volcanic alignments (discontinue black lines (L1, L2)); **13)** Relative direction of clockwise rotation (curve purple arrow).

Tiscapa Fault has vertical and left lateral movement (Brown *et al*., 1973; Plafker, 1973). Similar structures have been identified in: **1)** CR (Tilaran Fault/ earthquake of 14.04.1973) (Matumoto and Latham, 1973); **2)** ES (earthquake of 3.05.1995) (Molnar and Sykes, 1968). Segura (2018) assures that the Tiscapa fault is not a local structure but has a regional connotation. The transverse faults system around Managua Lake cuts and displaces all structures of the SE-NW direction (**Figure 3D**). This implies that: **1)** it is active; **2)** it does not allow the configuration of small rotation and turning cells in the interior; **3)** it justifies the differential clockwise rotation of the zone; **4)** rotational movements are staggered; **5)** between the transverse faults there are only inactive segments.

The regional process (first order) has produced the irregular deformation of the Nicaraguan Depression. This can be seen in the disparate geometric configuration of the Depression and of Lakes Managua and Nicaragua. The repeated and temporally irregular regional compressional influence, in the form of pulses with different period and amplitude, is well appreciated in the shapes of the mentioned lakes and their immediate surroundings (**Figure 2**). Effects of transcompression can be distinguished in a transverse band from the coast to the continental interior (**Figure 3A3**). This **figure** also includes the deformations and displacements of the blocks.

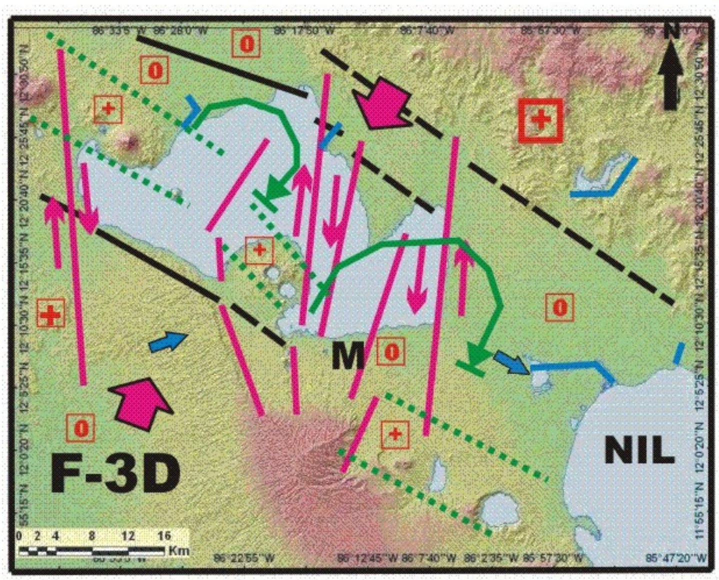


Figure 3D. Interpretation of the neotectonic activity in Managua Lake.
Appear: **1)** Active faults (red lines); **2)** Fluvial drainage (blue arrows); **3)** Inactive faut segments (black lines); **4)** Main stress (large red arrows); **5)** M=Managua City; NIL=Nicaragua Lake; **6)** Relative rotating movements (green curve arrows); **7)** Sense of fault movements (red arrows); **8)** Uplifting movements (0 or + inside orange rectangle); 9) Volcanic Chains (discontinue green lines).

From the above it can be argued that the Nicaraguan Depression, with its volcanoes, volcanic calderas and lakes, is tectonically affected and has an active secondary transverse faulting. In this structure seismic events of low magnitudes are generated, and a few strong ones. In order to sustain the existence of Managua Knot we use: **1)** the idea of Zhidkov *et al*. (1975) that the strongest earthquakes occur mainly on tectonic knots; **2)** the occurrence of other earthquakes at Managua vicinity: 29.04.1898 (7 deaths), 2.01.1906 (1.000 deaths), -.08.1951 (500 deaths), 4.01.1968 (2.000 affected) and 6.07.2000 (7 deaths/ 42 injuries/ 5.650 affected); **3)** the activity of volcanoes: Apoyeque (h~520 m/ the most active volcano in NI and the second most active on the Planet (Zijlstra, 2015)) and Masaya; **4)** the abrupt deviation of main division of river network; **5)** the modification of volcanic bodies alignment; **6)** the arching of coastline; **7)** the differences in density of fractures in Managua Lake.

In **figure 3A2** is represented: **1)** an active area as circle between Managua and Nicaragua Lakes. This structure includes the mentioned Managua Knot; **2)** the very large structural difference in the NE of the Volcanic Depression in two different regions (Mountain relates with Honduras and Plain related to the Nicaragua Rise). The clockwise movement shown in the box of **figure 3A2** corresponds to that shown in **figure 3**. This one is in Managua Lake surroundings and allows to suppose the existence of N-S fault. The clockwise movement is also identified in Gulf of Fonseca and on NI-CR border. The set of lateral displacements observed may correspond to the differences in the interaction of the Cocos-Caribbean Plates. Clockwise rotation movements are slow, sequential and differential.

The study of the main faults and alignments allows to determine, in a schematic way, the kinematics that affect them. Some cases are shown in **figure 4**. We emphasize that, in general, trans current kinematics prevails under a trans-compressional framework due to the action of the Caribbean-Cocos-Northamerican Plates. Similar models and figures have been presented by other specialists for the entire CA.

Other aspect of our analysis is reelected with the Apoyeque volcano. We consider it has a high potential to cause a natural disaster in Managua City. Our rationale idea is by comparison with the Mount Santa Helens Volcano (U.S.A.), which was dormant for many years. Santa Helens Stratovolcano (h2.539 m) has a very high threat potential as demonstrated by the activity of 18.05.1980.

From the hydrological study of INETER (2014), it is possible to argue that: **1)** There are significant differences in the number of watersheds to the N and S of the two large Nicaraguan lakes (**Table 3A**); **2)** The areas (km^2) of the Pacific (12.183) and Atlantic (117.420) slopes are very different; **3)** The number of basins is also different in the Pacific (8) and Atlantic (13) zones. In addition, all Pacific rivers have L<80 km (the longest is Estero Real, L~138.5 km). It drains into the Gulf of Fonseca in a direction approximating the Volcanic Depression; **4)** The areas (km^2) of the two large lakes are different: Managua=1.040 and Nicaragua=8.200; **5)** The main rivers are Coco (Northern part of NI/ Border with Honduras, 18.972,17 km^2) and Gran Matagalpa (to the Atlantic/ 18.856,55 km^2); **6)** There is a straight N-S contact between basins 9533 [Numbering and denomination of INETER] (El Pacífico) and 952 (San Juan) to the NW of Lake Managua; **6.1)** Basin 9533 (12.191,67 km^2) is much larger to the N of Lake Managua. It has 8 basins; **6.2)** Basin 952 has a larger area to the N of the two lakes; **7)** Basin 952 follows the Main Surface Water Divide in its N part and to the N and S surrounds the two lakes. The shape of this area is approximately rectangular; **8)** The areas (km^2) of the Atlantic Autonomous Region: **8.1)** North (9517)=23.879,21/ 8 basins; **8.2)** South (9519)=25.672,62/ 8 basins; **9)** The connection between the two lakes has an undulating shape with two inflexions to the N and one to the S, related to the Laguna de Tisma.

Table 3A. Basins in the N and S parts of the two largest Lakes.

Lake	North	South	Total
Managua	3	7	**10**
Nicaragua	1	4	**5**
Total	**4**	**11**	**15**

Other important morphological features that distinguish NI from other CA countries are as follows: **1)** NI has an important fluvial asymmetry; **2)** values of: H_{max} (m)= 2.107; H_{mean} (m)~700; River L_{max} (km)= 680; Longitude (km) of 2 coastlines= Pacific (~300) and Atlantic (~600)/ L~900; Ks of the main superficial water divider=0,81; **6)** there is a set of inland water bodies subjected to neotectonic deformations within the Volcanic Depression; **7)** there are three spatially well differentiated types of relief (volcanic, plains and mountainous) but integrated on the Caribbean Plate; **8)** the average distances (km) between the Pacific coastline and the southern lakes are different: **8.1)** Managua ~30; **8.2)** Nicaragua <20.

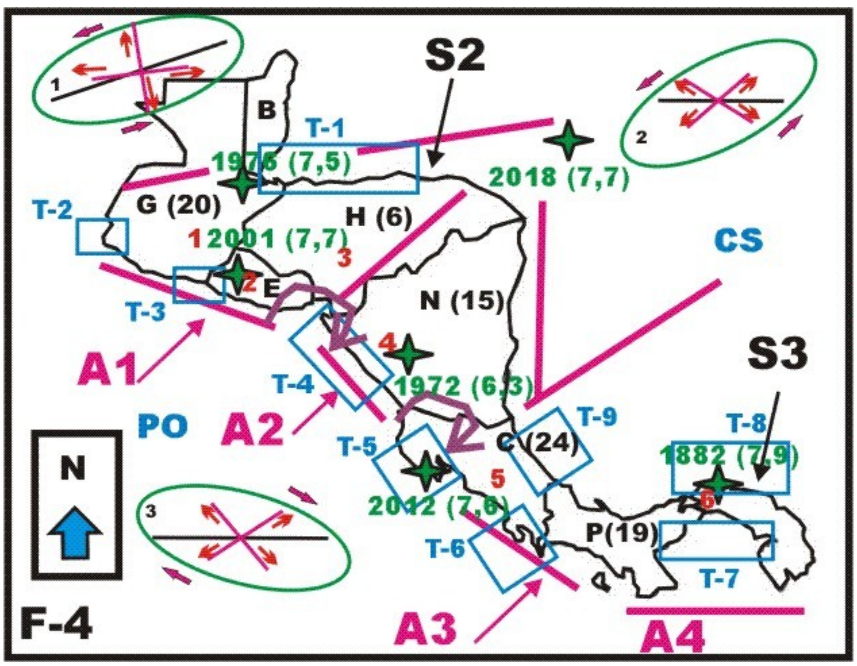


Figure 4. Selection of strongest seismic events in Central America.

Appear: **1)** Cities (1=Ciudad de Guatemala, 2=San Salvador, 3=Tegucigalpa, 4=Managua, 5=San José, 6=Ciudad de Panamá (in red)); **2)** Countries and quantity of earthquakes (Table 11) (B=Belize, C=Costa Rica, E=El Salvador, G=Guatemala, N=Nicaragua, P=Panamá (in orange)); **3)** Curve arrows (relative rotation of blocks in purple); **4)** Linear fault segments with acronym (A1-A4 in red); **5)** Main deformation ellipses: **5.1)** Directions of relative motion (orange arrows (1 and 2=Left lateral; 3=Dextral lateral)); **5.2)** Faults (red lines); **5.3)** Localities (1=Guatemala-Honduras area; 2=Honduras; 3=Nicaragua Graben); **5.4)** Prevailing direction of motion (red arrow); **6)** Regions (CS=Caribbean Sea, PO=Pacific Ocean (in blue)); **7)** Structural steps of the Caribbean area (S2 and S3)); **8)** Strongest earthquakes (star, year and M (in green)); **9)** Tsunami regions (rectangle with acronym (T-1) in blue).

After all above data and considering the following elements: **1)** the oblique subduction of the Cocos plate beneath the Caribbean plate; **2)** the slowdown in the convergence rate from Costa Rica to El Salvador; **3)** the higher altitude of Lake Managua than that of Nicaragua; **4)** runoff of the Tipitapa River from Lake Managua to Lake Nicaragua; **5)** the drainage of the Estero Real River to the Gulf of Fonseca; **6)** location of major neotectonic deformations from Lake Managua to the Gulf of Fonseca; **7)** the differentiation of the two large blocks to the NE of the Nicaraguan Depression; **8)** the different distances between the Pacific coastline and the southern borders of the two lakes; **9)** the clockwise rotation of the transverse structures of the Volcanic Depression, we assure the existence of the NW tilting of the Volcanic Depression.

2-SEISMICITY

"No aplicado, de nada sirve el saber".

Pedro Calderón de la Barca (España, 1600-1681)

2-SEISMICITY

An extensive list of references has been used for the development of this section (Álvarez, 2021; Álvarez *et al*., 2018; Ambraseys and Adams, 1996, 2001; Arce *et al*., 1998; Barquero, 1990; Benito, 2008; Bergoing and Protti, 2009; Brown Jr. *et al*., 1973; Burbach and Frohlich, 1986; Burbach *et al*., 1984; Burkart and Self, 1985; Byrne *et al*., 1993; Calix-Matute, 2011; CAPRA, 2008; Chacón-Barrantes, 2015; Cheal and Stewart, 1982; Chuy (1984); Cruz, 1999; DeMets, 2001; Dewey and Algermissen, 1974; Dewey *et al.,* 1975; Durham, 1931; Fernández, 2002; Figueroa, 1970; French *et al*., 2010; Frez and Gámez, 2008; Hansen and Chávez, 1972; Ide *et al*., 1994; INETER; IRIS; ISC; Kanamori and Kikuchi, 1993; LaFemina *et al*., 2004; Langer *et al*., 1974; Leeds, 1974; Martínez, 1993; Martínez-Díaz *et al*., 2004; Molina *et al*., 2009; Montero and Peraldo, 2004; Monterroso and Kulhánek, 2003; NOAA, 1982; Peraldo-Huertas *et al*. (2006); Pindell and Kennan, 2001; Plafker and Brown Jr., 1975; Protti *et al*., 1995; Rojas *et al.,* 1993; Rubí-Tellez, 2006; Strauch, 2005; Sultán, 1931; Tanner and Shepherd, 1997; Tunner *et al*., 2007; UNESCO, 2018; USGS; von Huene *et al*., 2000; Ward *et al*., 1974; White, 1991; White and Harlow, 1993; World Stress Map, 2016; Ye *et al*., 2013). It is known that USGS catalog indicates that in CA (1973-2000) 19 earthquakes occurred (M>7,0). Most of the recorded S-A is shallow (<50 km) and is located in subduction zone and Volcanic Chain. The seismicity at CA has, a very important, spatial relationship with the largest number of human settlements (Examples: **1)** NI (earthquake of 1972/ M6,2/ Managua); **2)** CR (earthquake of 1910/ M6,4/ Cartago; 1973/ M6,5/ Tilaían; 1990/ M6,0/ Piriscal; 2012/ M7,9) (**Figure 4**). Also: **1)** CR-Panama had ~14 earthquakes (fourteen with M>7,0), and that in the Central American-Caribbean region (not CR or Panama) there are few earthquakes. This implies the existence of a regime of neutral strengths; **1.1)** this figure shows two morphotectonic elements of relevance in CA (the two steps of the Caribbean and the four linear modifications of the Pacific relief); **2)** **figures 5A and 6**, and **tables 4-11** illustrate the framework of contemporary S-A and main tectonics in CA-Caribbean and NI; **3)** the seismicity of NI has four types of seismogenic sources (Subduction Zone (~90%/ M_{max}7,7), Fore-arch Zone (M5,0), Volcanic Arc Zone (M6,0), and Trans-arc Zone (M4-5)). They are located as quasi parallel bands.

Table 4. First information about earthquakes in Central America.

Country	Early earthquakes Date/ Locality	Some earthquakes/ Deaths
ES	1524/ San Salvador	1902.09.15/ 400; 1917.06.7/ 1.050; 1951.05.6/ 400; 1986.10.10/ 1.500; 2001.01.13/ 944; 2001.02.13/ 300= ~4.600
H	1539.11.24/ Cabo Higueras	1539/ <100
NI	1609/ Volcán Momotombo	1931.03.31/ 2.500; 1951.08.2/ 1.000; 1972.12.2/ 20.000= ~14.000

Table 5. Summary of the approximate numbers of significant earthquakes and deaths.

Country	Earthquakes (Century)							
	XVI	XVII	XVIII	XIX	XX	XXI	Total	Deaths
NI	1	-	1	7	1	2	12	~24.000
ES	1	3	-	9	13	5	31	>4.000
H	2	5	9	13	12	13	54	~100
Total	4	8	10	29	26	20	97	>50.000

Table 6. Selection of earthquakes in America with more than a thousand deaths.

Nº	Date	M	Deaths	Country	Nº	Date	M	Deaths	Country
1	2010.01.12	7,0	300.000	Haiti	6	1906.04.17	7,9-8,6	~3.000	U.S.A.
2	1970.05.31	7,9	50.000	Peru	7	1986.10.10	5,7	1.500	ES
3	1939.01.24	7,8	30.000	Chile	8	1999.01.25	6,2	1.230	Colombia
4	1976.02.4	7,5	23.000	Guatemala	9	1973.08.28	7,3	1.200	Mexico
5	1985.09.19	8,1	3.150	Mexico					

Table 7. Earthquakes of America (M>8,4) recorded by U.S.G.S.

Country (Locality)	Date/ Time	M/ h (km)	Coordinates
Chile (Bio-Bio/ Valdivia)	1960.05.22/ 19:11	9,5/ 35	38,44 S 73,41 W
U.S.A. (Alaska)	1964.03.27/ 3:36	9,2/ 23	61,02 N 147,65 W
Ecuador-Colombia	1906.01.31/ 15:36	8,8/ 25	9,6 N 79,37 W
Chile (Atacama)	1922.11.11/ 4:33	8,5/ 120	28,295 S 69,85 W
Peru (Arequipa)	2001.06.23/ 20:33	8,4/ 33	16,27 S 73,64 W

Table 8. Selection of strong earthquakes (instrumental stage) in the region of study.

Country	Date	M/ h(km)/ I (MM)	Characteristics	Country	Date	M/ h(km)/ I (MM)	Characteristics
ES	1902.09.15	8,1/ 25/9	Tsunami/ 400 deaths	H	2009.05.28	7,3/ 10 / -	
	1915.09.7	7,7/ 60/9	Salcoatitlán/ 5 deaths		2004.10.9	7,0/ 35/ -	
	1982.06.19	7,3/ 73/7	The whole country/ 9 deaths	NI	1992.09.2	7,4/ 44,8/ -	Tsunami/ 116-178 deaths
H	1856.08.4	7,5/ -/ -	16,0 N 88,0 W		2014.04.10	7,3/ 10/ -	León-Managua/ 2 deaths
	1910.01.1	7,5/ 60/ -	17,0 N 85,0 W		1972.12.23	6,2/ 5/ 8-9	3.000-10.000 deaths
	2016.06.9	7,5/ 10/ -	17,483 N 83,520W		1931.03.1	6,0/ 5/ -	1.500 deaths

Table 9. Recent earthquakes that significantly affected Central America.

Date	M/ h(km)	Affected people (Countries)
1982.06.13	7,3/ 80	9 deaths/ 56 injured/ 5.000 affected (Mexico-CR)
2001.01.13	7,7/ 60	827 deaths/ 4.000 injured (Guatemala-ES-H-NI)
.02.13	6,6/ 10	315 deaths/ 3.400 injured (Guatemala-ES-H-NI)
2009.05.16	7,3/ 10	7 deaths (Guatemala-H-NI (Caribbean Sea))
.11.26	5,9/ 56,8	(ES-Guatemala)
2012.11.7	7,4/ 24	44 deaths (Guatemala and the coast of Pacific Ocean)
2014.04.10	7,3/ 10	2 deaths/ 40 injured (ES-NI)
	Total	**~1.300 deaths/ ~8.000 injured/ ~20.000 affected**

Table 10. Selection of U.S.G.S. earthquakes (periods: 1950-1990 and 2000-2019).

