

HISTORICAL SEISMICITY OF THE NORTH PANAMA DEFORMED BELT

Eduardo Camacho^{1,2)} and Vilma Viquez¹⁾

¹⁾Instituto de Geociencias, Universidad de Panama, Panamá, R., de Panamá

²⁾Departamento de Física, Universidad de Panama, Panamá, R., de Panamá

ABSTRACT: In this study we have reviewed original documental sources and interviewed old persons with the purpose of better assess the seismic potential of the North Panama Deformed Belt.

Based on the found seismicity pattern we have subdivided this region into three main segments: Eastern, Central and Western. The Western Segment is also subdivided into two subsegments: western and eastern. The Western subsegment has been shaken by strong events in 1798, 1822 and 1904. Large events from this subregion are apparently accompanied by coastal vertical ground deformation. The Eastern subsegment has been shaken by strong events in 1910, 1916 and probably in 1867.

The Central Segment, which extends from 81.4°W to 80.0°W, shows an absence of large historical events.

The Eastern Segment has been shaken by strong events in 1879, 1882, 1909 and 1930.

Large events from the Panama Deformed Belt usually cause local tsunamis.

RESUMEN: En este estudio se han revisado fuentes documentales originales y entrevistado a personas mayores con el propósito de evaluar mejor el potencial sísmico del Cinturón Deformado del Norte de Panamá.

Con base en los patrones de sismicidad encontrados se ha subdividido este cinturón en tres segmentos principales: Oriental, Central y Occidental. El Segmento Occidental se ha subdividido a su vez en dos subsegmentos: el Oriental y el Occidental. El Subsegmento occidental ha sido sacudido por eventos fuertes en 1798, 1822 y 1904. Los eventos grandes del Subsegmento Occidental aparentemente están acompañados por deformación vertical de la costa. El Subsegmento Oriental ha sido sacudido por temblores fuertes en 1910, 1916 y probablemente en 1867.

La zona Central, que se extiende de 81,4°W a 80,0°W, muestra una ausencia de sismos históricos grandes.

La zona Oriental ha sido sacudida por eventos fuertes en 1873, 1882, 1909 y 1930.

Los eventos grandes del Cinturón Deformado de Panamá producen usualmente tsunamis de tipo local.

INTRODUCTION

Until few years ago the North Panamá Block region was considered with a low seismic potential. With the exception of the earthquake of September 7, 1882, $M_s = 7.9$, very little is known about the seismicity and tectonics of this region.

The purpose of this paper is to summarize the seismic history of the North Panamá Deformed Belt (NPDB) to attempt, on the basis of the written evidence prior to 1930, to assess the seismicity of this region.

TECTONIC SETTING

The Isthmus of Panamá is located on a microplate called the Panamá Block (KELLOG et

al., 1985). This block is surrounded by four major tectonic plates: the Caribbean plate to the north and the west, the Cocos plate to the southwest, the Nazca plate to the south, and the South American plate to the east. The northern boundary is conformed by a submarine fold and thrust belt known as the North Panamá Deformed Belt (BOWIN, 1976; CASE et al., 1980; LU & MCMILLEN, 1982; BOWLAND, 1984; STEPHAN et al., 1988; SILVER et al., 1990).

The North Panamá Deformed Belt extends offshore with an arcuate shape from the Gulf of Urabá in the Panamá-Colombia border up to the shore northwest of Puerto Limón in Costa Rica. This overthrust boundary, which has originated from the convergence between the Caribbean Plate and the Panamá Block is not a subduction

zone (ADAMEK et al., 1988). STEPHAN (1988) and SILVER et al. (1990) have proposed that the deformation of the Panamá Block has caused this wide belt of folds and thrusts north of Panamá, which are not associated with a Benioff zone or an active volcanic arc. According to these authors this deformed belt can be explained by a movement of blocks in the Caribbean plate.

The eastern portion of the NPDB shows a more regular pattern of thrust deformation than the western part which shows rapid changes in structural style and thrust vergence, probably due to variations in sediment thickness, crustal structure and convergence velocity (SILVER et al., 1991). In the western part near 81.4°W the trend of the fold belt changes from almost east-west to northeast. According to BOWLAND (1984) the deformation front along the northeast trending segment of the deformed belt is not defined by a thrust fault, but by the first antiform of the fold belt.

Until the April 22, 1991 event, the eastern portion was thought to be more seismically active than the western segment. The events of this zone are dip slip, mainly of the thrust type, as has been demonstrated among others by WOLTERS (1986), MacCAFREY (personal comm., 1986), and ADAMEK (1987).

SEISMIC HISTORY

The Caribbean coast of Panamá, with the exception of the trans-isthmian region, was very thinly populated (ROBERTS, 1827) until the mid Nineteen Century. It was not until the second half of the last Century, when the tropical products trade, mainly bananas, started and the plantations began to develop, principally around the Laguna de Chiriquí and the Bocas del Toro Archipelago. The population of this region grew, receiving immigrants mostly from the West Indies and some from Europe, Colombia and Central America. This makes very difficult to study the historical seismicity of the region, because the documental sources are very scarce and the time span covered by them is too short.

In the following pages there is a description, taken from original sources, of seismic events in the Panamá Caribbean Region and surroundings, which have been strongly felt or caused damage from 1798 to 1930. Whenever possible, the location and magnitude has been estimated by the authors. To calculate the magnitude of most of the events up to 1909 we employed an empirical magnitude to intensity conversion formula for the Panamá Block (ACRES, 1982):

$$I_0 = 1.58 M_s - 3.00 \quad (1)$$

Where I_0 is the maximum intensity, and M_s is the surface wave magnitude.

For the events from 1909 to 1930 CAMACHO (1991) BHP duration magnitude formula was used:

$$M_s = 0.847 \log t - 0.003 D + 4.895 \quad (2)$$

Where M_s is the surface wave magnitude, t is the duration of the event in seconds, and D the epicentral distance in kilometers.

When the seismic parameters come from other sources the reference is included in parentheses.

A listing of all these events appears on Table 1 and the corresponding map with the spatial distribution of these historic epicenters is on Figure 1.

1798, FEBRUARY 21, 7:00-8:00 p.m., 10.2°N, 82.9°W

According to GONZALEZ VIQUEZ (1910) the Lieutenant at Matina, Costa Rica, sent a note to Governor Acosta on February 22, 1798 which says: "Last night between 7 and 8 a strong sound coming from the sea left in horror most of the inhabitants of this village. Six to eight minutes after this terrifying sound the ground started to shake"....." Added to this the sea became turbulent, right from the moment the quake started, in such a manner that seems it is going to swallow us all. Due to the fact that this land is easy to flood and the terrain so contemptible me and all the dwellers of this village have decided to leave for high ground"

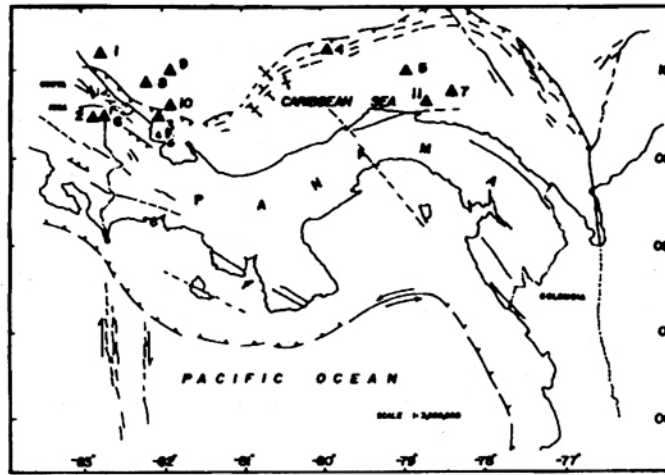


Fig. 1: Distribution of historical events epicenters, from Table 1, along the North Panamá Deformed Belt.

Table 1
Earthquakes in the Panama deformed Belt from 1798 to 1930

Date	Loc. Time	Lat. N	Long W	Ms	Observations
1798/02/21	7-8:00 p.m.	10.2	82.9	-	Tsunami
1822/05/07	1:30-2 a.m.	9.5	83.0	7.5-8.0	Tsunami
1867/11/26		9.5	82.2	-	-
1873/10/03	6:05 p.m.	10.2	80.0	-	-
1882/09/07	3:18 a.m.	10.0	79.0	7.5-8.0	Tsunami
1904/12/20	12:00 p.m.	9.5	82.9	7.2 (ABE)	-
1909/08/30	8:02 a.m.	9.8	78.4	6.1	-
1910/12/21	10:24 p.m.	9.8	82.3	6.5	-
1916/04/24	3:03 a.m.	10.0	82.0 (DUDA)	7.3 (G-R)	-
1916/04/25	9:30 p.m.	9.6	82.0 (V-T)	6.9 (DUDU)	Tsunami
1930/03/7	10:45 p.m.	9.67	78.83	6.2	-

1822, MAY 7, 1:30-2:00 a.m., 9.5°N, 83.0°W, Ms = 7.6

This event has been previously studied by MONTERO (1986a; 1986b; 1989). He estimated a minimum surface wave magnitude of 7.5 for this event and located its macroseismic epicenter at 8.5°N, 83.0°W., in the Osa Seismic Region in the southwest coast of Costa Rica. NISHENKO (1991) has also proposed that the epicenter of this event is in the Osa Seismic Region.

MONTERO & GONZALEZ (1990) suggest that the epicenter of this event is located in the Caribbean region of Costa Rica. In a more

recent study MONTERO et al. (1991) also affirm that historical accounts suggest that this event is similar to the Limón Earthquake of April 22, 1991, which occurred in the southeast Caribbean region of Costa Rica, near the Panamá border.