Country (total)	Date/ Time	M/ h(km)/ Coordinates (N W)	Site
CR (24)	1950.10.5/ 16:09:42	7,5/ 97,9/ 10,481 85,046	Coast
	1973.04.14/ 08:34:00	6,5/ 33/ 10,679 84,759	Tilarán
	1983.07.3/ 17:14:23	6,5/ 33/ 9,652 83,688	The whole country
	.04.3/ 2:50:01	7,1/ 37/ 8,717 83,123	
	1990.04.28/ 1:23:11	6,4/ 22,7/ 8,887 83,500	
	.03.25/ 13:22:55	7,3/ 22,2/ 9,919 84,808	
	1991.04.22/ 21:56:31	7,6/ 10/ 9,685 83,073	
	2000.07.21/ 1:53:35	6,4/ 33/ 9,416 85,329	Coast
	2002.06.16/ 2:46:14	6,4/ 35/ 8,784 83,992	The whole country
	2004.11.20/ 8:07:22	6,4/ 16/ 9,602 84,172	Coast
	.06.29/ 7:01:30	6,3/ 9/ 10,738 87,043	
	2009.03.11/ 21:03:58	5,9/ 17/ 8,493 83,206	
	.03.11/ 17:24:36	5,9/ 14/ 8,504 83,219	
	.01.8/ 19:21:35	6,1/ 14/ 10,165 84,197	
	2010.10.9/ 1:54:04	5,8/ 91/ 10,211 84,293	
	.06.1/ 3:26:15	6,0/ 18/ 9,331 84,206	
	.05.20/ 22:16:30	5,9/ 21/ 9,247 84,302	
	2011.05.13/ 22:47:54	5,9/ 72,8/ 9,954 84,313	
	2012.10.24/ 00:45:32	6.5/ 17/ 10,086 85,298	The whole country
	.09.5/ 14:42:07	7,6/ 35/ 10,085 85,315	
	.02.13/ 10:55:09	5,9/ 16/ 9,183 84,121	
	2017.11.13/ 2:28:23	6,5/ 19,4/ 9,515 84,487	W of Parrita
	2018.08.17/ 23:22:24	6,1/ 15/ 8,779 83,153	N of Golfito
	2019.05.12/ 19:24:50	6,0/ 19/ 8,625 82,830	N of Canoas

ES (23)	1978.08.23/ 00:38:32	7,0/ 56/ 10,204 85,222	
	1982.06.19/ 6:21:58	7,3/ 73/ 13,332 89,387	Coast
	1985.06.3/ 2:45:32	6,3/ 65,5/ 13,175 90,138	
	1995.06.14/ 11:11:47	6,6/ 25/ 12,128 88,36	Guatemala Border
	1997.11.9/ 22:56:42	6,5/ 176,4/ 13,849 88,808	Sensuntepeque
	2001.12.13/ 14:22:05	6,6/ 10/ 13,67 88,938	
	.02.13/ 14:22:05	6,6/ 10/ 13,671 88,561	The whole country
	2001.01.13/ 17:33:32	7,7/ 60/ 13,049 88,660	Coast
	2003.09.7/ 00:13:29	6,4/ 66/ 14,606 92,125	
	2004.11.20/ 22:01:45	6,3/ 40,6/ 13,376 90,056	
	2007.05.12/ 10:41:26	6,2/ 16/ 12,919 90,061	SSW (Acajutla)
	2008.06.18/ 2:32:55	5,7/ 98,3/ 14,130 90,172	
	2009.11.26/ 19:08:11	5,9/ 56,8/ 13,514 89,907	Coast
	2010.01.18/ 15:40:26	5,9/ 54,7/ 13,728 90,132	
	2012.06.27/ 6:30:05	5,7/ 132,6/ 13,834 89,967	NW of Santa Rosa
	.08.27/ 4:37:01	7,3/ 28/ 12,139 88,590	San Miguel and La Unión
	2013.07.15/ 2:52:45	5,7/ 55/ 3,290 89,172	
	.07.8/ 2:52:42	5,7/ 55/ 13,290 89,172	El Rosario
	2014.10.14/ 3:51:34	7,3/ 40/ 12,526 88,123	Intipuca
	2016.11.24/ 14:24:30	6,9/ 10/ 11,910 88,897	SSW of Puerto El Triunfo
	2017.05.12/ 10:41:26	6,2/ 6/ 12,919 90,061	
	2019.05.30/ 9:03:32	6,6/ 65,1/ 13,243 89,272	La Libertad
	.07.22/ 16:26:36	5,9/ 43/ 13,148 89,395	
Guatemala (20)	1976.02.4/ 9:01:43	7,5/ 5/ 15,324 89,101	The whole country
	1980.08.9/ 5:45:09	6,4/ 22/ 15,888 88,516	
	1982.04.6/ 19:56:53	6,5/ 64,8/ 14,315 92,082	Coast
	1983.12.2/ 3:09:05	7,0/ 67,1/ 14,066 91,924	
	1988.11.3/ 14:47:10	6,6/ 68,5/ 13,881 90,450	The whole country
	1999.06.6/ 7:08:05	6,3/ 33/ 13,897 90,897	Coast of Santa Rosa
	.07.11/ 14:14:16	6,7/ 10/ 15,782 88,33	
	2003.01.21/ 2:46:47	6,5/ 24/ 13,626 90,774	Coast
	2006.12.3/ 20:52:15	6,0/ 61,2/ 13,994 91,207	The whole country
	2007.06.13/ 19:29:40	6,7/ 23/ 13,554 90,618	SSW (Port of San Jose)
	2009.05.3/ 16:21:45	6,3/ 108/ 14,546 91,143	
	2010.02.23/ 15:16:00	5,6/ 10/ 5,967 91,260	The whole country
	2011.09.19/ 18:33:55	5,6/ 9/ 14,186 90,238	SSW (Port of San Jose)
	2012.11.7/ 16:35:46	7,4/ 24/ 13,988 91,895	
	.11.11/ 22:14:59	6,5/ 20/ 14,129 92,164	San Marcos
	2013.03.25/ 23:02:12	6,2/ 189,0/ 14,487 90,463	Santa Catarina Pinula
	2017.06.14/ 7:29:04	6,9/ 93,0/ 14,909 92,009	Port of San Jose
	.06.22/ 12:31:03	6,8/ 38,1/ 13,717 90,972	
	2018.01.9/ 2:51:33	7,5/ 19/ 17,483 83,520	
	.06.18/ 2:32:55	5,7/ 99,2/ 14,133 90,715	Guanagazapa
Panama (19)	1962.07.26/ 8:14:46	7,2/ 25/ 7,512 82,729	
	1976.07.11/ 20:41:47	7,0/ 3/ 7,409 78,127	
	1982.08.19/ 15:59:01	6,8/ 10/ 6,718 82,680	S of Panama
	1987.01.4/ 17:52:36	6,3/ 10/ 5,973 82,601	
	1990.12.17/ 11:00:29	6,3/ 19,3/ 6,638 81,926	
	.05.8/ 00:01:40	6,5/ 9,6/ 6,905 82,622	
	2002.07.31/ 00:16:44	6,5/ 10/ 7,929 82,793	
	2003.12.25/ 07:11:11	6,5/ 33/ 8,416 82,824	
	2005.05.5/ 19:12:21	6,5/ 18/ 5,710 82,845	
	2012.06.4/ 3:15:24	6,3/ 7/ 5,508 82,563	
	.06.4/ 00:45:15	6,3/ 7/ 5,305 82,629	
	.05.30/ 00:45:15	6,3/ 7/ 5,305 82,692	
	2009.07.6/ 4:10:38	5,3/ 61,2/ 9,582 78,979	
	.7/ 6:49:35	6,1/ 38/ 9,590 78,966	
	.03.12/ 23:23:34	6,3/ 9/ 5,686 82,767	
	2014.12.8/ 8:54:52	6,6/ 20/ 7,940 82,687	ESE of Punta de Burica
	.05.13/ 6:35:24	6,5/ 10/ 7,210 82,305	SE of Punta de Burica
	.03.02/ 9:37:54	6,3/ 60/ 12,556 87,688	
	2019.06.26/ 05:23:51	6,2/ 32,6/ 8,461 82,754	
NI (15)	1956.10.24/ 14:42:18	7,1/ 35/ 11,682 86,556	
	1967.10.15/ 8:00:52	7,1/ 160,4/ 11,925 85,872	
	1972.12.23/ 6:29:44	6,3/ 10/ 12,184 86,223	The whole country
	1985.12.16/ 2:44:36	6,3/ 22,1/ 11,725 85,838	
	1988.05.6/ 14:46:17	6,6/ 86,7/ 11,493 85,911	

	1992.09.2 / 00 16:01	7,7/ 44,8/ 11,742 87,340	Corinto. Tsunami
	2004.10.9/ 21:26:53	7,0/ 35/ 11,422 86,665	Coast
	2005.08.3/ 11:03:15	5,3/ 14/ 11,247 85,541	Port of San Jose
	.07.7/ 2:16:43	6,6/ 27/ 11,245 86,172	
	2011.11.7/ 22:35:25	6,0/ 177/ 11,560 85,861	
	2013.06.15/ 17:34:27	6,5/ 30/ 11,763 86,926	Masachapa
	2014.04.11/ 20:29:12	6,6/ 135/ 11,642 85,878	Belén
	.03.2/ 9:37:54	5,2/ 60/ 12,556 87,688	SW of Jiquillo
	.10.24/ 3:51:34	7,3/ 40/ 12,526 88,123	
	2016.06.10/ 3:25:22	6,1/ 10/ 12,832 86,963	Puerto Morazan
H (6)	2005.09.23/ 13:48:30	5,9/ 23/ 16,129 87,473	Coast
	2009.05.28/ 08:24:46	7,3/ 19/ 16,731 86,217	
	.06.8/ 5:13:14	5,4/ 10/ 15,792 86,865	
	.05.28/ 8:24:46	7,3/ 19/ 16,731 86,217	
	2018.01.9/ 2:51:24	7,5/ 190/ 17,483 83,520	Great Swan Island
	2020.04.16/ 08:04:37	6,0/ 10/ 16,933 85,710	
Total	**107**		

Table 11. Statistics from the table above.

	2000-2019			1980-1990			
Country	**Quantity**	**M (min-max)**	**h(km) (min-max)**	**Quantity**	**M (min-max)**	**h(km) (min-max)**	**Total**
CR	17	5,8-7,6	9-91	7	6,4-7,3	22,2-37	24
ES	20	5,7-7,7	10-132,6	3	6,3-6,6	65,5-73	23
Guatemala	13	5,6-6,8	9-189	7	6,4-7,0	25,1-176,4	20
Panama	13	5,3-6,6	7-61,2	6	6,3-6,8	9,6-19,3	19
NI	9	5,2-7,0	10-177	6	6,3-6,6	22,1-86,7	15
H	6	5,9-7,5	19-190				6
Total	**78**			**29**			**107**

According to USGS in H and its vicinity: **1)** there were 4.276 earthquakes for 1648-2009 period; **2)** 2.420 earthquakes were recorded in the 20th century; **3)** for that century there are two surface earthquakes in the Western region (1915.12.29; 1934.12.3/ M6,2/ Gracias-Comayagua). This allows to suppose that seismic hazard of H is: **1)** mainly on the borders with Guatemala and ES; **2)** in the west where Pacific subduction zone (Gulf of Fonseca); **3)** in the country interior. It can be assured that there are two types of seismic sources (intraplate and interplate). **Table 12** is a partial modification of Tanner and Shepherd (1997) (Macroseismic events for 1471-1899 period/ 2.623 earthquakes). Using the Nicaragua macroseismic data (1520-1972) with 263 of Chuy (1984) we made **table 12A**. It shows the very good accuracy of that data. In **tables 13-15** are the data from USGS and IRIS that complement the information.

Table 12. Data from Tanner and Shepherd (1977).

Period	Number of events	Period	Number of events
1499	1	1700-1799	480
1500-1599	75	1800-1899	1.959
1600-1699	108	Total	2.623

Table 16 has a brief comparison between five countries of American Pacific region. These statistics allow to complement **tables 6, 8 and 9**, and confirm that the greatest damages are located in Chile and Peru. However, according to **tables 6, 8-10, 13, 15 and 16**, there are some strong earthquakes ($M \geq 7,0$) with a significant number of deaths in Guatemala, ES and NI. In our study we indicate that NI has suffered two very destructive earthquakes: 1972 (in Managua, although with

Ms6,2) and 1992 (M7,7 in Corinto, with associated tsunami) (**Figure 3, Table 10**). These are perfect examples of S-A in two different sources, both at Managua Lake surroundings.

Table 12A. Macroseismic data of Nicaragua (Chuy, 1984).

Period	Number of events	M	Number of events	h (km)	Number of events
1520-1586	17	<5,3	132	0-70	227
1609-1697	10	5,3-5,9	86	70-220	36
1700-1799	15	6,0-6,9	31	**Date**	**Number of events**
1800-1898	100	7,0-7,7	13	Complete	179 (68%)
1901-1972	121	7,75-8,5	1	No day	34
Total	**263**	**Total**	**263**	No month or day	50

Table 13. Earthquake selection (ES-Guatemala-H) by U.S.G.S. (1902-1919).

Nº	Date/ Time	M/ h(km)	Coordinates (N W)	Site
1	1902.04.19/ 2:23:00	7,5/ -	14,000 91,000	Guatemala (SSW of San Pablo)
2	1921.02.27/ 18:23:37	7,3/ 15	13,635 87,090	
3	1921.02.4/ 8:22:41	7,0/ 15	15,681 90,805	
4	1919.04.17/ 20:53:9	6,8/ 35	14,229 91,715	Retalhuleu
5	1918.10.18/ 3:23:4	6,6/ 35	13,880 90,023	ES (Guatemala Border)
6	1919.06.29/ 23:14:13	6,6/ 20	12,330 88,291	
7	1915.12.29/ -	6,3/ -	14,565 88,450	H
8	1934.12.3/ -	6,2/ -	14,565 88,450	Gracias and Comayagua

Table 14. Earthquakes recorded by IRIS (1970-2018).

Country	Earthquakes	M	h (km)	Country	Earthquakes	M	h (km)
Mexico	19	7,0-8,0	20-159	Guatemala	2	7,0-7,4	24-67
CR	5	7,0-7,6	10-56	NI	1	7,3-7,5	10
ES	4	7,3-7,7	28-73	H	1	7,0-7,7	35-45
Total	**28**				4	32	

Table15. Earthquakes selection from IRIS.

Country (earthquakes)	Date	Time	M/ h (km)	Coordinates (N W)
Guatemala (5)	1902.04.19	02:23:00	7,5/ 0	14,0 91,0
	1921.02.4	08:22:41	7,0/ 15	15,681 90,805
	2012.11.7	16:35:45	7,4/ 24	13,99 91,89
	2019.11.9	08:32:52	5,6/ 197	14,48 90,29
	.11.13	16:28:54	5,5/ 61	13,67 90,96
ES (4)	2012.08.27	04:37:19	7,3/ 28	12,14 88,59
	2014.10.14	03:51:34	7,3/ 40	12,53 88,12
	2018.10.28	22:23:53	6,1/ 22	13,03 90,37
	2019.05.30	09:03:32	6,6/ 65,08	13,24 89,27
Mexico (3)	2017.09.19	18:14:38	7,1/ 48	18,55 98,49
	2018.02.16	23:39:39	7,2/ 22	16,39 97,98
	2019.02.1	16:14:13	6,6/ 67,93	14,76 92,30
CR (2)	2012.09.5	14:42:07	7,6/ 35	10,09 83,51
	2018.08.17	23:22:24	6,1/ 15	8,78 83,15
Panama (2)	2019.06.26	05:23:50	6,2/ 26,22	8,45 82,77
	.10.19	18:29:06	4,2/ 12	7,32 80,38
Guatemala-H (Swan Fault) (1)	2018.01.10	02:51:33	7,5/ 19	83,52 17,48
NI (1)	2019.11.1	15:24:12	5,3/ 10	11,57 86,79
Total	**18**			

In agreement with the exposed in previous epigraphs it is assured that there are five types of earthquakes in CA. They are located in the interacting plates and their contact zones; and correspond to the two types of seismicity mentioned above. In a W-E (Pacific-Caribbean Sea) profile, earthquakes are of the type: 1) Fore-MAT, associated with the immediate area of deformation or curvature of the Cocos Plate under Northamerican-Caribbean Plates. They are from the Cocos intraplate, low magnitude and cortical and do not produce local tsunamis; 2) between plates, correspond to the direct interaction of Cocos-Caribbean Plates. They occur in the contact-coupling zone (h<20-30 km) and have M6,0-8,0; and can produce tsunamis; 3) transcurrent faults (or lateral displacement), in the contact between the plates (Caribbean, Cocos and Northamerican). These do not generate tsunamis, and have M5,0-7,9; 4) of interior of the Cocos Plate, when this one undergoing to Northamerican. The hypocenters are of h50-200 km and M until 8,0. The effects and damages are very important in continental zone; 5) of Caribbean Plate, with h<20 km. The magnitudes are mostly low, but cause serious losses. Seismic structures associated with this type (intraplate) are two: 1) H and NI depressions; 2) fault zones (Guayape and South Panama) and the Hess Escarpment.

Table 16. Strongest seismic activity data from five Pacific American countries.

Nº	Country	Area (km^2)/ Population	M_{max}/ h (km)/ Deaths	Volcanoes/ Tsunamis
1	Chile	756.10^3/ $17,6.10^6$	9,6/ 35/ 1.655-2.000	~500/ 35
2	Peru	$1,3.10^6$/ 32.10^6	8,4/ 33/ 240	~400/ 123
3	NI	62.10^5/ $130,4.10^3$	7,9/ 45/ 22.870	21/ 8
4	Panama	$75,5.10^3$/ $4,1.10^6$	7,9/ -/ 5	3/ 4
5	CR	51.10^3/ $4,9.10^6$	7,6/ 10/ 125	17/ 15
		Total	**~26.000 deaths**	**~1.000/ ~160**

The results of Hansen and Chávez (1973) on the 1972 Managua earthquake have been compared with those of Chuy (1984). In particular, the two pairs of isoseismic figures for the Managua area (Nº 1 and 6b, respectively) and the NI territory (Nº 2 and 6a, respectively) indicate a very acceptable coincidence. We consider that the general figure of the Nicaraguan isoseismals indicates two axes perpendicular to each other. One of them is quite well adjusted to the Nicaraguan Depression and the other is of greater extension.

Tsunami threats in CA: **1)** are associated with the regions: **1.1)** of Pacific Ocean (the highest level); **1.2)** of Caribbean Sea; **2)** for 1539-2001 period were 50 in total (37 of them are from Pacific Ocean and Caribbean Sea (13)). In the Pacific there are two tsunamigenic segments: **1)** Guatemala-NI; **2)** the central part of CR; while for Caribbean two other: **1)** Gulf of Honduras; **2)** coast of CR-Panama. There is another segment in Mexico (California-Puerto Vallarta and Puerto Vallarta-Guatemala). **Table 17** has the summary statistics of these reports. Most of tsunamis have produced waves with h<1 m and the largest were those of NI 1992 with 10 m waves and approximately 500 deaths. **Figure 4** shows that local tsunami areas are segmented and well differentiated.

The quality (accuracy) of seismological data is very important for the preparation of develop a SMP. This is based on the fact that the place where a strong earthquake occurs is an unstable region of the Earth interior. So, when determining an epicenter, historical or instrumental, we have the certainty of future occurrence site. From the data and tables set on seismicity presented here, it is known to NI that: **1)** the first earthquake report was in 1520 (Leeds, 1974; Chuy, 1984); **2)** has approximately 24.000 deaths from earthquakes; **3)** the most damaging earthquake was the 1972 one in Managua (3-10.000 deaths); **4)** according to USGS (**Table 10**) in 1956-2020 period there have been 15 earthquakes with M5.2-7.0; **5)** IRIS ensures (**Tables 14 and 15**) that for the time interval of 1970-2018 there is only one report. From **table 16** it is well known that NI has the following characteristics: M_{max}7,9/ h45 km/ 22.870 deaths/ 21 volcanoes/ 8 tsunamis.

Table 17. Summary of the tsunamis in Central America.

	Caribbean/ Pacific/ Local/ (Total)
All periods	12/ 37/ 1/ (50)
Period 1539-1900	7/ 8/ -/ (15)
Period 1901-1950	2/ 20/ -/ (22)
Period 1951-1989	2/ 6/ 1/ (9)
Period 1990-2019	1/ 03/ -/ (4)
Percentage of all periods (%)	12/ 24 %; 37/ 74 %; 1/ 2 %/ (50)

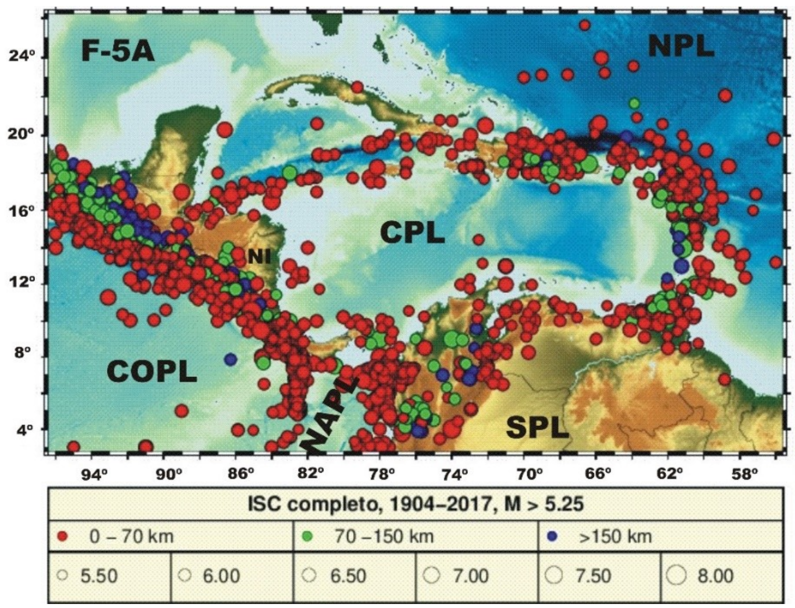


Figure 5A. Seismicity of Central America-Caribbean (1904-2017) according ISC.

Seismicity recorded by INETER (January, 1975-May, 2017) for the area east of the Nicaraguan Depression up to the Caribbean Sea shows to be of low magnitude and spatially distributed. The highest density corresponds to the vicinity of the border with Honduras, where the highest altitudes and uplifting areas are located (**Figure 6A-1, 6A-2, 6A-3**). Three epicentral high-density clusters stand out, including the one located at the H-NI boundary. It is maintained in all figures and correspond to knot NU-2 (**Figure 6**).

Figure 5B has a selection of 13 focal mechanism solutions (Álvarez *et al*., 2018) in the area along the Pacific coast of NI. Twelve of them in Nicaraguan Depression and one to the north, in mountain area. The latter is characterized by a solution of normal type and N-S direction (Z4 (h15 km/ M4,4)). This one is transversal to the Depression. All the mechanisms in the Depression are grouped into three segments: **1)** Z1 (L=100 km/ h=0-7 km/ M5,3-6,1); **2)** Z2 (L=100 km/ h=0-7 km/ M5,3-6); **3)** Z3 (L=160 km/ h=10-31 km/ M6,1-6,3). These three zones have transcurrent type to the left solutions with the direction perpendicular to Pacific coast. From Gulf of Fonseca to Nicaragua

Lake we indicate that these segments (in Nicaraguan Depression) are distinguished by successive staggering and their difference with the fourth zone of mountainous north. In addition, the seismic complex of the Depression has an average thickness of 10 km, so its earthquakes should produce important effects on the populations located in the area. When comparing this result with **figures 3 and 3A3**, we highlight that: **1)** there is segmentation of the main seismogenic zone; **2)** the greatest activity is associated with Managua Lake segment; **3)** the transversal faulting associated with the segmentation is active. **Figures 2, 3C, 3A2 and 4** show in the vicinity of Managua Lake there is a seismically active zone with crustal deformation. All this corresponds very well with the location of segments, volcanic activity in the Depression and in marine part indicated in **figure 5B**.

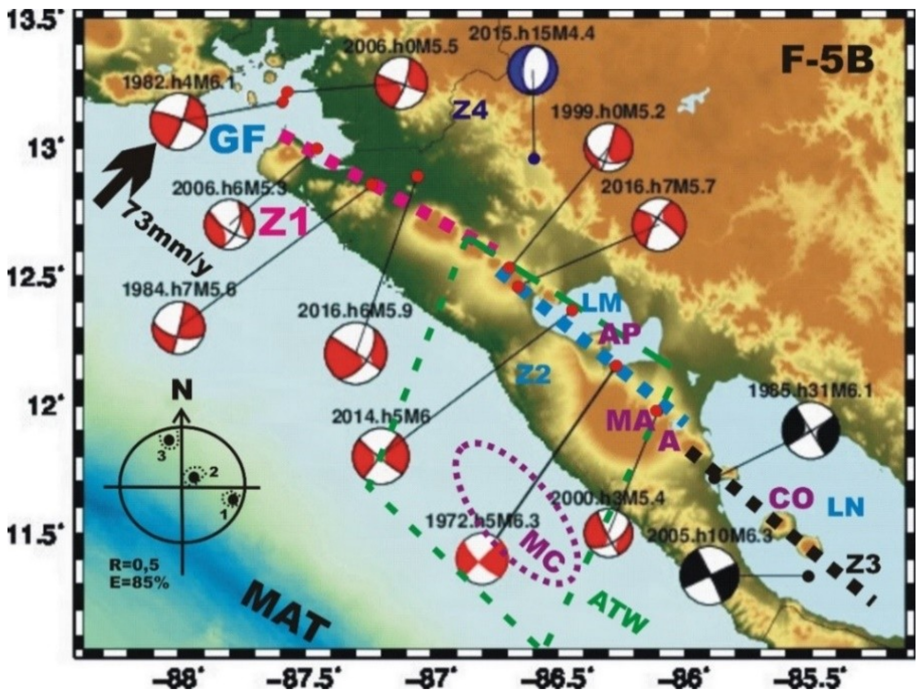


Figure 5B. Focal mechanism solutions.

Appear: **1)** Area of the greatest tectonic weakness (discontinue green rectangle with acronym (ATW)); **2)** Black arrow (Cocos Plate's speed); **3)** GF=Gulf of Fonseca, LM=Managua Lake, LN=Nicaragua Lake, MAT=Mesoamericana Trench, MC=Mound Complex (Baula, Carablanca, Colibri, Congo, Iguana, Perezoso (dashed purple ellipse) (modified from Kutterolf *et al*., 2008)); **4)** Mechanisms (year,depth (km).M); **5)** Volcanic Structure in the Nicaraguan Depression (C=Consigüina, AP=Apoyeque, MA=Masaya, A=Apoyo, CO=Concepción (in purple)); **6)** Zones of mechanism segments (dashed lines with acronyms): **6.1)** Z1 (red), Z2 (blue), Z3 (black); **6.2)** Zone 4=Z4 (purple)); **7)** Stress tensor, in the left-inferior border (1=σ_1 (vertical), 2=σ_2 (maximum horizontal), 3=σ_3 (minimum horizontal), R=(σ_2-σ_1)/ (σ_1-σ_3) (Shape Factor) [$\sigma_1 > \sigma_2 > \sigma_3$]).

In the project RESIS-II it was prepared an earthquake catalogue for CA (period 1519-2007). In **Figure 6** it is shown a selection for 1519-1903 a M>4.75 together with some elements already discussed in this paper. By the other hand, seismicity recorded by INETER (January, 1975-May, 2017) for the area east of the Nicaraguan Depression up to the Caribbean Sea shows to be of low magnitude and spatially distributed. The highest density corresponds to the vicinity of the border with Honduras, where the highest altitudes and uplifting areas are located (**Figure 6A-1-, 6A-2, 6A-**

3). Three epicentral high-density clusters stand out, including the one located at the H-NI boundary. It is maintained in all figures and correspond to knot NU-2 (**Figure 6**).

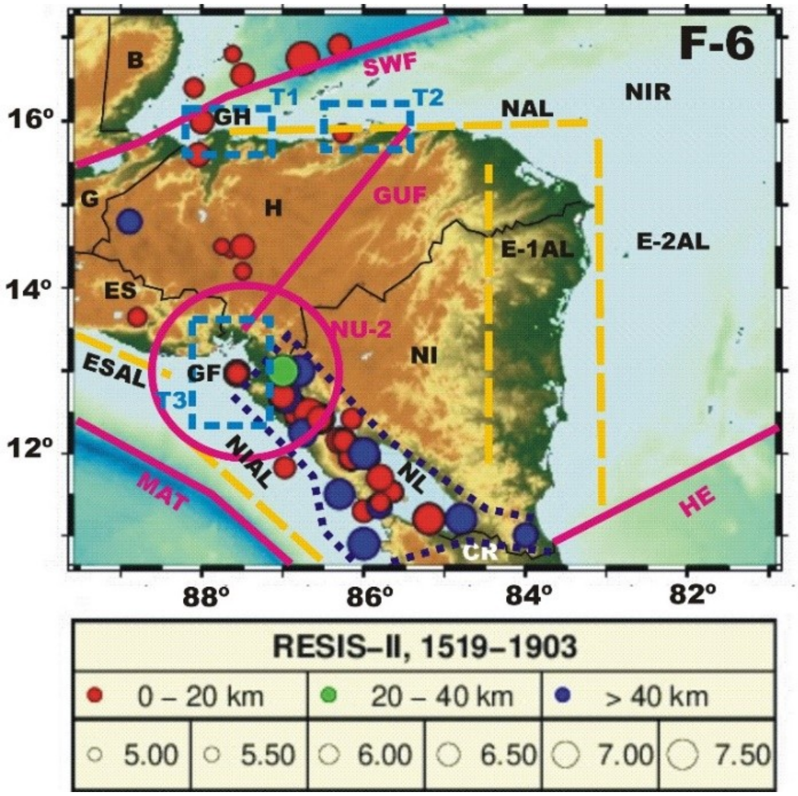


Figure 6. Seismicity of Honduras-Nicaragua (1519-1903) according to RESIS-II.
Appear: **1)** Alignments (yellow dashed lines: NAL=North, E-1AL=East-1, E-2AL=East-2, ESAL=El Salvador, NIA=Nicaragua); **2)** Area of deep seismicity (purple dashed line; **3)** Countries (B=Belice, CR=Costa Rica (in white), ES=El Salvador, G=Guatemala, H=Honduras, NI=Nicaragua); **4)** Epicentres (see legend); **5)** HE=Escarpment of Hess (continue red line); **6)** Fault (SWF=Swan (in red)); **7)** Gulf of (GF=Fonseca, GH=Honduras); **8)** Knot (red circle with acronym, NU-2); **9)** Local tsunami generating areas (dotted rectangles with blue acronym, T1); **10)** MAT=Mesoamerican Trench (continuous red line); **11)** NL=Nicaragua Lake; **12)** NIR=Rise of Nicaragua.

Figure 41 of Segura (2018) presents a segmented band of focal mechanisms for the Nicaraguan Depression. The lengths are different as well as the types of mechanisms. Those segments are: **1)** Gulf of Fonseca-Chonco (reverse faulting); **2)** Chonco-Managua Lake (the most extensive (transcurrent faulting)); **3)** Managua Lake-Costa Rica (normal faulting). However, we consider that the mechanisms used include events of different M (strong, moderate and weak), so the conclusions are limited.

From the population of focal mechanism we determined the Shape Factor (Rivera and Cisternas, 1989) that is represented in **figure 5B**. The result give a transcurrent left type. Also, with the determination of the Centroide-Moment Tensor [**CMT**] in Seismology (Dziewonski *et al.,* 1981) a more complete Geodynamic analysis is possible. Thus, with the Global CMT project (Ekström *et al*., 2012) the solutions of the period 1962-2020 were used, with two variants between Guatemala and CR: **1)** components of the moment tensor; **2)** orientation of the planes corresponding to the best double pair. Three depth intervals were used in them (in km): 0-40, 40-110 and 110-250. This allowed us to have three types of maps: **1)** the classic with "beach balls"; **2)** the orientation of the P and T axes; **3)** the percentage solution corresponding to the Compensated Linear Vectorial Dipole [**CLVD**]. For the calculation of the latter, the program "mopad" was used (Krieger and Heimann, 2012). The sequence of **figures 7A-C** can be considered as a photographic sequence of the lateral movement to the east where you can see the introduction of the Cocos Plate under the Caribbean. That space-time distribution of earthquakes confirms for CA: **1)** a first-order seismotectonic alignment; **2)** the active seismic differentiation of the segments.

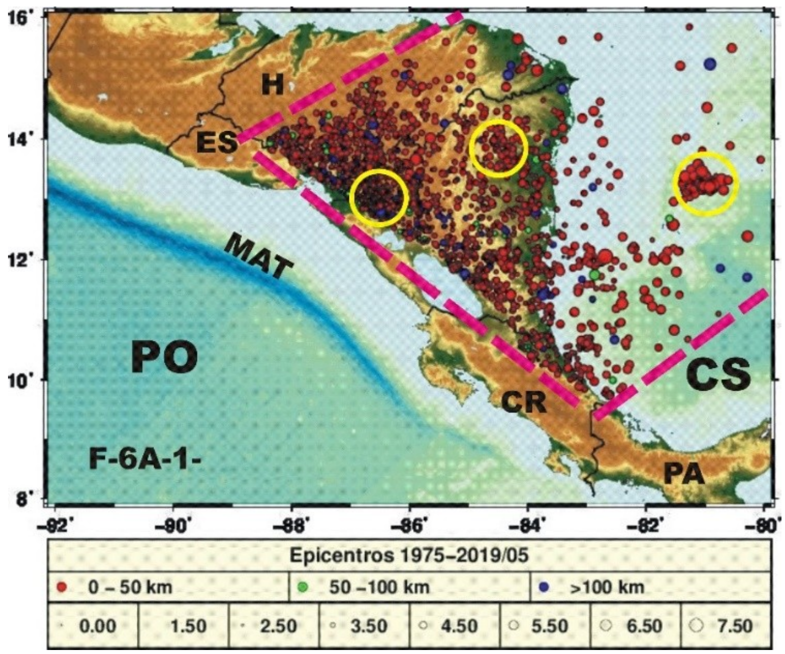


Figure 6A-1. Seismicity from Nicaragua network, INETER (January, 1975-May, 2019). Appear: **1)** CR=Costa Rica, CS=Caribbean Sea, ES=El Salvador, H=Honduras, MAT=Mesoamerican Trench, PO=Pacific Ocean; **2)** Yellow circle=Epicentral high density area. They are applied to **figures 6A-2 and 6A-3**.

Figure 7B shows the case of depth interval [40, 110) km, which coincides with the [110-250) (**Figure 7C**). It can be seen that: **1)** the number of earthquakes decreases in the sequence; **2)** there are no strong earthquakes outside a narrow strip corresponding to subduction. The few intermediate earthquakes are in the Chortis Block and the Caribbean. These must have erroneous values of the depth; **3)** the P and T axes have a preferential dip of 30°-60°, indicating the almost vertical orientation of the subducting plate (Cocos); **4)** increases the proportion of cases with high % CLVD.

There are other significant differences between **figures 7A-C** that support research on morphotectonics: **1)** the S-A up to the limit of NI-CR is maintained, but from there to the south disappears; **2)** the depth profile of the Cocos-Caribbean subduction zone, from the above mentioned sector, disappears in the range 110-250 km. The latter is located where there is a very important change in the types of mechanisms from the vicinity of the NI-CR border.

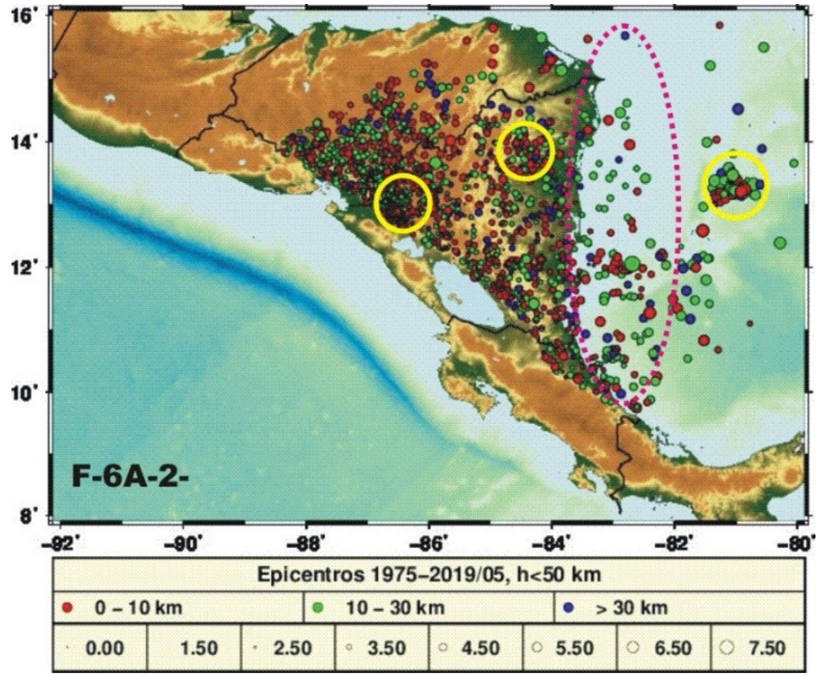


Figure 6A-2. Seismicity from Nicaragua network, INETER (January, 1975-May, 2019). Its is indicated a N-S alignment of epicentres (red discontinue ellipse).

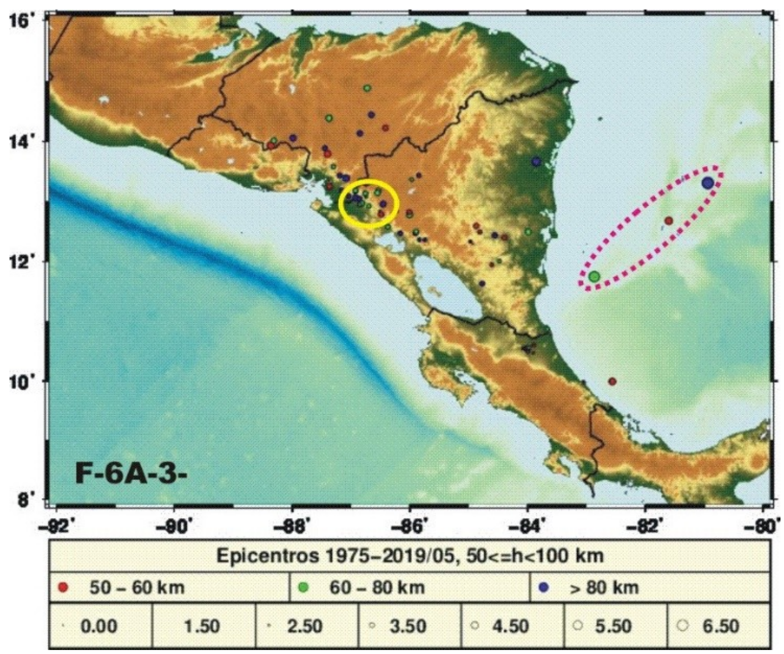


Figure 6A-3. Seismicity from Nicaragua network, INETER (January, 1975-May, 2019). The epicentral alignment of the Hess Escarpment has been indicated (red discontinue ellipse).

We consider that it is interesting to analyze the results of World Stress Map Project (WSM, 2016) for our region **(Figures 8 and 8A).** We highlight: **1)** that rectilinear alignment of determinations (red colors), on the American side, is relevant for the Pacific in two segments: Mexico and CA; **2)** complexity determined in two PTTs, north and south of CA, is evident; **3)** few determinations inside Cocos and Caribbean Plates; **4)** this data corresponds to that of the **figures 5A and 6**.

It has been verified that earthquakes' isoseismals allow to get seismotectonic relations. The immense majority, of the strong earthquakes in the Pacific coast of CA, has geometric figures with the main strike of the megastructures. An example is the CR earthquake of 29.05.1879 (Ms≥7,0). However, other important earthquakes such as in NI (14.11.1958 (VIII MM), 23.12.1972 (IX MM)) show a transversal adjustment.

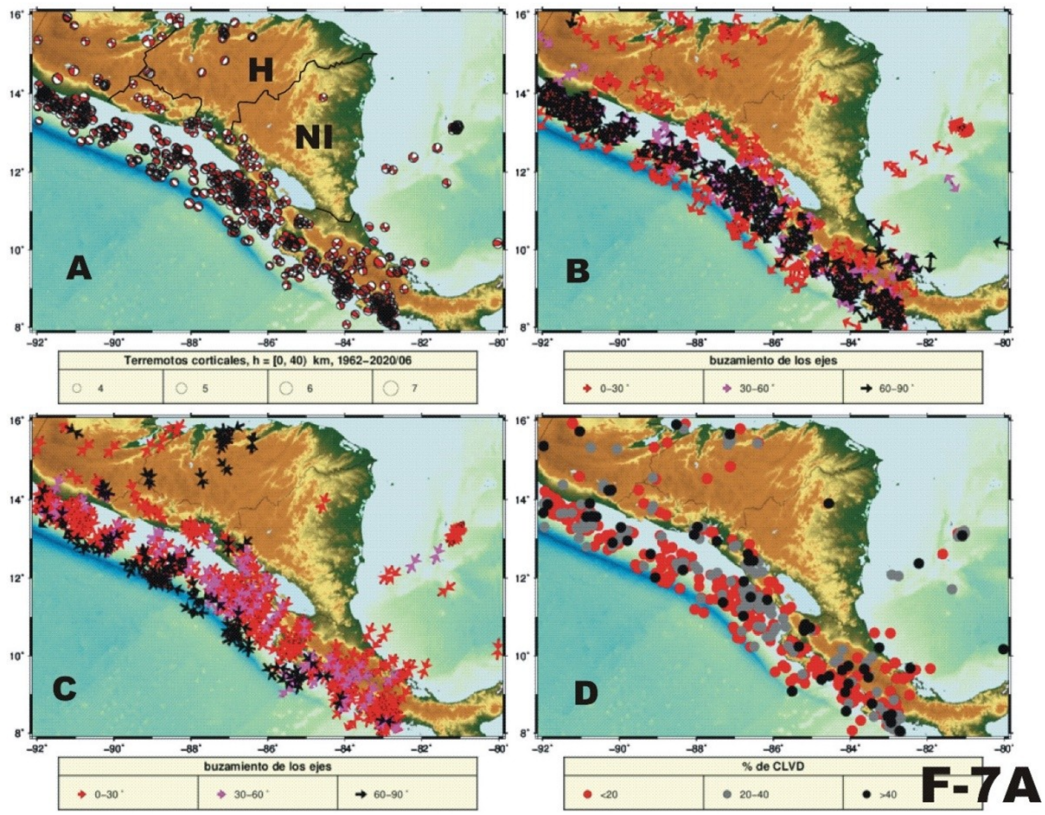


Figure 7A. Stress of earthquake to depths [0, 40) km (CMT). **A)** Moment Tensors; **B)** T-axis direction; **C)** C-Axis direction; **D)** % of CLVD in the solutions; Countries (H=Honduras, NI=Nicaragua).