According to GONZALEZ VIQUEZ (1910): "Raimundo Calvo declared to the City Council of Cartago that in Matina three violent shocks were felt, as no neighbor remembers to have ever felt; that the shakes lasted almost with no interruption for twenty four hours; that the ground cracked in several sites, leaving deep fissures from which salty water and black sand erupted; the rivers and bays grew and caused

floods and the neighbors decided to leave for Cartago; at Hondo River, near Matina they met Father Don Tomás Prieto, who once informed on the earthquakes took all the people to Pacuare River...(.) the tremors lasted several days, because on May 15 the Cartago City Council declares that due to the ruin of the City Hall in the morning of the seven it was necessary to freed the criminals and other inmates of the jail, because the earthquakes has not ceased (...) in September of the same year the Major of Ujarrás asked permission to take the timber and the tile from the ruined church to built a new ermit to Our Lady of the Rescue (...) on 1829 the Prefect of Missions Friar Pedro Moreno requested from the Executive permission to rebuilt the church of San Francisco de Térraba, which was destroyed by the May 7, 1822 earthquake (...) in Cartago as well as in this capital it caused great damage, because there it ruined many houses and walls, which the authorities almost immediately order to be demolished (..)in this instance as in different others it is referred to del Dragón, and this name is almost unknown today among us, I could mention that this name was given to the highest peak of Dota south of Aserri."

This last commentary is important because Drago or Dragón was the name given by Christopher Columbus, in 1502, to the western passage to Almirante Bay, between Tiribí and Lime Points. Colón Island, the westernmost island of the Bocas del Toro Archipelago, is also known as Drago Island (GUTIERREZ, 1991). And in narratives and maps of the XVII and XVIII centuries (WAFER, 1681; HACKE, 1710) the north-western region of Panamá is referred as Boca del Drago o del Toro.

FERNANDEZ GUARDIA (1937) reports: "Our Lady of the Conception had her sanctuary in the town of Ujarráz.....this beautiful temple was built by the Governor Don Miguel Gómez de Lara at the end of the XVII Century and its ruins, caused by the 1822 earthquake, can be admired today in the beautiful valley".

A chilean newspaper EL MERCURIO DE CHILE (1822) reproduces a letter by Father Atanasio García, from Cañasas in the Republic of Gran Colombia who reports on a strong earthquake in the Isthmus of Panamá: " On May 6 of

the current year around 1:30 p.m. an earthquake never felt before even by the oldest neighbors terrified the inhabitants of the Town of San Francisco Xavier de Cañasas, jurisdiction of the Province of Veraguas, and surrounding villages (..) it even moved the boulders of the rivers near the house (..) the inhabitants could not stand on their feet, because the earth waves were like those of the sea (..) they stayed lying on the ground (..) the house was bended and cut by half by a crack which crossed the house and extended to the backyard, as when a strong summer cracks the ground with very deep fissures.

The church built in the year 20, next day resulted cracked in three parts and its tower lost all its roof, which collapsed and the arch at entrance of the temple had considerable fissures."

ROBERTS (1827), a british privateer who lived among the indians of the Caribbean coast of Panamá from 1817 to 1822 was near the epicenter area at the time of the event and reported the following: " On the night that this event took place, I was in an indian house at *Monkey Point (Punta Chica)*, and had an opportunity of witnessing its effect on that part of the coast. About the middle of the night in question, I found the frame of the wicker bedstead on which I slept, shaken with very great violence; supposing that it was either my companion (one of the traders), or some of my Indian friends who wished to frighten, or awaken me suddenly, I rather angrily demanded, whether they meant to shake me to pieces? In a few seconds, however, the screams of the women, and the cries of the men, in the adjoining huts; together with the rolling motion of the earth, which was twisting the hut in all directions, put an end to my suspense. I instantly ran out of the place to the open air; and, although scarcely able to keep upon my feet from the rolling and trembling motions of the earth, I observed such a scene as will never to the last hour of my existence be erased from my memory. The ground under our feet seemed to heave convulsively, as if ready to open and swallow us, producing a low terrific sound; the trees, within a short distance of the huts, were so violently shaken from their upright position, that their branches were crashing, and their trunks griding against each other.