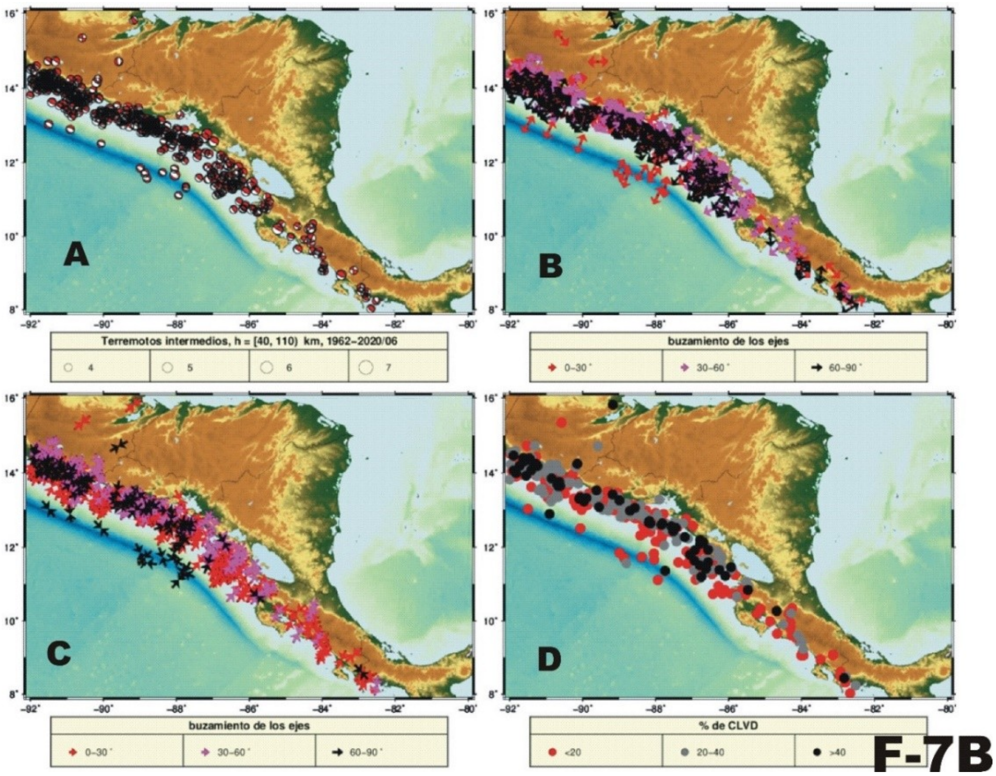


Figure 7B. Stress of earthquake to depths [40, 110) km (CMT). A-B-C-D=as in **figure 7A**.

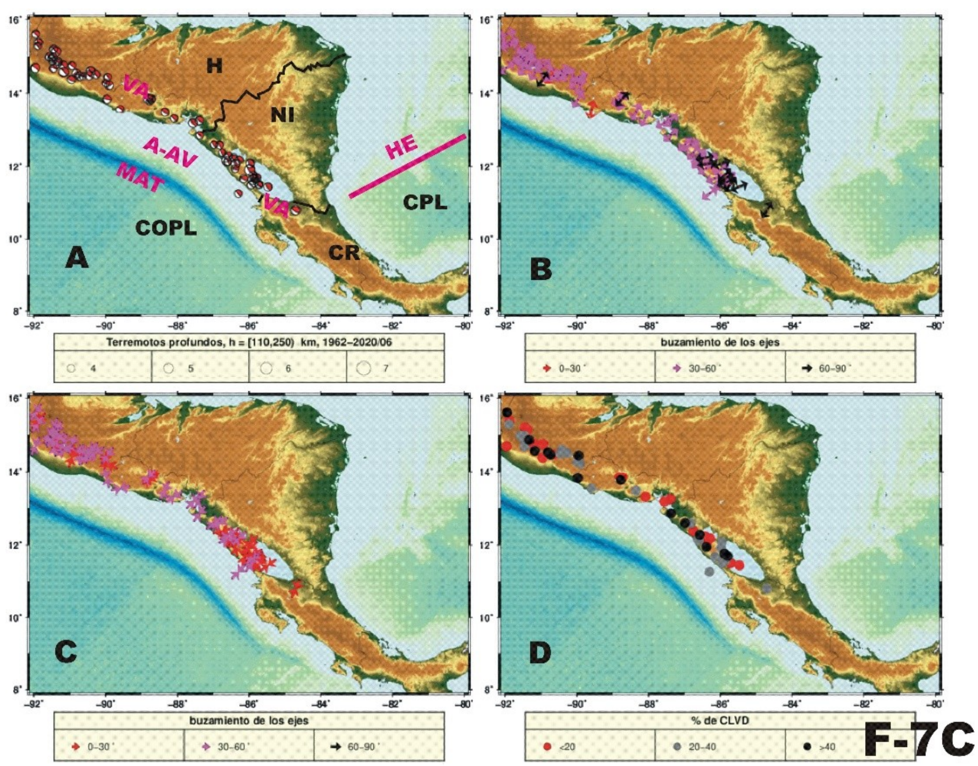


Figure 7C. Stress of earthquake to depths [110, 250) km (CMT).

Appear: **1)** A-B-C-D=as in **figure 7A**; **2)** A-AV=Fore volcanic arc, CPL=Caribbean Plate, COPL=Cocos Plate, HE=Hess Escarpment, VA=Volcanic Arc.

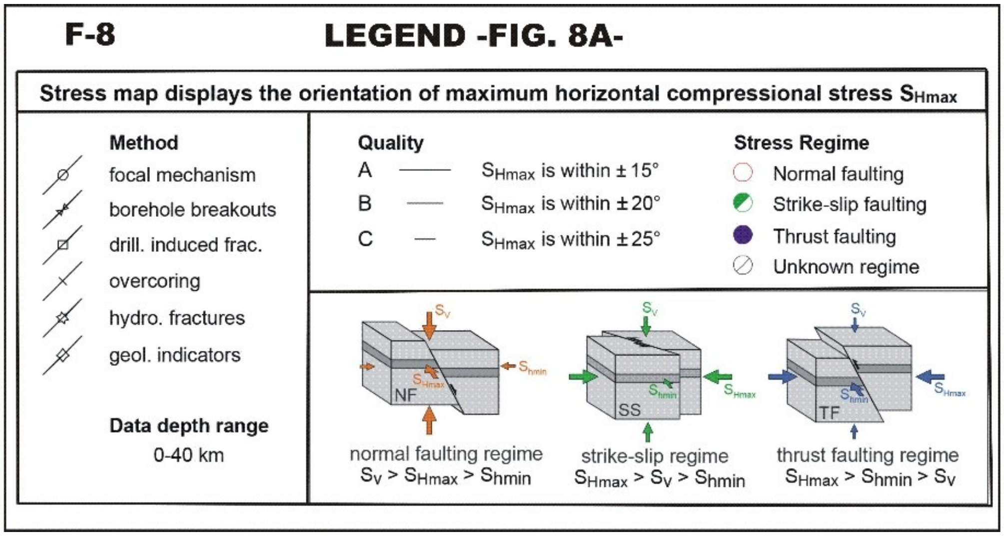


Figure 8. Legend of World Stress Map, 2016.

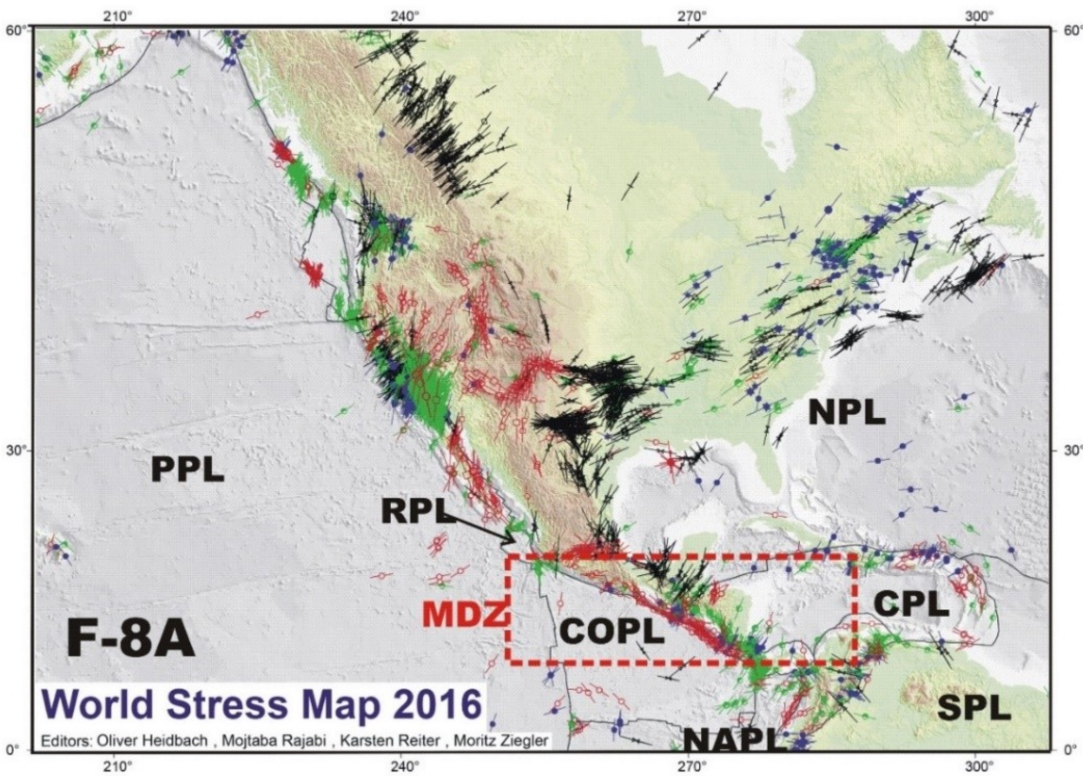


Figure 8A. Part of World Stress Map, 2016.

Appear: **1)** MDZ=Main Deformation Zone (orange discontinuous rectangle); **2)** Plates (CPL=Caribbean, COPL=Cocos, NPL=Northamerican, NAPL=Nazca, PPL=Pacific, RPL=Rivera, SPL=Southamerican). See **figure 8**.

Macroseismic data

"Las ideas no deben ser de nadie".
Antonio Machado Ruiz (España, 1875-Francia, 1939)

Macroseismic data

The use of macroseismic data has two important outcomes. First of all, it allows to estimate coordinates and magnitudes of pre instrumental earthquakes (or non-recorded in instrumental period) and second, in case of constructing isoseismal maps it is possible to infer structural characteristics of the affected region. In NI, first catalog of macroseismic data was prepared by Leeds (1974) and first isoseimal maps were constructed by several authors after 1972 Managua earthquakes (Hansen, 1965; Hansen and Chavez, 1973; Algermissen *et al*., 1974; White and Harlow, 1993). Later on, Chuy (1984) prepared a revised macroseismic catalogue for NI and included previous isoseismals maps with intensities converted to MSK-78 scale from original MMI scale, and other prepared in a joint work IGA-INETER (1981). The compilation of macroseismic data from earthquakes was continued by INETER from 1999 in advance with publication in some cases of isoseismals or felt intensities maps (Morales *et al.,* 2000, 2005, 2014). The general characteristics of published isoseismals' maps is that isolines were trace by eye fitting, and, although there are felt intensity data, they were not added to the maps.

When using macroseismic data an important point is the precision of original and processed data. There are several sources of uncertainty: **1**) possible not exact description of observed effects, **2)** expert-dependent intensity evaluations, **3)** estimated parameters dependent on the model used, **4)** eye fitting non-univocal isoline plotting. All that made necessary to use macroseismic results with some care.

In our case, we have eight isoseismal maps from which we can made the following inferences: **1)** earthquakes with epicentres in the zones in the accretion sliver or subduction zone have elongated isoseismals following NW-SE direction; **2)** earthquakes in the Nicaraguan Depression has isoseismals highly attenuated through the SW, and very elongated to the NE. No other regularities can be deduced from present data taking into account their intrinsic uncertainty.

From published data by Morales *et al*. already mentioned, it was possible to construct two isoseismal maps (**Figure 9**) by interpolation with the Delaunay triangulation method (Shewchuk, 1996) included in GMT`s software package (Wessel and Smith, 1998).

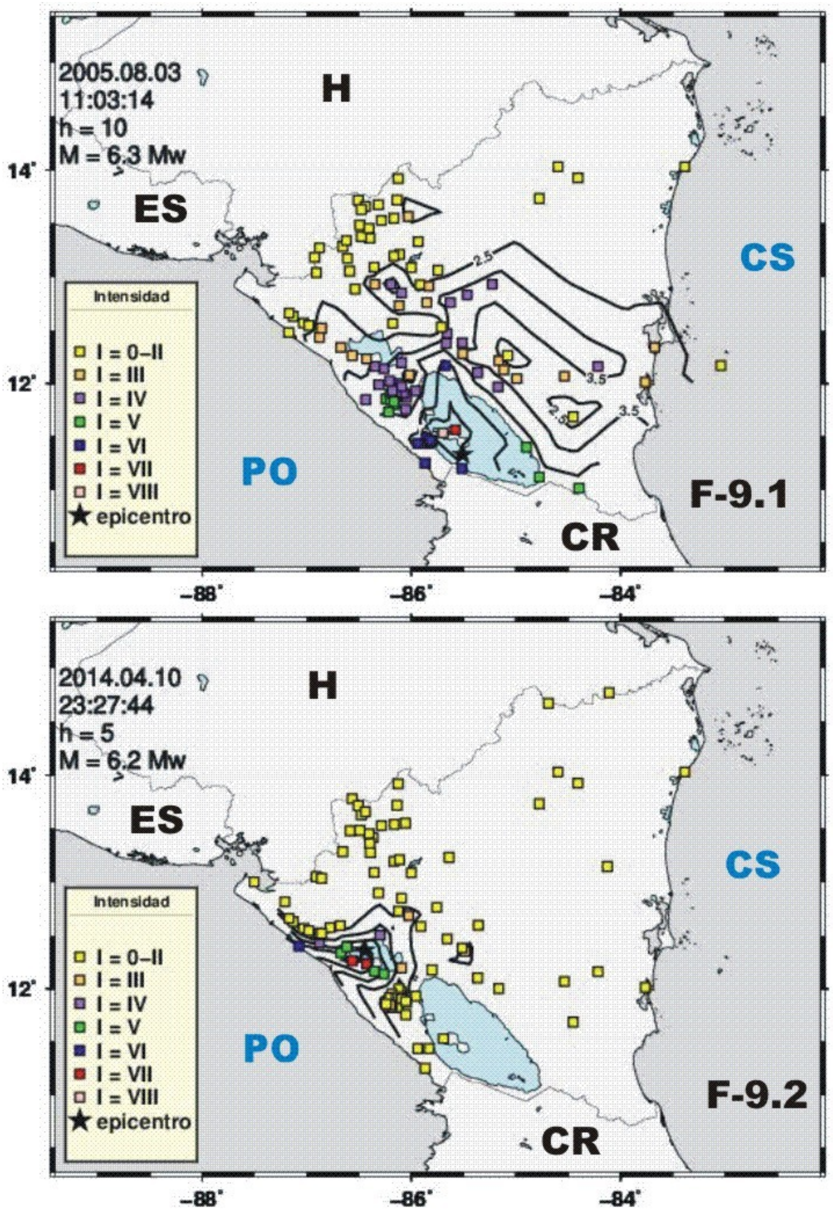


Figure 9. Isoseismal maps of two Nicaraguan earthquakes.

Appear: **1)** CR=Costa Rica, CS=Caribbean Sea, ES=El Salvador, H=Honduras, PO=Pacific Ocean; **2)** Intensities' data are from Morales *et al*. (2005, 2014); see legend; **3)** Isolines were calculated by Delaunay triangulation method (Shewchuk,1996).

Isoseismal maps and alignments

"La ignorancia es la madre de todos los males".
Francoise Rabelais (Francia, 1494-1553)

Isoseismal maps and alignments

The scientific literature shows several studies on the relationships of the geometric figures, which result from the intensities produced by earthquakes, with the alignments of the relief (Medvedev, 1978; Chuy, 1984; Álvarez and Chuy, 1985; Herraiz, 1997). The alignments include active faults. In our case we use isoseismal maps indicated in **table 18**. All they belong to Nicaraguan Depression and its southern boundary. From our interpretation of the maps used, it is feasible to argue that the seismogenic structures have two preferred strikes. These correspond to the seismic sources recognized by other specialists.

Table 18. The used data.

Date	M/ h (km)	Author (s)	Alignments (main/ secondary)
*31.03.1931	6,0/ 5	The authors	SW-NE
14.11.1958	5,8/ 72	Hansen and Chávez (1973); Chuy (1984)	SW-NE/ SE-NW
4.12.1958	-/ 100	Hansen (1965); Chuy (1984)	SE-NW
23.05.1961	6,5/ 138	Hansen (1965); Chuy (1984)	SE-NW
4.01.1968	4,6/ 5	Algermissen *et al*. (1974); Chuy (1984)	SE-NW/ SW-NE
23.12.1972	6,3/ 10	Hansen and Chávez (1973); Chuy (1984)	SW-NE/ SE-NW
14.10.1981	-/ 15	IGA-INETER (1981); Chuy (1984)	SE-NW
10.04.2014	7,3/ 10	Morales *et al*. (2014)	No preference

Note: *The authors developed a seismic intensity perceptibility scheme (see **Figure 3**).

The study and reinterpretation of the 1931 earthquake data (Chapter XI: Other interesting earthquake lessons from Nicaragua and New Zealand/ Earthquake at Managua, Nicaragua March 31, 1931-10.19 A.M. (589-595 pp.) of Freeman (1932) and Sultan (1931)) allows us to consider that this event was processed, for this time, in a very good scientific style. The specialists who developed it had engineering training and were logically familiar with the 18.04.1906 San Francisco work (M7,9/ 10.000 deaths). The authors have indicated in bold and underlined fragments of the original text to highlight important elements for the analysis.

From the texts consulted we have: *"The City of Managua, was partially destroyed by an earthquake which occurred at 10:19 a.m., local time, March 31, 1931…Fortunately,* ***<u>the surveyors of the United States Army Engineers, who were in the immediate vicinity, obtained unusually complete details of what happened, and took a very important part in the relief work</u>****… this earthquake presents no important threat of danger to the Nicaraguan Canal as planned…***The earthquake at Managua occurred in very recent volcanic strata***, distinct from the older rock formation along the Canal line…This is estimated to have a cost 1.000 lives, and a property loss of perhaps $15.000.000.* ***The greatest loss was in the penitentiary, a stone building which happened to stand <u>over the fault line</u>*** (**Figure 9A**)*…As illustrating current exaggeration, local had insisted that some of the cracks were a foot wide, and elevation the elevation of 8 inches…In general, the zone* *of the cracks is no more than 500 feet wide, and extends in a northeast-southwest direction through the western half of the city of Managua, as shown by the preceding map…**Damages naturally were greatest along the fault line, but <u>the zone of severe shocks was of very small area</u>**…In the eastern section of the city, one mile from the fault, the damage was slight. Apparently the serious disturbance did not extend more than 3 miles (~4,828 km) west of the fault line…At Granada, 26 miles (~41,843 km) southeastern of Managua, there was no damage…The same was true at Masaya, 18 miles (~28,968 km) from Managua…*

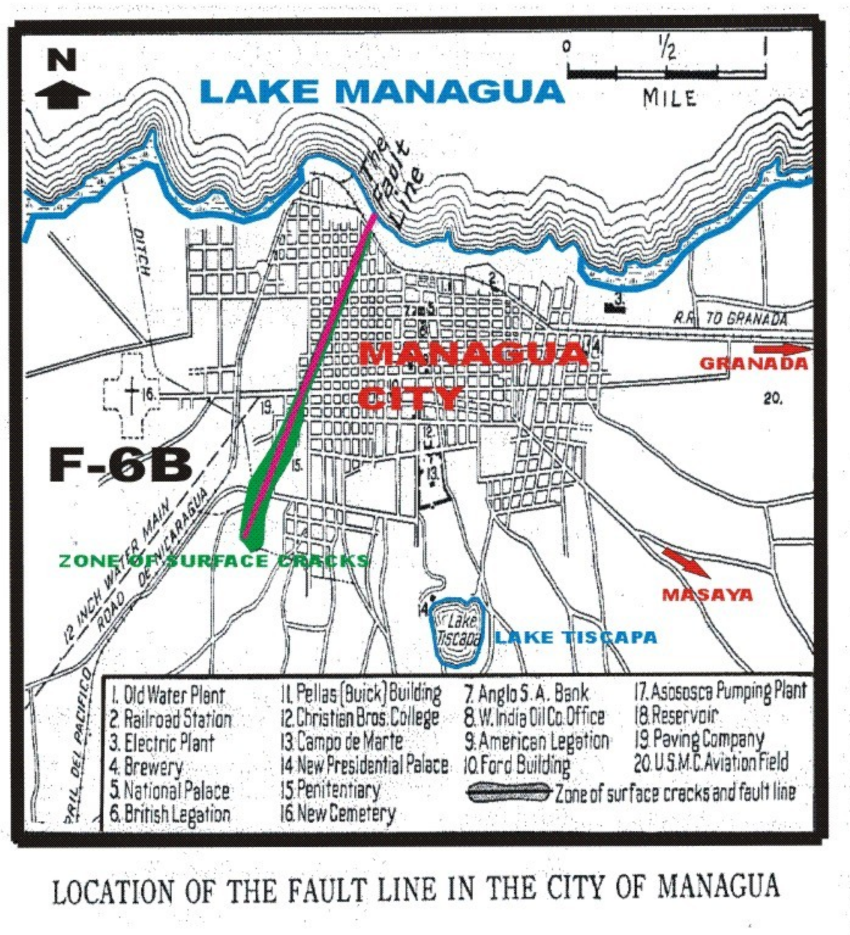


Figure 9A. Modified Managua City scheme from Sultan (1931).
Appear: <u>**1)**</u> Red line=The fault line delimited by Sultan (1931); <u>**2)**</u> Green color=Zone of surface cracks; <u>**3)**</u> Affected area is represented at **figure 3**.

In the other hand, damage to buildings and people is justified by: <u>**1)**</u> the location of epicentre on the fault line. We confirm the seismic structure is the Estadio Fault; <u>**2)**</u> the values of M5,6 and h5 km depth (the authors selected this M_S value of Pasadena station, instead of M_W=6 given by RESIS-II, by consideration of its reliabylity); <u>**3)**</u> the type of soil; <u>**4)**</u> the type of construction; <u>**5)**</u> the materials used in them. The data show that: *"…About 85% of the buildings in the city are of a local type of construction designated by names "Taquezal con piedra" and "Taquezal con barro terra", which, translated, mean "Pocket containing stone" and "Pockets containing ball and mid"…This Tarquezal* *construction bears resemblance in its timber frame work and in its safety from collapse and killing people within, to the Baraccata type developed in Southern Italy a hundred years ago, under the Bourbon Dynasty…"*

Taking into our consideration these data also the affected area at Managua: **1)** 23.12.1972 (~37.820 km^2); **2)** 4.01.1968 (~750 km^2); **3)** 14.11.1958 (~1.000 km^2), we estimated to 31.03.1931 earthquake an affected area of ~880 km^2 and it is represented in **figure 3.**

Special maps and seismicity profiles

“La ignorancia puede ser temporal, la estupidez es para siempre”.

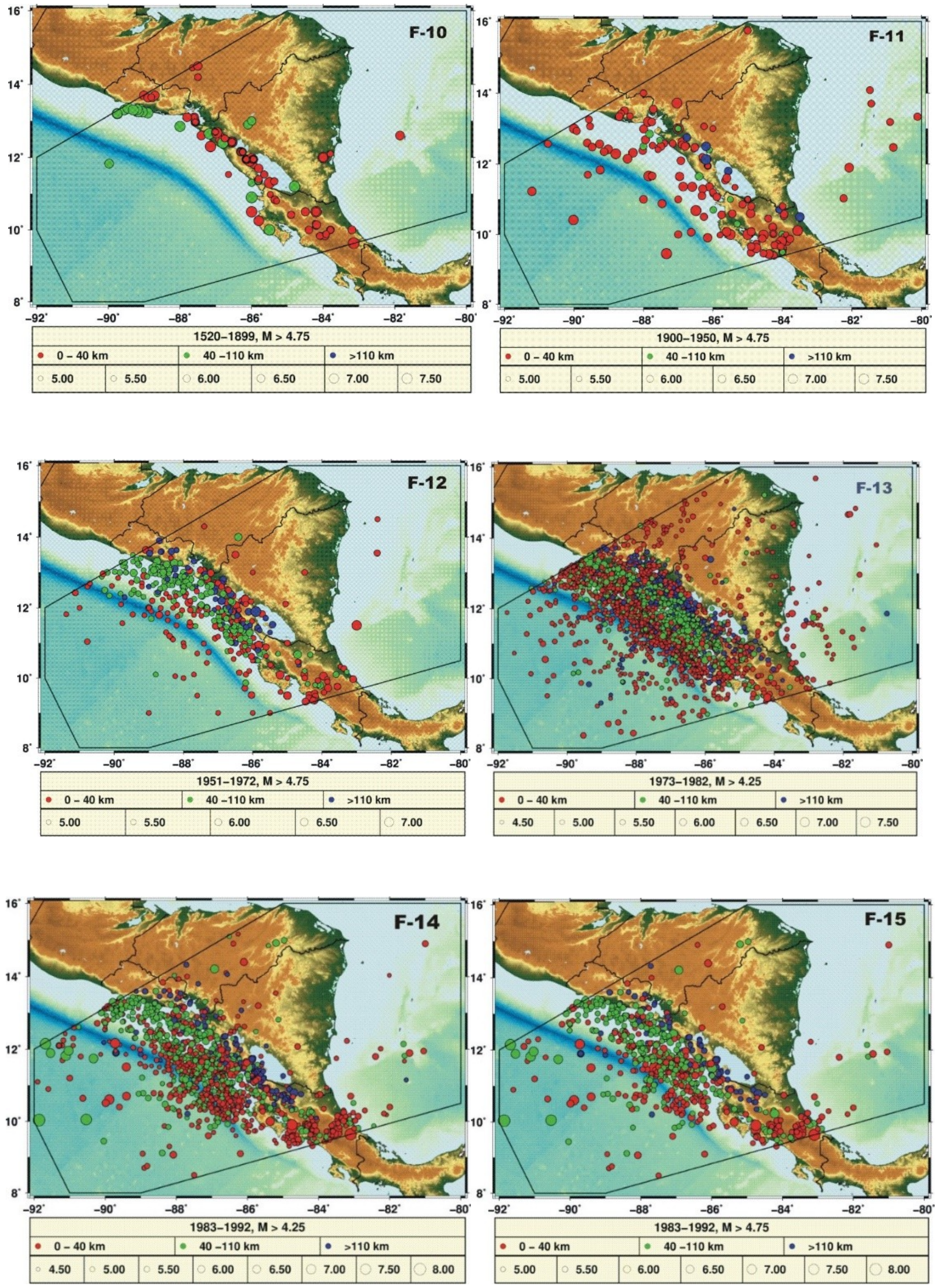
Anónimo

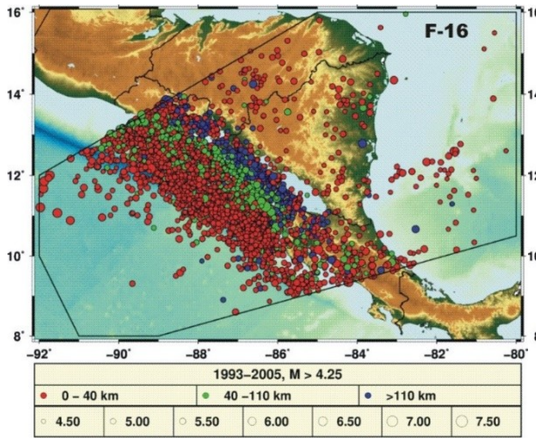
Special maps and seismicity profiles

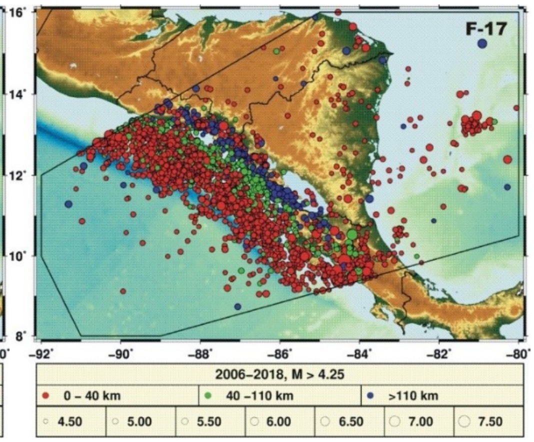
In order to analyze the behavior of earthquake occurrence as a function of recording period and magnitude, several epicentral maps were prepared. It was used a catalog deveopled for NI (Alvarez, 2021) for the period 1520-2018, with magnitudes converted to M_W. The region covered by the catalog is formed by a closed polygonal that includes NI, wide oceanic areas of Caribbean and the Pacific and small parts of neighboring countries of NI. It is seen in the maps **1)** the lack of data for non-instrumental period (1520-1899, **Figure 10**); **2)** that the majority of events in this period is located in continental part, which is in contrast with the first period of instrumental recording (1900-1950, **Figure 11**). It can be explained by different factors: **1)** the main cities of NI are placed along the volcanic chain, about 40-50 km from the coast; **2)** there are very little historic earthquakes with enough data for constructing isoseismal maps (Chuy, 1985), and their coordinates have been associated to points close to the main cities; **3)** earthquakes held in ocean, away from coast, produce lower intensities in the inhabited localities that if they would held on land, and then, the epicenter could be assigned to points in the interior of NI and their magnitude underestimated; **4)** the improvement of recording quality (1951-1972, **Figure 12**) is reflected in the increase of the number of events with depths greater than 40 km. After that data the magnitude threshold of recording events decreases (1973-1982, **Figure 13**). Nevertheless, this improvement is reverted in the next analyzed period (1983-1992, **Figure 14**), with the closing of Nicaraguan network of seismic stations because of the war. In this period most of reported events correspond to a bigger magnitude threshold characteristic of global networks (**Figure 15**). After that there are two periods: **1)** the previous recording level is recovered (1993-2005, **Figure 16**); **2)** the level of detection increases highly (2006-2018, **Figure 17**). In the last period, due to densification of Nicaraguan and some neighboring countries networks, the magnitude detection threshold decreases also (**Figure 18**).

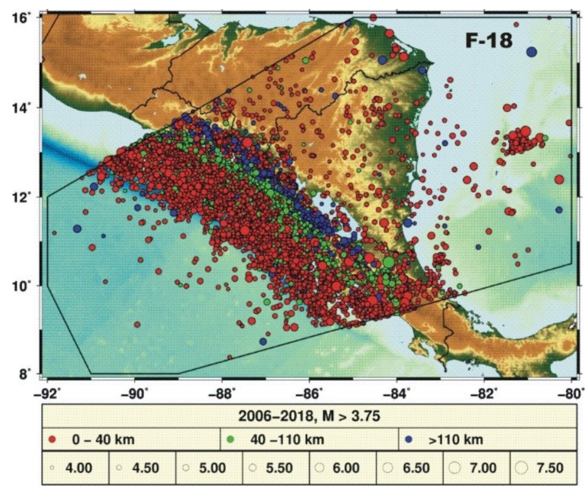
For the study of depth behavior (h (km)) of earthquake occurrence three profiles were constructed (**Figure 19**). The events are projected over a vertical plane indicated by the center lines that divide the area of profiles in figure. The center of profile is indicated by a star and the beginning by a diamond. For these profiles were not used the catalog of NI, already mentioned, but the ISC (2021) bulletin for the period 1900-2018, considered as the best of the global networks for this area. Profiles' longitude is 600 km, they cover depth interval 0-300 km y and the search for events is done to a distance until 100 km from profiles' planes. Two different magnitude ranges were analyzed (M_W>4 y M_W>5). Profile were named as "**noroeste**", "**centro**" and "**sureste**" for their relative position in the map. The profiles for both magnitude ranges are presented in the three analyzed cases (**Figures 19.1, 19.2 and 19.3**).

Figure 10-18. Seismicity map set









It is observed that the profiles, for both magnitude ranges follow the same trend with respect to subduction. They have an inclination of Benioff zone close to vertical, but in the case **"noroeste"** the zone is little wider in the upper part. This perhaps indicate the beginning of a transition of subduction type from very inclined at center and south to a more elongated as moving toward northwest in Central America (Cotilla *et al.*, 2019). If should be remarked the presence of alignment of epicenters at depths of 33, 50 y 100 km. This reflects a characteristic of the catalog, because in the initial stage of instrumental recording these there were fixed and no intermediate values estimated. Finally, the profiles for M_W>4 show bigger dispersion that the corresponding to M_W>5, that reflects the fact that precision of hypocenter determination grows with the increase of magnitude.

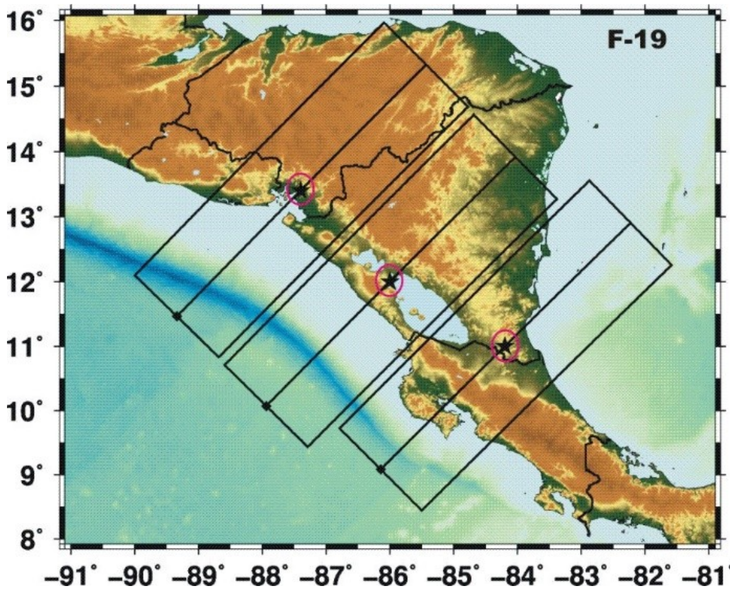
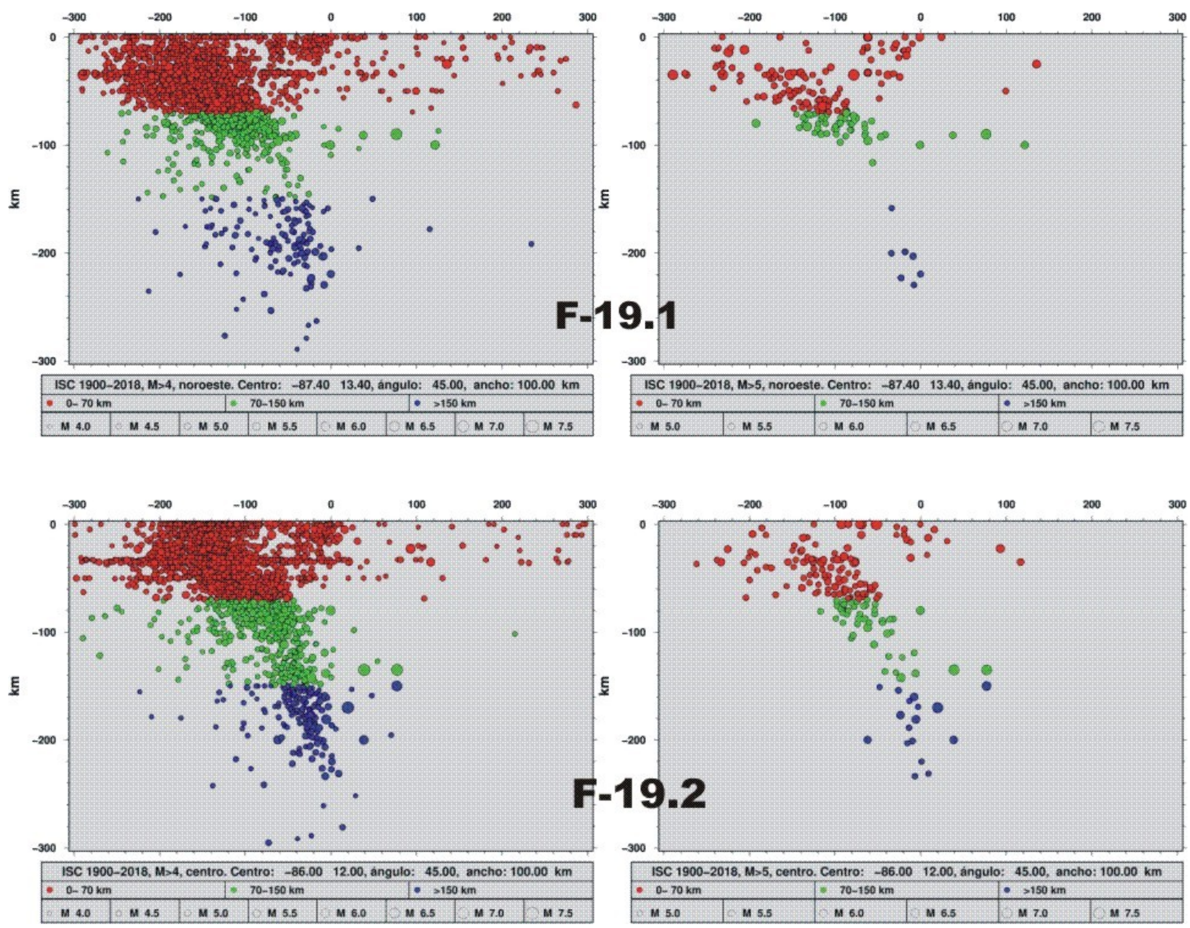
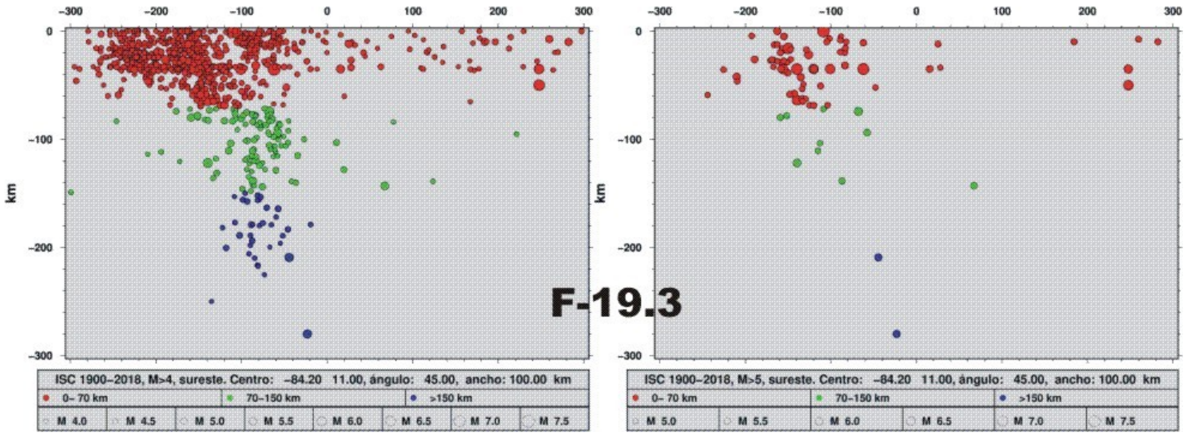


Figure 19. Location of the three seismic profiles.

Figure 19.1-19.3. Profiles set.





For getting precision in Benioff zone geometry a simple statistical procedure was applied, that consists in tracing a line resulting of a sliding average procedure. The process requires to order from lesser to bigger the depth values in the profile and to calculate the sliding average using 21 points in depth spacing at a fixed distance Δ. All the earthquakes in depth interval (y+2Δ, y-2Δ) are considered and an average of horizontal distance "x" is calculated, with $\Delta=(y_{max}-y_{min})/20$. The result of the process is shown in **Figure 20** for the profiles **noroeste (a)** and **centro (b)**. For profile **"sureste"** it was not prepared such plot because the data is not enough for getting reliable results with this algorithm. The lines drown below 40 km depth, corresponding to subduction may be considered an idealization of plates' limit. They begin by a zone with a slope greater than 60° and transform in almost vertical below 150 km. This is characteristics of the kind of subduction named "Marianas" (Uyeda y Kanamori, 1979, Uyeda 1983), that, between other facts, generates earthquakes with lesser magnitude that in the other cases. This is very important, because allow us to make estimations of $M_{máx}$ between 7,7 and 8,0 M_W, lesser that in the regions of Chile and Japan.