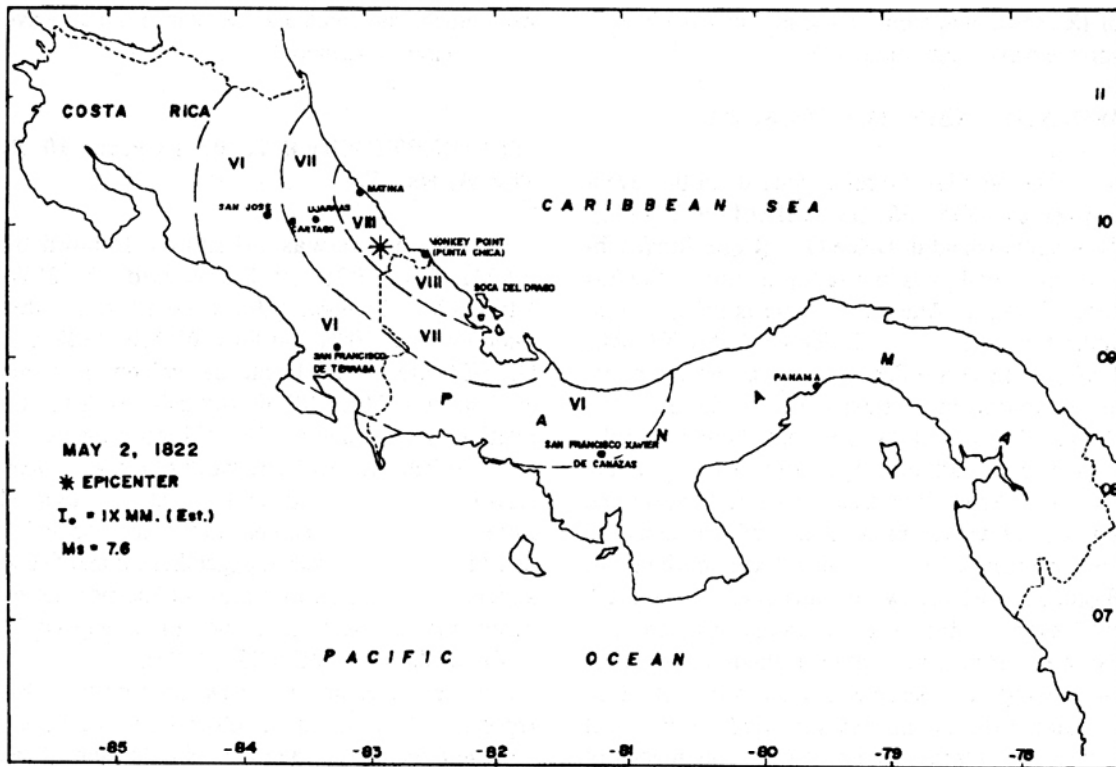


Fig. 2: Macroseismic map for the May 7, 1822 event. The proposed epicenter is indicated by a black star.

The shocks gradually became less violent; and, towards daybreak, had entirely subsided. No lives were lost here, or at the other Indian settlements, in the neighborhood, but the ground appeared rent in various places, the sand on the beach was either raised in ridges, or depressed in furrows; a place, in which several canoes were floating, was now become quite dry; most of the huts were violently cracked and twisted; and the effects of the earthquake, were everywhere visible.

The only persons in the neighborhood not frightened by this event, were a trader, and some of his indian friends, who were so intoxicated at the time it happened, that, until next morning, they were not aware that any extraordinary occurrence had taken place. They had a confused recollection that a puncheon of rum, which was in the hut, could not be kept from rolling on the floor; but whether some person was trying to steal it from them, or it was endeavoring to run away of its own accord, they could not, at the time, determine."

Monkey Point is located by Roberts as follows: "From the Tiribí River to Monkey Point (Punta Chica) the last headland in the Province of Veragua the distance is not more than eight or ten miles. It is easily known by a remarkably bluff rocky islet, distant only a few yards from the mainland."

We think it is worth of note to mention that Roberts also refers to a sandy bay between the Snake River and the Grape Cay, before the 1822 earthquake. According to VALDEZ (1898) the Snake River is the one located between Cahuita Point and Mona Point and marks the boundary between Colombia and Costa Rica. If we look an older colombian map (PONCE DE LEON & PAZ, 1864) we observe that between this river and Mona Point there is not a Grape Cay at all, but there is a Grape Point. This would may indicate the possibility that in this coast occurred coseismic vertical deformation on May 1822.

An isoseismal map for this earthquake is on figure 2. We estimated an epicentral intensity I_0

of IX MM., and from this value we calculated a surface wave magnitude of 7.6.

1867, NOVEMBER 26, 9.5°N, 82.2°W

The only known references about this event is given by MONTESSUS de BALLORE (1888): "Zapodilla Island in Dulce Gulf (Costa Rica) subsided in several parts and strong tremors shake this zone of Central America". There is not an island under this name in the Dulce Gulf (MONTERO, 1989), but there is a Zapadilla Island few kilometers to the southeast of Bastimentos Island, in the Chiriquí Lagoon, Bocas del Toro Province, in the Republic of Panamá. According to Mrs. Ligia Thomas de Paget, from Bocas del Toro City, she and a group of divers from the U.S. Southern Command visited these keys, located 4.0 km southeast of Bastimentos island, two months after the April 22, 1991 event, and noticed that the beaches are now narrower and in some parts have almost disappeared. Other divers have observed that the coral reef which surrounds the island has subsided several feet (AVERZA, personal comm., 1992). This reports of partial subsidence at Zapadilla Island, after the 1991 event, may also suggest that 1867 event occurred in the Caribbean instead than in Dulce Gulf, near the southern Costa Rica-Panamá border.

1873, OCTOBER 13, 06:05 p.m., 10.2°N, 80.0°W

This event was reported by the PANAMA STAR & HERALD on October 16, 1873: "In this city (Panamá City) the shock was strongly felt about 5 minutes past six, the night being dark and sky overcast. It was felt on board the ships in the harbor, along the line of the railroad and at Aspinwall (Colón). A correspondent writing from San Pablo, one of the stations, says: "We had two pretty severe shocks with an interval of but a second or two between them. The second shock was most severe and accompanied by rumbling sound resembling thunder. A man who happened on the Barbacoas bridge at the time, says the vibration was so great that he was afraid the bridge would give away". In Aspinwall... have been more severely felt than in Panamá. The people there

were much frightened and the fear of a tidal wave added to the excitement".

1882, SEPTEMBER 7, 03:18 a.m., 10°N, 79.0°W, Ms = 7.9

This event was originally located by RAMIREZ (1976) at 8.5°N and 76.2°W. VIQUEZ & TORAL (1987) have located this same event at 10°N and 80.4°W. MENDOZA & NISHENKO (1989) locate the epicenter of this earthquake at 10°N, 78°W, and using IDA (1983) relation estimate a Ms = 7.8-8.0 for this event.

At Panamá City "The shock began very weak slowly increasing for about 45 s., as was observed from the instrument records, so that the population had enough time to wake up, get dressed and flee to streets..... Next morning most of the population deserted the city and stay in the surrounding savanna for ten days." (CERMOISE, 1886).

The Prefecture of the Department of Colón reports: "Great damage is observed in the houses built with materials, up to the point that some have been left useless, as well as in many of the houses built out of timber. In the Railroad street from the house of Bostos Ju C. up to the Railroad Offices great fissures have open, but is important to point out that the parts that have subsided are the sections less consolidated of the town" (A.N.P., 1882a). The Major from Donoso, in the lower coast of Colón, reports to the Governor on September 11, 1882 that: "around 4:00 a.m. of today have occurred in this town an earthquake, which has caused great damage to most of the inhabitants, destroying completely eleven dwellings and leaving in all parts of the village cracks up to 36 cm wide and craters everywhere, from which water springs, the height of a house, erupted. Despite the fact that the collapsed houses trapped all their dwellers, this did not caused any casualty.

This Office has also learn that a person from Río Indio have informed of damage there and at Govea similar to what happen here. But there are no report of personal casualties.

It has also been informed that at Portobelo on the same day there were strong shakes, which caused damage to the walls of the Church, the

ruins of the Spanish Customs, and cracks in several parts of the town.

At the village of Río Indio two fresh water lagoons near the coast dried up almost immediately and kind of several sandy islands were formed in their former bed." (A. N. P., 1882a)

At Gatun " Three old and valueless ranches fell A beam from one of them struck and instantly killed a poor woman who was asleep ." (STAR & HERALD, 1882).

CANELLE-AILLARD (1882) reports that the church of Las Cruces, built of stones and with a tile roofing, collapsed. According to NELSON (1971) a photograph of the church ruins was taken by a worker of the French Canal Company.

At San Miguel Island in the Gulf of Panamá the Major reports: "most of the damage was caused in the church and in the house of the subscriber" (A. N. P., 1882b)

At Penonome the event "caused damage to the newly rebuilt church tower, two houses collapsed and many suffer damage....people abandoned their dwellings in panic". (A. N. P., 1882c)

"Letters have been received from the towns of La Villa, Chitré, Macaracas and Nata, all in this State, announcing that several shocks have been felt, but that the material of which the houses are built -bamboos and adobes- resisted the movement and have suffered no damage."....." At La Villa (Los Santos) the bells in the church rang several times" (STAR & HERALD, 1882).

A report from Darién, near the Colombia border, says the following: " There is no house in any of this region towns and villages that has not collapsed" (A. N. P., 1882b).

From David, near the Costa Rica border, the following was reported:" The earthquake that occurred on September 7, 1882 at 3:35 a.m. lasted approximately one minute..... Here, we do not have any damage to regret, because the shake was very slow and gentle." (A.N.P., 1882d)

According to MONTESSUS DE BALLORE (1888) and RAMIREZ (1976) the following effects were observed in Colombia: craters and sand volcanoes appeared at Río Sucio, in the Atrato river banks, and sandy warm water springs flooded parts of the town of Turbo, in the Urabá Gulf.

The Panamá City daily El Cronista reports:" Horrible earthquake, the City Hall has no facade, the frontal part of the Cathedral damaged, some victims, approximately \$ 200,000 in losses. The railroad traffic has been interrupted. In the eighty or ninety seconds that the tremor lasted.....".

According to GRASES (1974), Fuchs wrote: "At 3:18 a.m. on September 7 a great earthquake in Panamá City lasted almost a minute. The widest city walls cracked and many fell down. The tile fell from the roofs of the buildings and the streets were full with rubble. There was great damage to the Cathedral. The City Hall lost its facade and there were several deaths.

Weaker shocks were felt at 5:20 a.m. Another one at 11:20 a.m. and in the afternoon at 2:15 and 4:19 p.m. The shocks followed during the whole evening and some more ruins collapsed. The shocks were also felt by the ships at the ports and it is believed that some got cracks. There was no tsunami. The earthquake was felt in the bay island and the cable to the West Indies broke. The railroad tracks suffer great damage. The shocks came from the NE to the SW, and apparently there has never been an earthquake such a strong like this before. In Aspinwall (Colón) the railroad company warehouses were destroyed ".

MC CULLOUGH (1979) refers the following " The damage caused by this earthquake to the railroad tracks was very great. In some parts the railroad causeway subsided up to 3.0 m and the rails were kink or broken. At Colón a crack of almost half a meter wide opened near the cargo deposits and extended for more than 30.0 m along the Avenida del Frente. Next morning, before dawn there was another violent shock and this second time the panic was greater among the population. There were many landslides and at least five people got killed.....

The repair works for the railroad took almost a week. The cable communications to Jamaica and the United States was not reassumed until one month later."