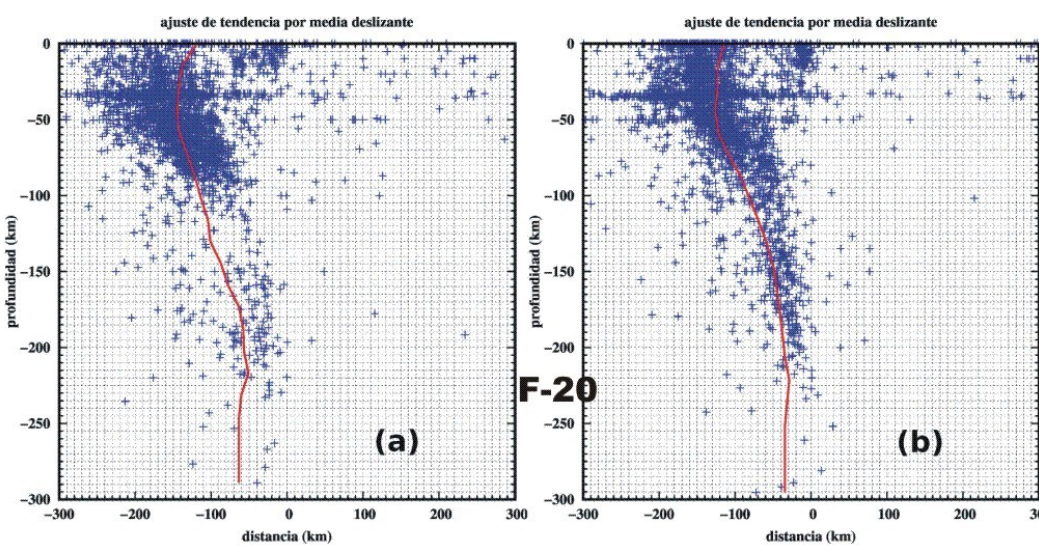


Figure 20. Sliding stocking.

Released energy and density maps

"Energía es deleite eterno".   William Blake (Reino Unido, 1757-1827)

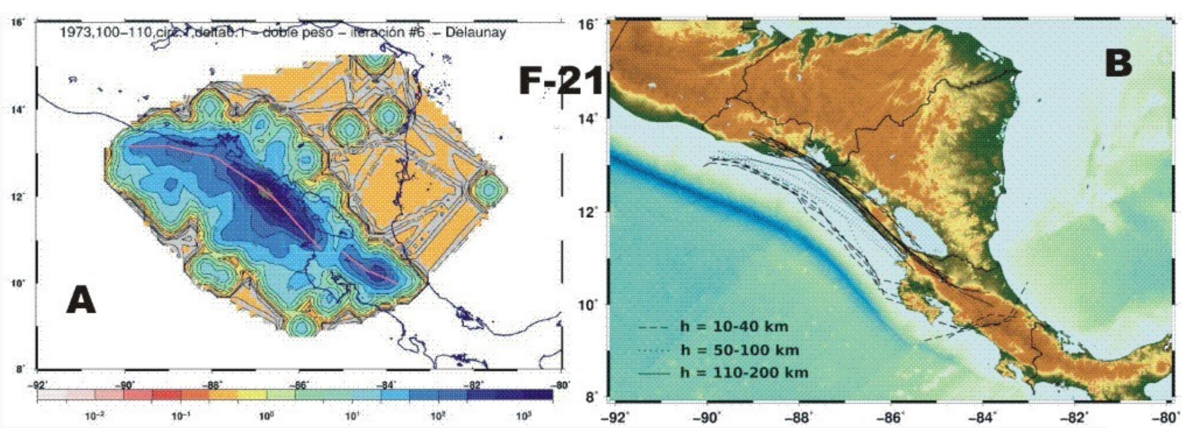
Released energy and density maps

The Benioff' zone geometry can be studied by using maps of density of epicenters. They are prepared by averaging the number of events in areas, more or less big, around a selected point. It is possible to delineate fault traces, over a fuzzy seismicity pattern, by applying the following formula in calculating the density of epicenters:

$$D_{ij}=\left(\delta N_{ij}+\sum_{k=j-m}^{j+m}\sum_{i=i-m}^{i+m}N_{kl}\right)/\left[\left(2m+1\right)^{2}+\delta\right]$$

Where: N_{kl} = number of earthquakes in cell *(k,l)*
D_{ij} = density of epicenters in cell *(i,j)*
m = quantity of cells at both sides of each direction used in average
δ = 0 or 1 (the second corresponds to double central weight, used to increase the fault trace contribution)

In order to highlight the fault traces it is calculated in a recurrent procedure, where better results have been obtained in the 3rd iteration, substituting each time N_{kl} by the calculated D_{kl} in the previous iteration. The algorithm was applied in cells of 0,1° x 0,1° with m=1. Then there were made 20 maps of density of epicenters using all the data of catalog NI in depth intervals of 10 km for the range 0-200 km. Each map was processed, with the help of a GIS (qGIS 2020), by tracing axes that join the maximum values of density (**Figure 21A**). The digitized lines were collected in text format and were plot in a map (**Figure 21B**). From the last figure is seen that the Benioff zone begin in an inclined way until 100 km depth and then pass to almost vertical behavior, as was pointed out in the analysis of depth profiles.

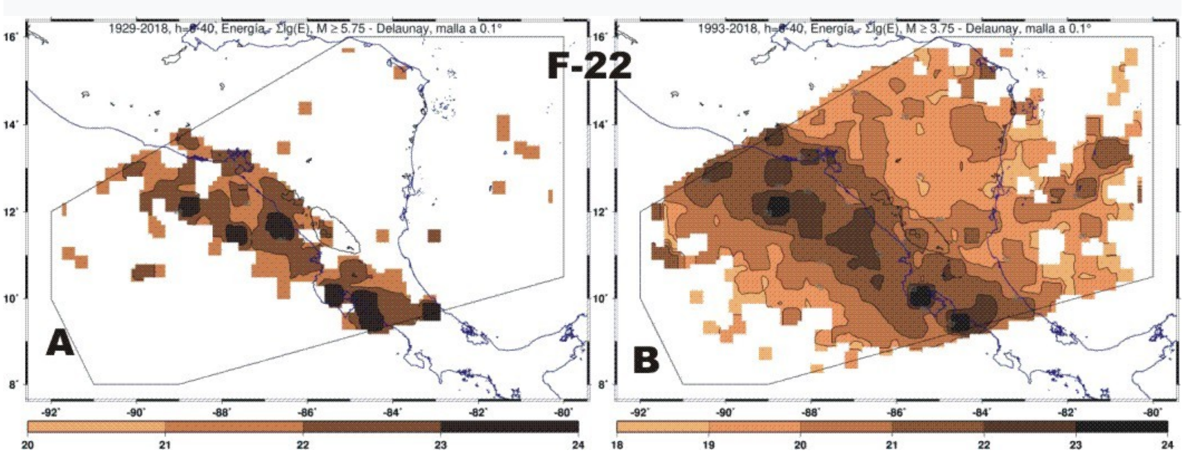


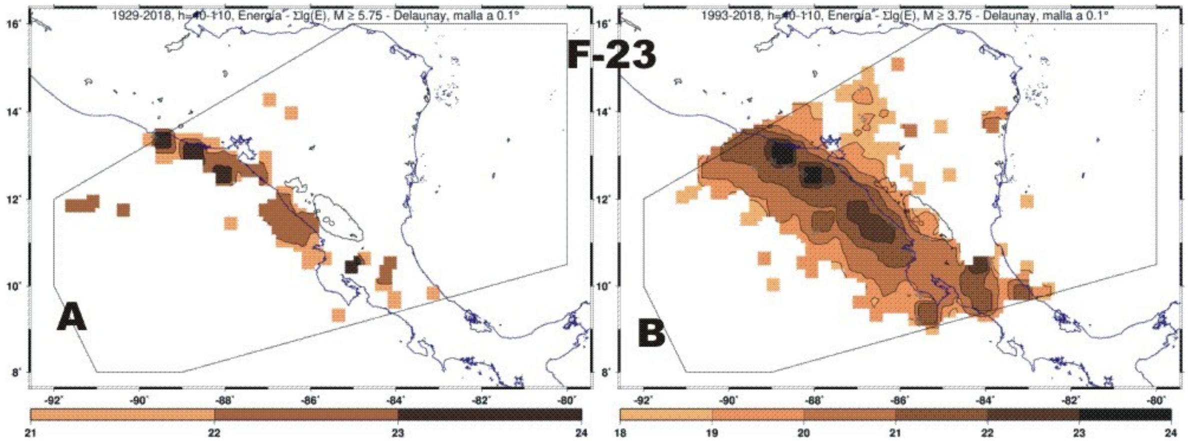
Figures 21A-B. Density of epicenters maps with the axis of maximum value.

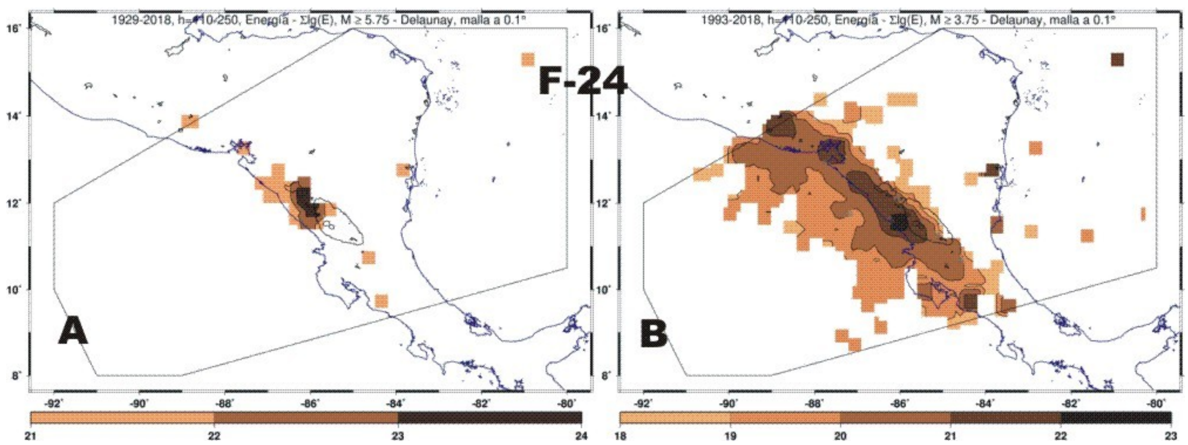
Other important line for studying the potential of different zones and to estimating its maximum possible magnitude [**Mmax**] is the analysis of spatial behavior of energy release. It requires to use representative events; i.e., those that belong to intervals (T, M) where, with a high probability, all the held events have been reported. Then for the study have been selected two temporal intervals: 1900-2018 and 1993-2018. Álvarez (2021) pointed out that for these intervals are representative the events with M≥5,75 and M≥3,75, respectively. Energy release maps were developed using the mentioned earthquake catalog of NI, with an algorithm that sums the released energy in cells of 0,1° x 0,1° with a posterior averaging with neighboring cells in a 9 cells square. This guaranties smoothing and the possibility of delineating zones were energy have been released.

In the process they were used three depth intervals: **1)** 0-40 km (**Figures 22**) where it can be seen that the most of released energy since 1929 correspond to the beginning of subduction zone. Nevertheless, since 1993 release process moved to volcanic chain. It is due to events that have magnitudes Mw<6,3 which contribution is hidden in the map for period since 1929 for the occurrence of higher magnitudes at the beginning of subduction zone; **2)** 40-110 km (**Figures 23**) where the main activity moved towards the NW half of plates' boundary and there is no difference between both observation periods; **3)** 110-250 km (**Figures 24**) where there is a contribution in the center of subduction zone, that corresponds to a M_W6,6 event in 2014, coincident in time with shallow earthquakes' activity in the western part of Managua Lake.

Figures 22A-B – 24A-B. Energy release set maps.



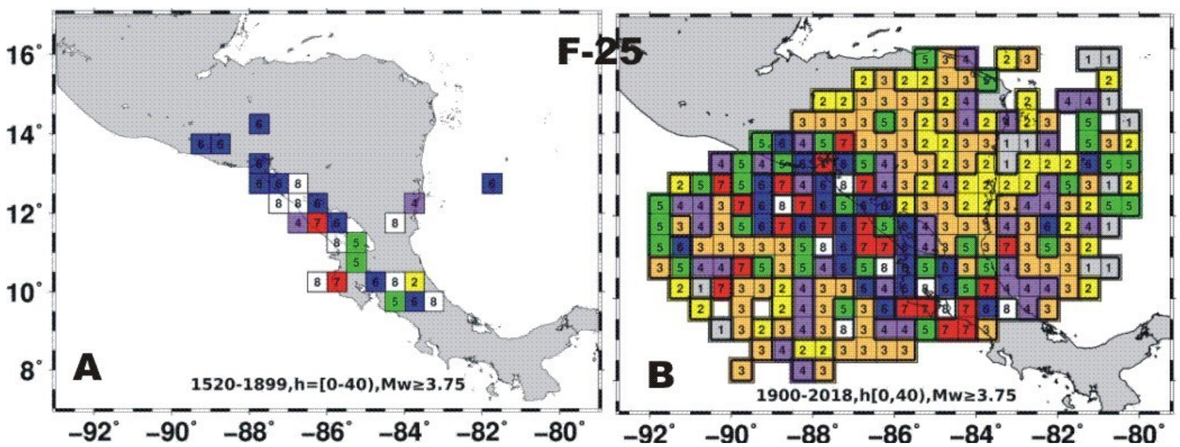




In order to complement the information the whole catalog was processed with the purpose of determining the reported Mmax distribution, being or not representative the earthquakes. The reported M_W maximums in cells of 0,5° x 0,5° were determined and represented in a maps. In the case of 0-40 km depth interval two maps were prepared (**Figures 25 and 26**): **1)** period 1520-1899; **2)** period 1900-2018. It was motivated by the need of considering independently historic and instrumentally recorded earthquake, because of relative vagueness of the first. For the other two depth intervals, practically there are not historic records and then a single map (1990-2018) was constructed for each one. In these maps, the magnitude range from M_W3,75 was divided in eight intervals as indicated in **table 18A-** “interval”. In the maps, for simplicity, it is represented the number of interval [M_{inf} , M_{sup}) to which belongs the reported Mmax.

Table 18A. Intervals.

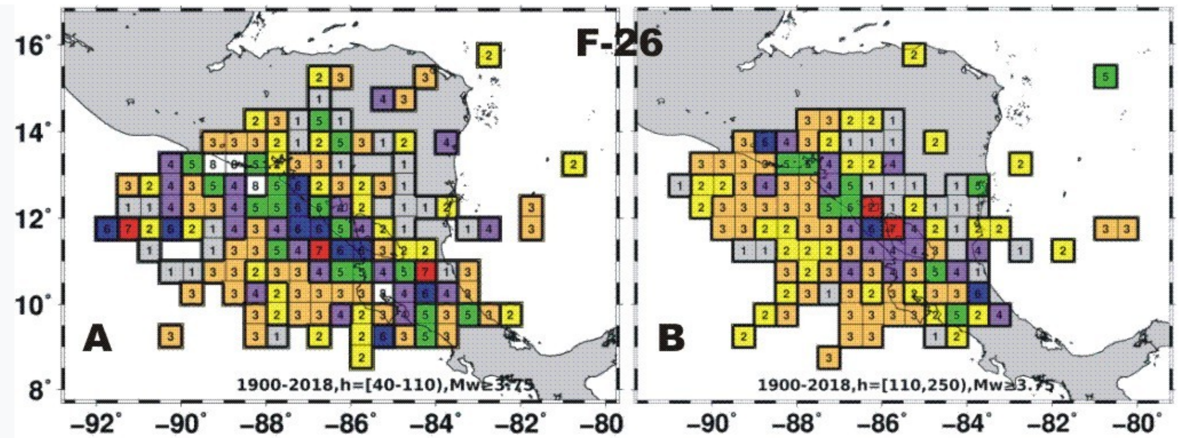
Interval	M_{inf}	M_{sup}
1	3,75	4,25
2	4,25	4,75
3	4,75	5,25
4	5,25	5,75
5	5,75	6,25
6	6,25	6,75
7	6,75	7,25
8	7,25	7,75



Figures 25A-B. Mmax distribution.

For [0, 40) km depth interval (Figures 25) it is seen that in period 1520-1899 the Mmax interval 8 is present in continental part, while in posterior period it moves towards the zone of subduction beginning, where several points several points appear of Mmax intervals 7 and 8. These values diminish as the distance to coast grows. The volcanic chain is characterized by interval 6, although in moving to the Fonseca Gulf appear higher Mmax. The Costa Rica zone appears higher values of Mmax (intervals 7 and 8), while the Hess Escarpment reports lesser magnitudes (intervals 5 and 6).

With the deeper intervals (Figure 26) the earthquakes placed long away of subduction axis has reported lesser Mmax values and dominate the low Mmax intervals; many of these events can have wrong depths as they have been pointed out before. Higher values are mainly close to the plates' boundary axis determined in profiles.



Figures 26A-B. Mmax distribution.

3-MORPHOTECTONIC ANALYSIS

"El que tiene imaginación, con que facilidad saca de la nada un mundo".

Jorge Mario Pedro Vargas Llosa (Perú, 1936-)

3-MORPHOTECTONIC ANALYSIS

Alekseevskaya *et al.* (1977) developed a deep work of morphotectonics considering the contributions of other specialists. Later on, Wesnousky and Scholz (1980) made an interesting research about the tectonic and seismicity interaction for the Northamerican Craton. Among the elements used was the structural configuration. Cotilla *et al*. (2017) applied the Russian methodology, with modifications, to the territory of Mexico in order to get a seismotectectonic regionalization. Such is the methodology that authors apply in NI. But, we have also taken into account review of Dengo (1968). That author defined and represented eight morphotectonic units in CA. Of these we indicate two: **1)** the Pacific Volcanic Chain and the Nicaraguan Depression; **2)** Sierras and Volcanic Plains. They are placed according to the interaction of the Cocos-Caribbean Plates. **Figure 1** shows three stages or steps between the Yucatan Peninsula and Panama, of a graphic morphic “staircase”. This figure maintains approximately the same interval between steps. On the Pacific Ocean side, the linearity of the “staircase” can be seen. This configuration is interpreted as a consequence of the plates influence (Cotilla and Udías, 1999). Schematically, for CA, it is possible to ensure that the main fault and fracture systems are: Guatemala (E-W (northern) and N-S/ NE, and NW (at Pacific)), H (E-W (northwestern) and N-S/ NE), ES (NW), NI (NW (at Pacific), CR (NW (at Pacific)). The main alignments defined in Guatemala and H have significant differences. For H these are: **1)** SW-NE (Gulf of Fonseca-northern H)); **2**) NW-SE (from Chiapas to Nicaragua Lake and parallel to the Pacific coast).

Also, taking into consideration what is stated in our previous section **-Alignments, fractures and geometrical arrangement-**, it can be added that the geometric figures on the neotectonic plane of Nicaragua and Managua Lakes, as well as the data on their dimensions, orientation and position are significantly different, despite being in the Nicaraguan Depression and separated by only a few kilometers. Both depressed water bodies are areas that are influenced differently by the Caribbean-Cocos plate interactions. The distances and velocities with respect to the convergence front are also different, as well as the typically Caribbean trans-arc morphostructures. In the Lake Managua area there are important neotectonic uplifts and mountain relief, while for Lake Nicaragua its northern margin is rectilinear and contacts a zone of low altitudes and wide plains. All these characteristics allow us to argue that both the dynamics and kinematics of both bodies are different, and correspond to the deformation of the volcano alignment and the strong seismic activity observed.

The authors have considered these morphotectonic elements and developed a new working scheme. Our morphotectonic basis include some data as appear in **tables 19-22**. All they were developed here for CA. **Figures 27 and 27A** show the main neotectonic features of ES and CA, respectively. From another side, **Figures 3 and 27** have a significant similarity in regards to the arrangement of the morphostructural elements. Both figures reflect the Pacific margin tectonics of NI and ES, respectively. The authors, when evaluating the regional features, determined the presence in ES of several abrupt deviations of the river courses and significant modifications of the drainage directions and alignments of the maximum altitudes. Examples are the Lempa and San Miguel Rivers. In particular the first one borders from the north and east to the capital San Salvador and Ilopango Lake. In Honduras study we determined that there is an area with a significant change in direction of the main river basins. The area is located in a N-S direction and spatially related to Cerrón Grande reservoir, in ES.

Table 19. Brief definitions of morphotectonic elements.

Nº/ Element	Definition
1/ Alignment	(alignment=lineament) The boundary between the TU (see below). It is an expression of tectonic activity during the most recent orogenic period. It has different rank according to the structures involved. It is possible to distinguish longitudinal and transverse types
2/ Zone of lineaments	A set of lineaments
3/ Lineament intersection	(Lineament intersection=knot) Always is wider than the lineaments from which is former. It is related with the rank of the structures involved
4/ Territorial Unit	(Territorial Unit=TU) Areas with the same geologic history
5/ Megablock	The largest TU of a region with the same geodynamic behavior in the current stage of geological development
6/ Macroblock	It is a TU inside the megablock. It is differentiated by the type of orogenesis and/or a large_scale tectonic features
7/ Mesoblock	The TU included in a macroblock. It differs either by the dominant type of relief or by average parameters of the relief (such as height of peaks, dominant strikes, relative area occupied by basins and ranges, etc.) or by the pattern of main elements of relief
8/ Block	A TU inside a mesoblock. In it is necessary considering the neotectonic history
9/ Microblock	It is a TU within which the quantitative indexes of major elements of relief change little, whereas across the limits of these areas a significant change in at least to quantitative index takes place
10/ Nanoblock	The most little TU. It is included in microblock. The quantitative indexes are taking in consideration
11/ Main watershed	A line over the top of heights that limit the fluvial basins

Table 19A. Main elements of the Central America-I Megablock.