NELSON (1971) gives the following description in his book: "... My bath tub had been partially filled with water the night before for my morning bath. The oscillation of the building had thrown a part of its contents over the floor, bottles

were knocked down, others were broken, and the ceiling and walls were cracked. In parts of the former had fallen. The wall of that strong building at the back, where it was fully two feet thick, showed a crack of nearly two inches. ...the tiles on the house came down in a perfect shower.... The upper part of the wall, marking the front of the facade of the Cathedral, had been shaken into the plaza; huge masses of masonry had fallen down upon the stone steps in front of the old building, breaking them and driving them into the earth. The Cabildo, or town hall, was wrecked. The lower part was a cloister of the old time Spanish type, with columns and arches. Above there had been another series of arches giving a front balcony with its roof. The latter with the columns had been thrown into the plaza, and many of them were broken into fragments, while a part of the main roof of the building had been shaken down and off. Its front was wrecked. The Canal company's building, while it showed no visible damage, was badly cracked, and a repetition of a shock of equal intensity probably would have thrown part of it down. As soon as a little daylight came in, it was found that the arches of the Cathedral had been badly damaged..." There was a vast deal of damage done in the city; walls had been thrown down, and there had been some accidents..... The cable of the West India and Panamá Telegraph Company from Colón to the West Indies, and thence to Florida in the States, had been broken..... Some people came over to Panamá from the Colón side, and then it was that we learned that the shaking in Colón had been even worse than on our side. From the city of Colón to Baila-Mono the Panamá Railroad had been rendered almost useless. In places the road-bed had sunk; in others it was completely thrown out of line, and for two and twenty miles this condition of things obtained. The long bridge, of over 600 feet, at Barbacoas was thrown slightly out of line When daylight came upon the scene in Colón, it was found that a great rent crossed the island from near the substantial stone freight sheds of the Panamá Railroad Company right along the front street to the earthen embankment connecting the island with the main land. Later on a fissure was discovered running along the right bank of the Chagres. It was traced some three miles and varied

in breadth from several inches to a mere crack, closing below in abysmal darkness".

This event caused a tsunami which affected the San Blas coast, northeastern Panamá, with waves 3.0 m high or more. These waves wash most of the islands of the San Blas Archipelago out, which remained submerged for several minutes. Between seventy five and one hundred natives were drowned (NELSON, 1971; CABALLERO, personal comm., 1991). Unfortunately the mareogram, of the French Canal Company tide gauge at Colón, with the record of the tsunami, is lost.

An isoseismal map for this earthquake is on figure 3. We have estimated an epicentral intensity I_0 between IX and X MM., and from this values we have calculated a surface wave magnitude of 7.9 for this event.

1904, DECEMBER 20, 12:01 p.m., 9.5°N, 82.9°W, $M_s = 7.0$

This event was instrumentally located by GUTENBERG & RICHTER (1954) at 8.5°N and 83.0°W, in the Osa Seismic region near the southwest coast of Costa Rica. MIYAMURA (1980), MONTERO (1986a), and NISHENKO (1991) have also located the epicenter of this earthquake in the Osa Seismic region.

The magnitude of this event estimated as $M_s=7.75$ by GUTENBERG & RICHTER (1956), and $M_s = 8.3$ by RICHTER (1958) has recently been found to be overestimated. ABE & NOGUCHI (1983a) has estimated a $M_s=7.2$ for this earthquake and more recently DUDA (1990) assigned a $M_s=7.35$ to this event.

From newspaper reports and other Costa Rican documents BOSCHINI (1989) has studied the intensity distribution for this event and proposes that the macroseismic epicenter of this event coincides with the instrumental epicenter proposed by GUTENBERG & RICHTER (1954).

Pittier in GONZALEZ VIQUEZ (1910) refers to this event as follows: " Since the earthquakes of 1888-1889 the event of December 20, 1904 and January 1905 have been the most intensely felt in Costa Rica.....

The data on the event of December 20, 1904 is very imperfect. The seismographs at San José

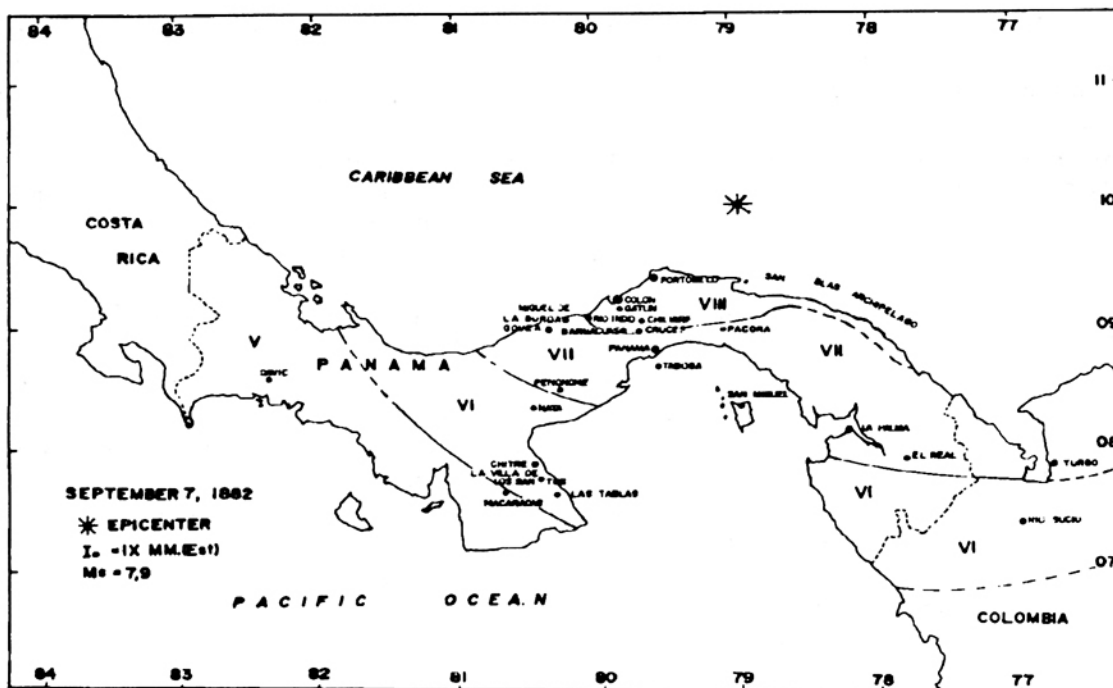


Fig. 3: Macroseismic map for the September 7, 1882 event. The proposed epicenter is indicated by a black star.

Observatory were in bad shape and did not work..... The area covered by this phenomenon was beyond the borders of the country, with the strange circumstance that the shakes were stronger at Limón and the Atlantic coast than in the Western approaches of the Cordillera Madre. At Limón I have estimated the total duration in 21 s., and the oscillations were of such a strength that even persons of phlegmatic character became scared when they saw the houses oscillating. Along the perimeter of The United Fruit Co. Building and at a height of two thirds its elevation a crack opened. At the interior of the country the earthquake was apparently less intense, but strong enough to open fissures in some buildings and scare the public “.

COLVERT (1917) reports that on May, 1909 during a chat with a medical doctor, who first came to Puerto Limón in the early 1904 he learned that: “Near the hospital the coast consists of a coral rock which forms cliffs, reaching a height of a hundred feet in some places, and flat reefs which are washed by the tide. Dr. Echeverría thinks the reefs are still forming, as a certain reef now visible, although awash, was not so when he first came to the hospital.”

In an interview with Mr. Agripino Caballero of Boqueron, Chiriquí, southwestern Panamá and born in March 11, 1892, we learn that this event “was strong and felt by everybody scaring many people, but it did not cause damage. I heard that up in the mountains, near the border with Bocas del Toro some bamboo and palm tree dwellings fell down”.

The STAR & HERALD (1905), of Panamá City, reports that: “during the last week of december, several shocks of earthquakes, more or less severe, were experienced in the city of David, capital of the province of Chiriquí.(...)the subterranean convulsions did not originate in this country, but in the neighboring Republic of Costa Rica, where did some damage and caused a great deal of consternation among the inhabitants.” (Until August 1921, the region east of the Coto-Colorado River was under panamanian authority and Coto constituted the westernmost district of Chiriquí, GARAY 1921).

The Limon Weekly has the following account; at midnight on Monday the entire city was thrown into a state of alarm by a very severe shock of earthquake, the like of which had never been

The oscillation was from north to south and its duration over forty seconds. It commenced with a slight motion which increased gradually, then partially subsided, and once more increased with redoubled force. About three minutes after, another and milder shock was felt.

Several private houses, and shops suffered... At the United Fruit Co. the water in the tanks was thrown out with considerable force.(,,)

The water tanks on the roof of Mr.C.V Lindo's residence emptied a good portion of their contents, flooding the lower portion of the house. It is satisfactory to note that Messrs Lind's two substantial concrete buildings..... stood the severe test admirably.

A slight shock of earthquake was felt in Limón at 7:58 Tuesday night and another at 4:00 a.m. Wednesday morning.

The earthquake on Monday night was felt in Bocas del Toro, where it is said the shock was very severe.

The Noticiero brings the following paragraphs: The citizens of San José passed the greater part of the night in the streets. In Cartago the shock was very severe, and no one attempted to sleep or even return to their dwellings,.... In Heredia the alarm was very great, and in Alajuela the citizens were panic stricken. News received from San Juan reports that four houses were seriously damaged. (..)

News from Escazú report that the Church bell tolled twice during the shock.

"By wireless telegraph we learn that the earthquake was very severe in Bocas del Toro and many houses suffered damage. The United States warship DIXIE at anchor there reported by means of her wireless apparatus that the shock was severely felt on board and the crew alarmed".

Damage in Bocas del Toro probably was not greater because this town was under almost total reconstruction, and the artificial sand fill construction did not began until 1905. More than one hun-