	Boundary
1	Northamerican Plate (mega alignment of the Pacific)
2	Cocos Plate
3	Caribbean Microplate
4	Mesoamerican Trench (Pacific Ocean)
5	Polochic-Motagua Fault
6	Swan Fault
7	PTT (Caribbean-Cocos-Northamerican)
8	Central America-II megablock

On a smaller scale are some other rivers such as Jiboa, in the vicinity of the aforementioned Lake, and the La Paz River on the border of ES and Guatemala. These rivers run with affectations of the volcanic axis of CA. Álvarez-Gómez *et al*. (2006) considered the presence of the El Salvador Fault Zone when analyzing the lateral displacement of the Jiboa River in the vicinity of Ilopango Lake. From the development of **figure 28** we assure that contemporary morphostructural plane of NI is heterogeneous and active. This highlights a major alignments system: NW-SE, NE-SW, N-S and E-W. The most extensive and important are the NW. The NE are imposed in sectors cutting all structures. Both systems are active. There are also three articulation knots, the most relevant being the one associated to Gulf of Fonseca, where the arching of Volcanic Chain is determined. The morphohypses method facilitate the determination: **1)** two large zones and the coining at the H border; **2)** the area of the largest neotectonic uplifting; **3)** the active area at Managua Lake.

Table 20. Alignments and knots of Central America countries.

Country	N-S	NE	NW	E-W	Total	Abnormal knot in relation to the MDFO N	S	Total
CR	2	3	4	4	13	7	5	12
Guatemala	3	4	2	10	19	13	3	16
H	2	10	5	4	21	6	2	8
NI	1	4	4	-	9	5	-	5
Total	**8**	**21**	**15**	**18**	**62**	**31**	**10**	**41**

Table 21. Features, structures and unique elements of Central America Provinces.

	Central America-I		Central America-II	
Type	**Quantity**	**Location**	**Quantity**	**Location**
Volcano Alignments	2	Pacific	1	Pacific
Magnitude	8,1	Pacific	7,7	Pacific
Main knots	3	Pacific (2), Caribbean (1)	2	Pacific
Plates	3	Caribbean, Northamerican, Cocos	4	Caribbean, Southamerican, Cocos, Nazca
Triple Point	1	Pacific	1	Pacific
Local Tsunamis	10/ 3	Pacific/ Caribbean	3/ 1	Pacific/ Caribbean
Active volcanoes	>50	Pacific (land and sea)	10	Pacific (land and sea)
Subduction zones	1	Pacific	2	Caribbean, Pacific
Maximum height (m)	4.222		3.820	
Area (km^2)	~76.000		~12.700	
Population (10^6 inhabitants)	~29		~10	
Fatalities by earthquakes	~60.000		~400	

Table 22. Selection of the main rivers of Nicaragua.

Nº	Title	L (km)	A (km^2)	Strike	Sense	IG	Slope (m/km)
1	Coco	680	18.972,17	Atlantic	NE	0,36	3,1
2	Prinzapolka	245	11.003,62	Atlantic	E	0,70	7,3
3	Wawa	160	4.426,58	Atlantic	SE	0,62	9,4
4	Ulana	92	1.107,16	Atlantic	SE	0,38	10,5
5	Escondido	88	11.1120,13	Atlantic	E	0,88	11,4
6	Indio	70	1.409,94	Atlantic	E	0,91	12,9

Note: IG=Gavelius Index.

The general morphotectonic plane of NI (**Figure 29**) differs from the corresponding ones of H and ES, despite its closeness and common framework of activity of the plates involved. NI is a Macroblock, like H, with three Mesoblocks well defined by two alignments (L1 (NW-SE) and L2 (WSW-ENE)): **1)** Mesoblock MEB-1 is a structure aligned between the Pacific coast line and the c (MDFO, see **Figure 28**). It includes the Volcanic Arc and the Nicaraguan Depression); **2)** Mesoblock MEB-2 (structure stamped on the border of ES and H with rectangular shape and direction WSW-ENE); **3)** Mesoblock MEB-3 (structure fitted between the two previous ones and with a limit in the Caribbean). In addition, it has eleven blocks.

The NI Macroblock has an important and extensive deformation zone with the NU-2 knot. In it there are Volcanic Arc, NE-SW cross-sectional area, and MDFO in the vicinity of Gulf of Fonseca. We identified a structural arrangement of 90º angle. The mentioned structures conform the Nicaraguan Morphotectonic Triangle. That figure reflects the great asymmetry of the fluvial networks of Pacific-Caribbean, and where there is the greatest density of fractures and faults according to INETER (1995). NI is also distinguished by having some structural characteristics similar to those determined in H and ES. Thus, we indicate that the Mesoblock: **1)** MEB-1 corresponds structurally to the Mesoblock of ES; **2)** MEB-2 has some features of H. However, the MEB-3 only corresponds, with an inverse figure, to the east in the Nicaraguan Rise.

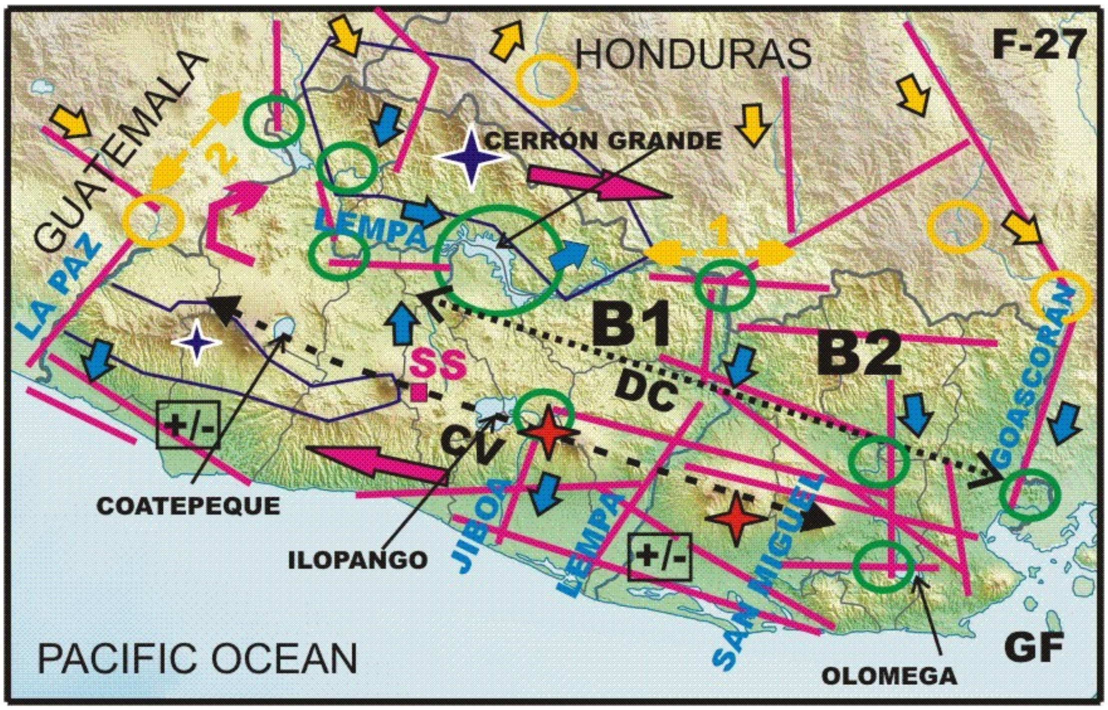


Figure 27. Morphotectonic scheme of El Salvador.
Appear: **1)** Alignments (continuous red lines); **2)** Blocks (B1=San Salvador, B2=Gulf of Fonseca); **3)** CV=Volcanic Active Chain; **4)** DC=Central Depression; **5)** Deformation axis: **5.1)** Main in the Mesoblock (double black arrow with dotted line); **5.2)** Secondary outside the Mesoblock (double yellow arrow with dotted line); **6)** GF=Gulf of Fonseca; **7)** Joint knots: **7.1)** In the Mesoblock (green circles); **7.2)** Outside the Mesoblock (yellow circles); **8)** Neotectonic uplift area: **8.1)** Intense (purple star); **8.2)** Middle (orange star); **8.3)** Low (square with the symbols +/-); **9)** Rivers (Goascorán, Jiboa, San Miguel, La Paz, Lempa); **10)** San Salvador City (square and acronym (SS) in red); **11)** Sense of movement: **11.1)** Relative lateral (red thick arrow); **11.2)** Rotating (red curved arrow); **12)** Surface drainage direction: **12.1)** in the Mesoblock (blue arrow); **12.2)** Outside the Mesoblock (yellow arrow); **13)** Volcanic activity axis (double arrow with dotted line).

The segment with the highest structural deformation of ES and NI coincides with the zone of highest convergence speed of Cocos Plate in relation to Caribbean Microplate. This explains why the main S-A of these two countries is in the surroundings of the Volcanic Arc (Mesoblock ES and MEB-1 of NI); and that it is higher than the one produced in H.

The main structural deformation in Central America is in Gulf of Fonseca. There is an arching (15º) south of the Volcanic Arc and the coastline between ES and NI. We interpret this as the predominance of mega order over lower orders. However, it is not excluded that strong earthquakes may occur in lower orders, but always with a much longer period of recurrence.

H and NI territories prove to be two independent macroblocks and show the existence of parallel alignments to Pacific coast. In NI the E-W and perpendicular to Caribbean coast prevails, while in H it is to the NE. We consider, theoretically, the morphotectonic junction between Honduras and El Salvador **[HES]**. From it we would see that the resulting morphostructural structure for HES would be equivalent to that of Nicaragua. However, the stress transfer favors a higher S-A in the offshore NI.

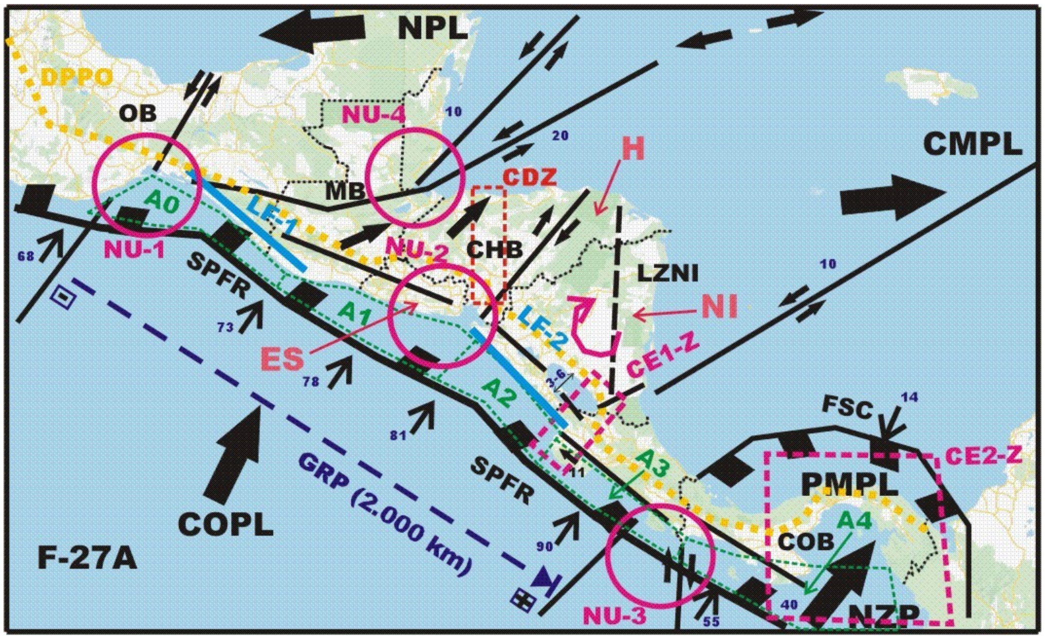


Figure 27A. Morphotectonic scheme of Central America.

Appear: **1)** Blocks (CHB=Chortis, COB=Chorotega, MB=Maya, OB=Oaxaca); **2)** Countries (ES=El Salvador, H=Honduras, NI=Nicaragua; in pink letters); **3)** Drainage Change Direction Zone (dashed rectangle with orange acronym, CDZ); **4)** GRP= Pacific Gradient (purple discontinuous arrow); **5)** Fore-arch area (discontinuous rectangle with green acronym, A0); **6)** Knots (circle and acronym in red, NU-1); **7)** Linear front (dashed line and blue acronym, LF-1); **8)** LZNI=Lower Zone of Nicaragua; **9)** Main faults (continuous black lines) with sense of movement; **10)** MDFO= First Order Main Watershed (yellow dashed line) (defined by Cotilla *et al*., 2003); **11)** Plates (COPL=Cocos, NPL=Northamerican, NZPL=Nazca, SPL=Southamerican) and Microplates (CMPL=Caribbean, PMPL=Panama) with a sense of motion; **12)** Relative speed in mm/year (numbers in purple); **13)** Relative rotation (curve red arrow); **14)** Structural Change Zone (dashed rectangle with red acronym, CE1-Z); **15)** Subduction front (SPFR=Pacific, FSC=Caribbean) thick black line with subduction indication.

The CA-II TU study, with Costa Rica and Panama, is reflected as two Mesoblocks. They show significant differences in relation to the structures delimited in the CA-I TU. We emphasize the significant difference, as a jump or lateral-transverse deviation, of the Volcanic Arc Axis in Nicaragua and Costa Rica. It is scenario that describes the Zone of Structural Change, CE1-Z, represented in **figure 27A**. In both Mesoblocks: **1)** there are two blocks in each of them. These are transversal; **2)** the boundaries between their respective blocks have different directions and link Pacific Ocean and Caribbean Sea; **3)** the areas of greatest intensity of neotectonical uplifitng are linked at the border; **4)** the MDFO in CR (0,85) is much less flexed than the one in Panama (0,52). But, the deformation of this hydrographic element indicates an important anomaly of the relief in San José. The **tables 23A-B** gather a set of data on characteristics that distinguish the morphotectonics of five countries.

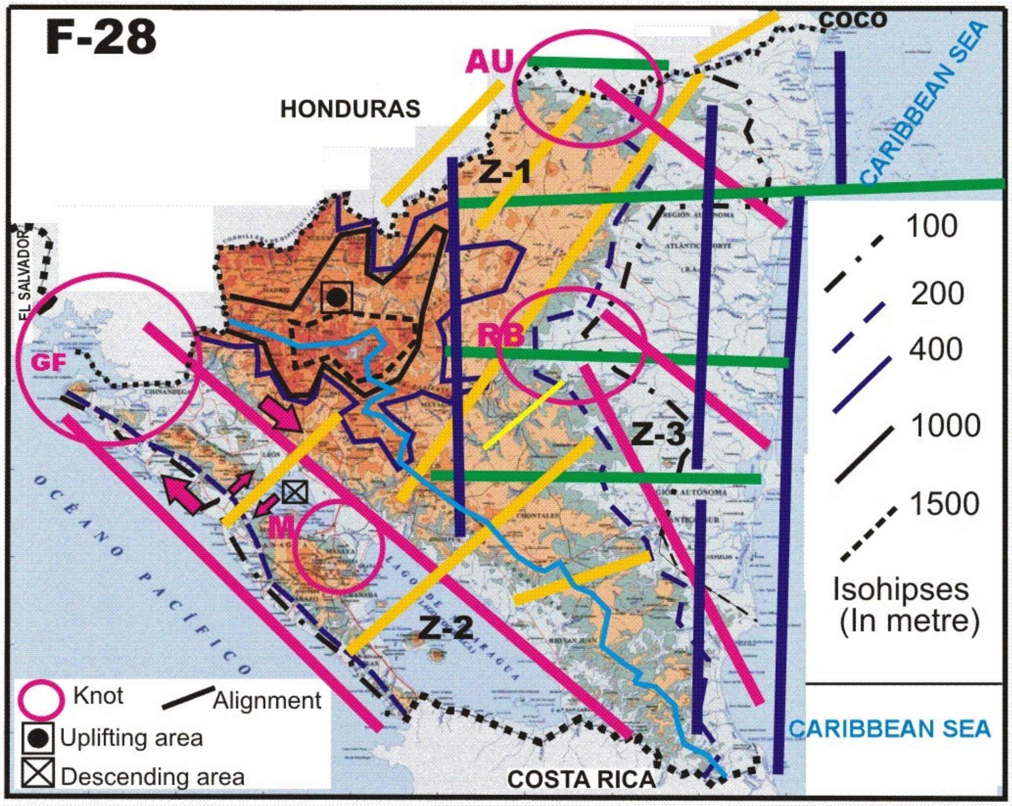


Figure 28. Morphoisohipses scheme of Nicaragua.
Appear: **1)** Alignments (thick lines): **1.1)** N-S (purple color); **1.2)** NE (yellow color); **1.3)** NW (red color); **1.4)** E-W (green color); **2)** Localities (AU=Auasbila, GF=Gulf of Fonseca, M=Managua, RB=Río Blanco); **3)** Main watershed (blue line); **4)** Zone (Z-1); **5)** Relief with isohipses (curved lines, see legend).

Table 23A. Main local morphotectonic data (Part 1).

	AC-	MAC	MES	B	MIC	SZ	TS	AV	NP	AL	ALT	M_{max}
CR	II	-	1	2	6	1	2	9	3	12	3.820	7,8
ES	I	-	1	2	5	1	3	22	8	20	2.730	8,1
H	I	1	3	12	37	-	2	6	5	13	2.870	7,5
NI	I	1	3	7	21	1	8	20	3	20	2.107	7,9
Panama	II	-	1	2	5	2	1	3	4	24	3.474	7,9
	Total	**2**	**9**	**25**	**74**	**5**	**10**	**60**	**23**	**89**		

Notes: **1)** AC=Central America (I and II) Megablocks; **2)** AL=main alignments; **3)** ALT=highest altitude (m); **4)** B=Block, MAC=Macroblock, MES=Mesoblock, MIC=Microblock; **5)** M_{max}=Maximum magnitude; **6)** NP=Main knot; **7)** Active volcano; **8)** TS=Tsunami; **9)** SZ=Subduction zone.

A distinguishing feature of AC morphotectonics is related to the plate segment kinematic data. There is a slight increase in the subduction angle of Cocos Plate from 25º in Oaxaca to 35º in the Isthmus of Tehuantepec and 40º beyond Chiapas. In the northern segment of Costa Rica the angles vary from 15º to 75º, and in the central segment the values are 15º-40º. This is related to the speed variation (68-90 cm/year), as a gradient, from northern Guatemala to Costa Rica (distance ~2.000 km) (**Figure 27A**). In this tectonic segment there are three active nodes (NU-1, NU-2, and NU-3) that we believe justify the rotational articulation of the region. From this plate interaction it is possible to distinguish two different geometric figures in the emerged continental part (a large triangle (G-NI) and a small rectangle (Costa Rica)). Both figures conform to the quasi-linearity of the MAT.

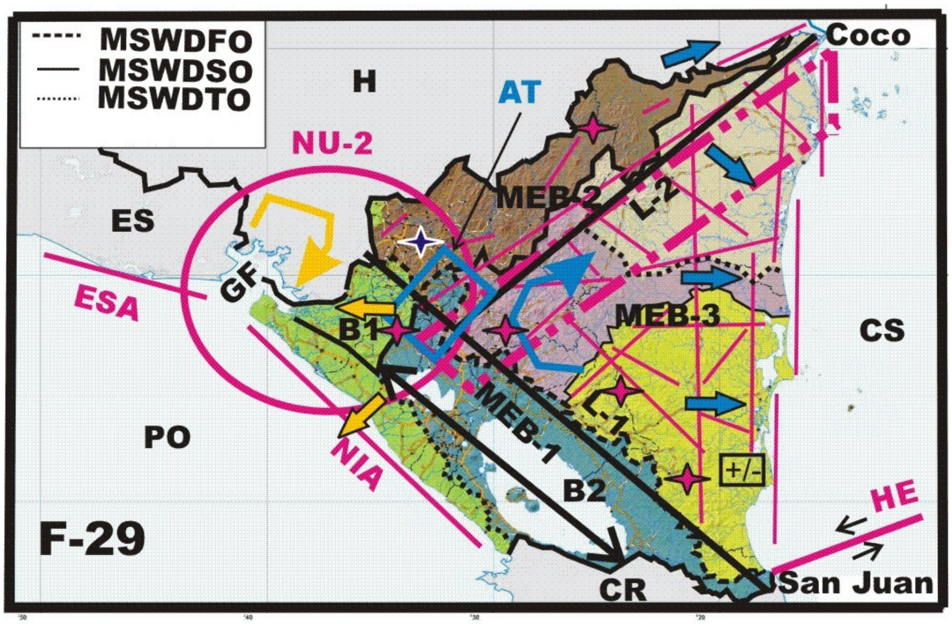


Figure 29. Preliminary morphotectonic diagram of Nicaragua.

Appear: **1)** AT=Abnormal turn of the main surface water divider (blue rectangle); **2)** Alignments (red line (HE=Hess Escarpment, NIA=of Nicaraguan Pacific, ESA=of El Salvador); **3)** Articulation knot (circle with acronym (NU-2) in red); **4)** Average direction of surface runoff to the: **4.1)** Caribbean Sea (blue arrow); **4.2)** Pacific (yellow arrow); **5)** Blocks (B1=Managua, B2=Nicaragua); **6)** Boundary of Mesoblocks (thick black line, and acronym L1); **7)** Countries (CR=Costa Rica, ES=El Salvador, H=Honduras); **8)** Main surface water divider of: **8.1)** First Order; **8.2)** Second Order; **8.3)** Third Order (see legend); **9)** Mesoblocks (MEB-1=Pacific, MEB-2=Norte, MEB-3=Caribe); **10)** Neotectonic uplifting area: **10.1)** intense (purple star); **10.2)** middle (red star); **10.3)** very weak or null (square with +/-); **11)** relative sense of rotation in the: **11.1)** Atlantic (blue curved arrow): **11.2)** Pacific (yellow arrow); **12)** Transversal deformation area (rectangle with dotted line and two red points); **13)** Volcanic Axis (black line with double arrow).

Table 23B. Main local morphotectonic data (Part 2).

	Drainage	Asymmetry	Basins	Ks (MDFO)	KsL (Coasts)
CR	Caribbean and Pacific	0,4	9/ 10	0,85	0,87/ 0,71
ES	Pacific	-	-/ 10	-	-/ 0,87
H	Caribbean	0,5	6/ -	0,45	0,81/ -
NI	Caribbean and Pacific	0,8	13/ 8	0,81	0,80/ 0,74
Panama	Caribbean and Pacific	0,4	18/ 34	0,52	0,40/ 0,41
		Total	46/ 62		

Notes: **1)** Asymmetry=Asymmetry of the surface basin; **2)** Surface basins at the: **2.1)** Caribbean; **2.2)** Pacific; **3)** Drainage=Basin surface drainage Caribbean/ Pacific; **4)** Ks=Sinuosity Coefficient of the Main Division Watershed of the First Order; **5)** KsL=Coastline sinuosity coefficient: **5.1)** Caribbean; **5.2)** Pacific.

4-SEISMOTECTONIC

“Hay quienes no pueden imaginar un mundo sin pájaros; hay quienes no pueden imaginar un mundo sin agua; en lo que a mí se refiere, soy incapaz de imaginar un mundo sin libros”.

Jorge Luis Borges (Argentina, 1899-Suiza, 1986)

4-SEISMOTECTONIC

For the introduction of this section, we have selected a set of seismotectonic results obtained for three countries in the Americas, which show high values of M_{max}: **1)** Chile (Madariaga, 1998)/ ≥9,0; **2)** México (Cotilla *et al*., 2019)/ 8,2; **3)** Perú (Tavera y Buforn, 1998)/ 8,6. A simple comparison of this information with the seismicity data presented in the preceding sections shows that the S-A in NI is lowest. We consider that the main studies on seismotectonics in CA and NI in particular are: Álvarez-Gómez (2010); Álvarez *et al*. (2018); Benito (2008); Bergoing and Protti (2009); Brown Jr. *et al*. (1973); Cruz (1999); Dewey *et al.* (1975); and Plafker and Brwon Jr. (1975). Based on these, the authors maintain the following elements as the main basis of the article: **1)** the morphotectonic study that supports the existence in Caribbean Plate of an active morphostructure (megablock CA-I), relatively independent, continental type, which includes the study area (**Figure 28**); **2)** the knowledge that seismic hazard levels have been shown to be comparable in ES, Guatemala and NI. This is because the main seismic sources are common and have similar characteristics.

In **table 24** a very simplified regionalization of seismic hazard in six countries is presented and **table 25** contains the main types of seismogenic structures of the region.

Table 24. Seismic hazard regionalization.

Country	Characteristics
CR	The greatest hazard is in the area around the Volcanic Chain (Nicoya Peninsula, Osa Peninsula and Punta Burica)
ES	The greatest hazard is in the coastal area, where the Volcanic Chain
Guatemala	The hazardr is: **1)** Minor in the Petén area; **2)** Major in the Pacific coast and decreases to the E; **3)** North Fault Zone System
H	The hazard is: **1)** Minor in the east; **2)** Major at the north (Guatemala) and in the west (where the Volcanic Chain of ES) and in the south where the Gulf of Fonseca
NI	The greatest hazard is in the area associated with the Volcanic Chain and decreases significantly at east and south
Panama	The greatest hazard is in the Volcanic Chain (Panama's Fracture Zone) and on the border with Colombia

Table 25. Structure and hazards.

Nº	Seismogenic structure	Hazards	
		Order	**Sub type**
1	Caribbean Plate [CP]	1	Tectonic (**1.1**- Earthquake; **1.2**- Volcano; **1.3**- Tsunami)
2	Province [SPR]	2	Surface area (**2.1**- Flood; **2.2**- Slope slide)
3	Unit [SEU]		
4	Seismogenic element (fault [F], alignment [AL] and knot [K])		

There are two relatively similar, but essentially different, point of views of the specialists on the Seismotectonic concept from: **1)** Northamericans (which studies the relationship between earthquakes, active tectonics and individual faults in a region); **2)** Russian (they make up a seismotectonic research framework in three main stages based on a selection of geological-geophysical indicators that lead to: **2.1)** preparation of a SMP; **2.2**) distinction and characterization of potential active seismic zones; **2.3)** development of seismic hazard materials. Among them are maps of seismogenic zones and origin of earthquakes, which in Western literature are equivalent to "seismotectonic corridors"). The Russian methodology was applied in Cuba (Cotilla *et al*., 1991) and Mexico (Cotilla *et al*., 2019). In this last work is their figure 6 with the three SPR and eleven SEU (1=North-Western (2); 2=Western (4); 3=Central Eastern (5)). The first two are narrow strips that follow Pacific coast line; while the third is the largest area and reaches Gulf of Mexico. It is ensured that the structures have a relationship and continuity with neighboring countries (north and south).

The North American model was applied for CA in: **1)** Guendel and Protti (1998) presented in their table 1 eight earthquake source zones (Polochic-Motagua, Coastal (Guatemala-ES and NI-CR), Volcanic (Guatemala-ES and NI-CR), Panama Fracture, and Intermediate (Guatemala-ES and NI-CR)); **2)** Benito (2008) proposes a set of five figures (3.4-3.9) with the Seismic Zoning (Regional and National). In them there are Seismogenic Zones: **2.1)** 31 Cortical or superficial (h<25 km); **2.2)** nine Inter plate (Subduction, h60 km); **2.3)** seven Intraplate (Subduction, h=5->60 km); **3)** Guardiola (2010) describes eight seismic zones (Subduction Zone (MAT), Volcanic Arc, Northamerican-Caribbean Plate Boundary, Faults and Deformation Caribbean Plate, H Depression, Guayape Fault System, and Hess Escarpment). While for H, Cruz (1999) assured that the main seismic sources are outside the emerged territory; but that the Central Depression turns out to be a primary source of S-A for CA and NI.

Taking into consideration what is expressed in the previous paragraphs, the main seismotectonic elements of NI are defined on the basis of the: **1)** features: **1.1)** tectonic environment; **1.2)** neotectonics; **2)** main tectonic elements; **3)** geographical spread; **4)** composition and configuration of the relief; **5)** seismicity (historical and instrumental); **6)** predominant focal mechanisms; **7)** structure of the lithosphere. Thus, the seismotectonic hierarchical structure of the territory has been established; and it has been determined that the region is different in relation to its immediate surroundings. **Tables 26 and 27** show data from the SPR of CA (**Figure 29**).

Table 26. Overall ranking.

Nº	Province	Countries	M_{max}/ $Depth_{max}$ (km)	Tsunamis / Volcanoes
1	Central America I	ES, Guatemala, H, NI	7,7/ 200	~40/ 53
2	Central America II	CR, Panama	7,6/ 100	~30/ 8
3	Mesoamerican Trench	Mexico-Panama	8,1/ 120	15/ >100
4	Volcanic Chain	Mexico-Panama	7,7/ 150	5/ 80
5	Interior Region	Guatemala-NI	7,8/ 120	-/ 10

Table 27. Regional seismogenic linear structure.

Order	Type	M_{max}
1	Plate boundary: **1)** Northern (Caribbean-Northamerican); **2)** Southern (Caribbean-Southamerican); **3)** Eastern (**3.1)** Caribbean-Cocos; **3.2)** Caribbean-Nazca); **4)** Western (Caribbean-Pacific)	<8,0
2	Limits and lines of weakness of the interior (faults: **1)** actives; **2)** potentially actives)	<7,0

The authors, based on the morphotectonic study consider that NI is an active Seismotectonic Unit mainly within the Caribbean Microplate. It is different from the neighboring territories and is in the SPR of Central America I. The Cocos and Northamerican Plates are the structures that directly affect it and generate the deformations, the S-A, and local tsunamis. Based on the above, we defined: **1)** SEU; **2)** seismogenic zones, included in the SEU (**Figure 30, Table 27**). Many of the areas have continuity in neighboring regions. The main features are in **table 28**.

Table 28. Main characteristics to Seismotectonic Province of Central America I.

Nº	Characteristics	Data
1	Identification	SPR of CA-I
2	Units [SEU]	Pacific (Mesoamerican Trench-Fore Arc, Volcanic Arc), Interior (Guatemala, Honduras, Nicaragua), North (Polochic-Motagua-Swan Fault System)
3	M_{max}	8,1
4	h_{max} (km)	190
5	Earthquakes USGS (**Table 10**)	64
6	Earthquakes USGS (M≥7,5/ ≥8,2)	4/ -
7	Type of seismicity	Intraplate (Caribbean) and Interplates (Caribbean-Cocos)
8	Maximum Intensity Value (MM)	X
9	Related large structures	5
10	Sources of tsunamis	Caribbean Sea and Pacific Ocean
11	H_{max} (m) of sea waves	10
12	Quantity/ Plates	3/ Caribbean, Cocos and Northamerican
13	Hazard level	Middle
14	Population (10^6 inhabitants)	~30
15	Fatalities by earthquakes	~60.000

DISCUSSION AND CONCLUSIONS

"El terremoto más fuerte del mundo es chileno".

Joaquim Barañao-Díaz
22.08.2017

DISCUSSION AND CONCLUSIONS

The seismotectonic study presented here for Central America, and NI in particular, forces to sustain a way of research different from the one used up to the moment (**Figure 30**). **Table 29** shows some works: **1)** that use other alternatives to seismic sources such as alignments, knots of alignments and seismic zones; **2)** all results are achieved by multidisciplinary teams; **3)** the research spans the period 1975-2020. They consider that areas of pre-existing tectonic weakness, in the interior of the plates, determine the earthquake occurrence. This is evidenced, for cases of: **1)** U.S.A. (Wesnousky and Scholz, 1980; Zoback, 2012); **2)** Mexico (Nieto-Samaniego *et al.,* 2012); **3)** Cuba (Cotilla-Rodríguez, 2017). Such hypothesis relates the crust heterogeneity with the spatial distribution of the seismic events in a stress frame by power transmission from remote sources (Wdowinski, 1998). In our case, **figure 7A** shows very well the transversal fragmented seismic activity.

Table 29. Alternative seismogenic references.

Regions	Year	References	Regions	Year	References
Armenian	1975	Zhidkov *et al.*	Russia	1990	Imaev *et al.*
California	1976	Guelfand *et al.*	Barents Sea	1994	Assinovskaya and Soloviev
Cuba	1983	Belousov *et al.*	Carpathians	2000	Gorshkov *et al.*
	1983	Krestnikov *et al.*	Romania	2000	Radulian *et al.*
	1991	Cotilla *et al.*	Italy	2002	Gorshkov *et al.*
	2011	Cotilla and Córdoba	Alpes	2004	Gorshkov *et al.*
Spain	1987	Gvshiani *et al.*	Hispaniola	2007	Cotilla *et al.*
	2010	Gorshkov *et al.*	Black Sea	2018	Novikova and Gorshkov
	2013	Cotilla and Córdoba	Mexico	2019	Cotilla *et al.*
			Grecia	2020	Gorshkov *et al.*

NI has two regional morphostructures as knots of articulation on the borders with El Salvador and Costa Rica. It also has another lower category knot in the vicinity of Managua. The three knots are related to the Nicaraguan Depression and show seismic activity. This is the first time that this structural type has been reported in Nicaragua.

The methodology applied and reflected in **Figures 2, 3, 3A2, 3A3, 3C, 3D, 4, 5B, 27, 27A, 28 and 29** allows us to distinguish the main set of lines of weakness, knots and zones. Obviously, each of the methods has a range and scale of validity. But, it has been demonstrated that the main areas and elements coincide. In this regards, the Pacific and Volcanic Depression alignments are the main morphostructures (first rank) and the transverse alignments are of second and third rank. All of them are segmented. The alignment knots in: **1)** the Triple Points in Costa Rica has a higher rank; **2)** the Gulf of Fonseca is of second order; **3)** the vicinity of Managua and Cerrón Grande (ES) have level 3.

We consider that Nicaragua can suffer strong earthquakes and tsunamis, with human and economic losses. For this reason, the presented regionalization holds that Central America is an extensive and complex Seismotectonic Province located, mostly, in the Caribbean Microplate and has two types of seismicity (interplate and intraplate). From this point of view, there is an active and interrelated hierarchical structure with Units and Seismogenetic Zones. It has become clear that its main seismotectonic elements have a continuous relationship with other neighboring countries, such as Costa Rica, El Salvador and Honduras. Also, it is confirmed that the Depression (Gulf of Fonseca-Costa Rica) is the area of greatest seismic hazard in Nicaragua.

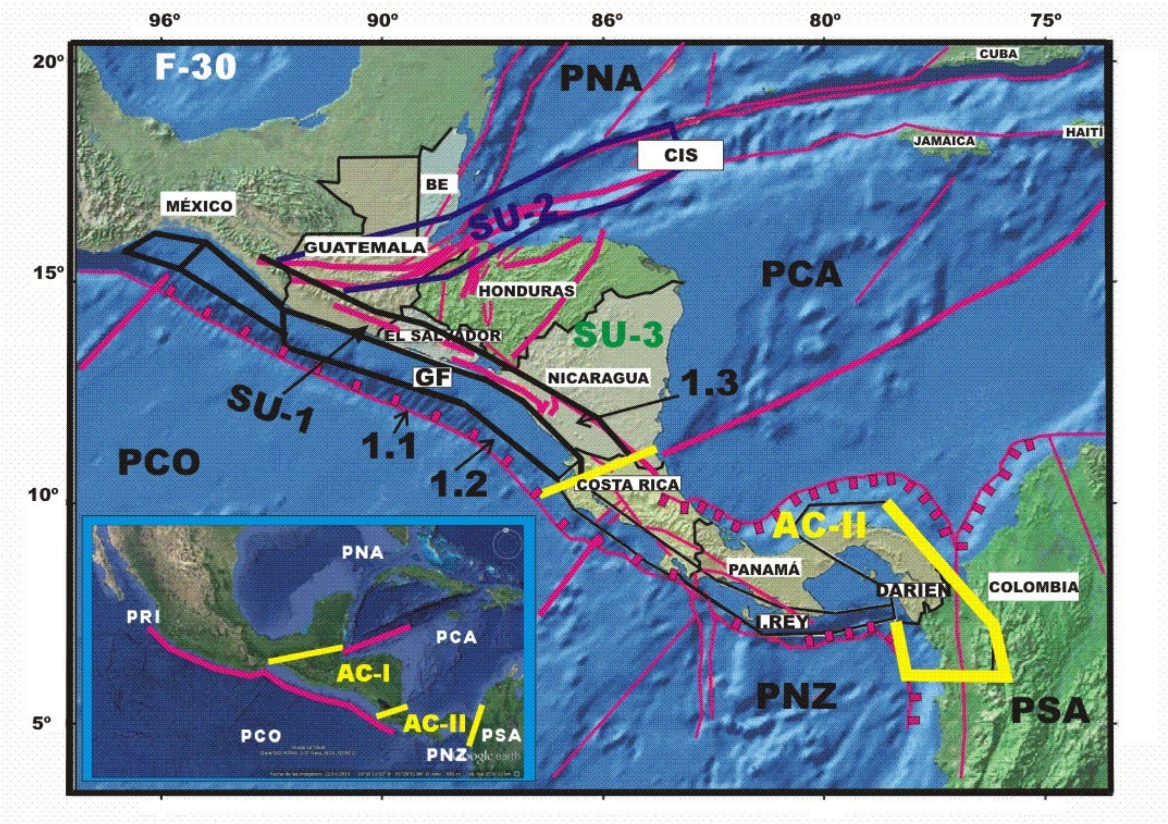


Figure 30. Seismotectonic model of Nicaragua.

Appear: **1)** Boundaries of Seismotectonic Provinces (yellow line); **2)** Faults (red lines); **3)** Plates (PCA=Caribbean, PCO=Cocos, PNA=North American, PNZ=Nazca, PSA=South American); **4)** Seismotectonic Provinces (AC-I, AC-II (in yellow)); **5)** SU=Seismotectonic Units (SU-1=Pacific (in black), SU-2=North (in purple), SU-3=Interior (in green)); **6)** Sub Units (1.1=Mesoamerican Trench, 1.2=Fore Arc, 1.3=Volcanic Arc).

Other conclusions are: **1)** Central America is a territorial unit with two distinct segments: Central America-I (El Salvador, Guatemala, Honduras and Nicaragua) and Central America-II (Costa Rica and Panama) (**Figure 30**). The boundary is located between Nicaragua and Costa Rica. These Units are defined by the interaction of the plates; **2)** the highest altitude areas in Central America are at their north (Guatemala=4.220 m) and south (Costa Rica=3.820 m) extremes. They are linked to a single Main Division of First Order of the surface drainage network, in a straight N-S direction and a Ks of 0,77; **3)** the strong seismic activity of Central America is characterized for being of distributed and self-organized type so that an asymmetric transference of stress can be appreciated that favors the configuration of the main forms of the relief; **4)** the morphotectonic regionalization shows that the figure delimited for Central America has a triangular shape, with six blocks, four knots and eight alignments (of first order) with relative movements of clockwise and counterclockwise rotation; **5)** the most active structure in the Central America-I segment is

Guatemala; **6)** Honduras and Nicaragua are two macroblocks with different geometric shapes and with the following elements: Mesoblocks (H (3)/ NI (3)), Blocks (H (12)/ NI (11)), Alignments (H (13)/ NI (23)) and Knots (H (18)/ NI (19)); **7)** El Salvador and Nicaragua have more seismic activity than Honduras; **8)** local tsunami zones of Honduras (two to the north and one to the south), Nicaragua (to the south); **9)** Honduras has in the contemporary plane a zone of change of direction of the transverse drainage (N-S) that connects with Gulf of Fonseca; **10)** it is confirmed that the capitals (Costa Rica, El Salvador, Guatemala, Honduras, and Nicaragua) are located at areas of greatest seismic hazard; **11)** AC-I has lower seismogenerator potential (earthquakes and tsunamis) than Mexico and Peru-Chile.

Finally, from the humanitarian point of view, all highly developed societies in the world have a moral obligation to help Nicaragua, among other things, in earthquake disaster prevention and recovery plans.

ACKNOWLEDGMENTS

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"Saber para prever. Y prever para proteger".

Pilar Gallego

LYCHNOS, Cuadernos de la Fundación General CSIC, No. 4, 2010

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"San Francisco is devasted".

Los Angeles Herald, 1906

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“Comienza haciendo lo necesario; luego haz lo posible y de repente estarás haciendo lo imposible”.

Francisco de Asís (Italia, ¿?-1226)

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"Cada vez que enseñes, enseña a dudar de aquello que enseñas".
José Ortega y Gasset (España, 1883-1955)

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Acronyms

ALT= Alignment Tisma
CA= Central America
CA-I= Central America-I
CA-II= Central America-II
CLVD= Compensated Linear Vectorial Dipole
CMT= Centroid Moment Tensor
CR= Costa Rica
ES= El Salvador
H= Honduras
HES= Honduras + El Salvador
IGA= Instituto de Geofísica y Astronomía
INETER= Instituto Nacional de Estudios Territoriales
IRIS= International Research Institute of Seismology
ISC= International Seismological Centre
MDFO= First Order Main Watershed
NI= Nicaragua
PTT= Triple Tectonic Point
S-A= Seismic activity
SEU= Seismotectonic unit
SMP= Seismotectonic map
SPR= Seismotectonic province
TU= Tectonic unit
U.S.A.= United States of America
U.S.G.S.= U.S. Geological Survey

Note: In the tables and figures there are other abbreviations.

"A different language is a different vision of the life".
Federico Fellini (Italia, 1920-1993)

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"Las acciones de los hombres son las mejores intérpretes de sus pensamientos".

James Augustine Aloysius Joyce (Irlanda, 1852-Suiza, 1941)