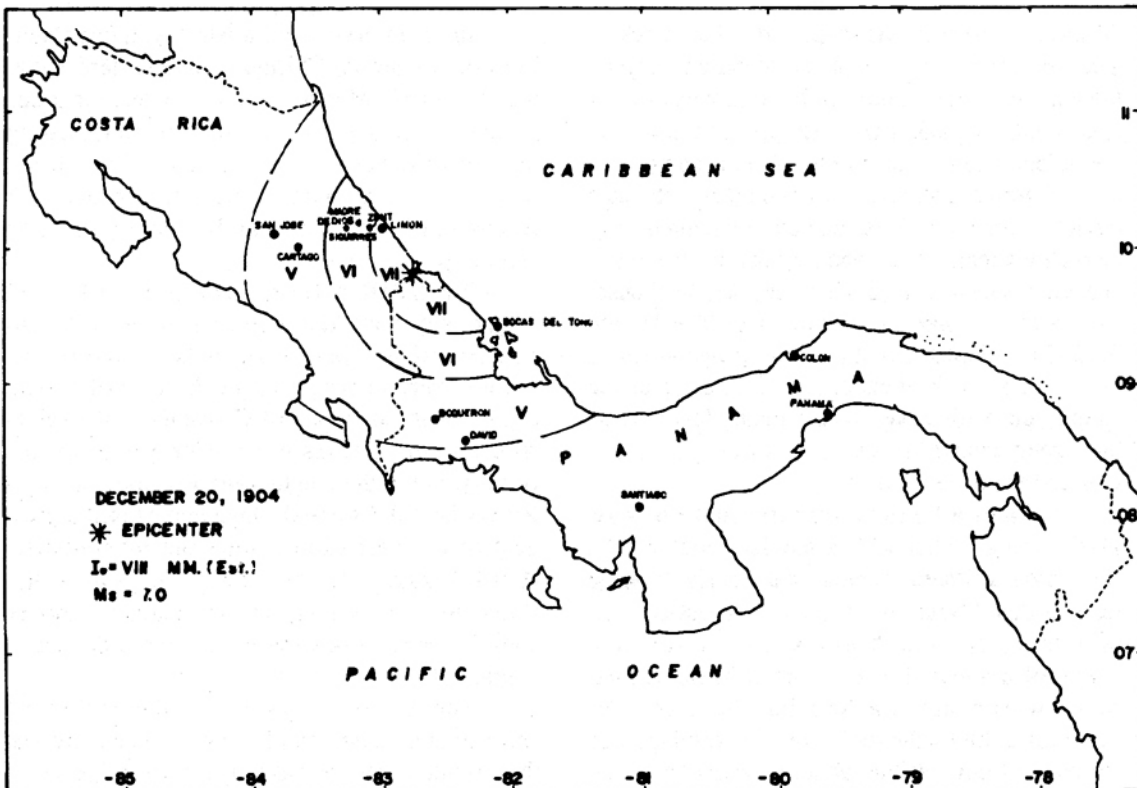


Fig. 4: Macroseismic map for the December 20, 1904 event. The proposed epicenter is indicated by a black star.

dred thirty houses, the two schools, most of the commercial district and all of the public buildings were destroyed by a fire on March 6, 1904 (GUTIERREZ, 1991).

It is also important to mention that a day or two after the event there were huge river floods and landslides in the Atlantic region of Costa Rica which caused great damage to bridges and the railroad between Limon and San José (The Star & Herald, 1905).

An isoseismal map for this earthquake is on figure 4. We estimated an epicentral intensity $I_0 = VIII MM.$, to this event, and from this value we calculated a surface wave magnitude $M_s = 7.0$.

1909, SETEMBER 30, 08:02 a.m., 9.8 N, 78.4 W, M_s 6.0.

"Pens thrown off. Felt in Balboa Heights Panamá and Nombre de Dios". (BHPF, 1909).

1910, DECEMBER 21, 05:24 a.m., 9.8°N, 82.3°W, $M_s = 6.4$

"Earthquake felt in Culebra, Canal Zone. Practically everyone in Bocas del Toro aroused and left houses, which were all frame construction. No damage except few dishes broken. Pendulum clock stopped at 10h32m 20s" (BHPF, 1910). This event was preceded by a $M_s = 6.0$ foreshock on December 20, 1910 at 06:09 p.m. from the same epicentral zone. "It was distinctly felt by a great number of people in Bocas del Toro, Panamá but no damage." (BHPF, 1910)

1916, APRIL 24, 3:03 a.m., 10.0°N, 82.0°W (Duda 1965), $M_s = 7.3$ (G-R)

This event and the next on April 25 have been considered by ASTIZ & KANAMORI (1984) as a doublet. Unfortunately is not well documented, its location, time of origin and magnitude are very uncertain. It is also interesting the fact that this event apparently did not cause a tsunami.

GUTENBERG & RICHTER (1954) calculated a $M_s = 7.3$ for this event, while DUDA (1965) calculated a $M_s = 7.6$ and ABE &

NOGUCHI (1983a) a $M_s = 7.4$. We consider the magnitude calculated by GUTENBERG & RICHTER (1954) to be more reliable.

ACRES (1982) and GUENDEL (1986) suggest that the instrumental epicenters (GUTENBERG & RICHTER, 1954) of this event and the one on April 25 (11°N, 85°W and 10°N, 85°W respectively) appear to be grossly misplaced.

GUENDEL (1986) believes DUDA (1965) location (10°N and 82°W) to be in better agreement with the distribution of intensity and damage reports.

According to MIYAMURA (1980) the daily La Prensa Libre of San José, Costa Rica reports on this event the following: "two strong shocks at 02:26 and 02:28 a.m. were felt throughout the country but no damage was reported".

THE CANAL RECORD (1916a) reports: "Two seismic disturbances were recorded at the seismographic observatory at Balboa Heights the night of April 23-24 the second started at 03:03:30 and ended at 3:36:00 a.m. on the 24th. The maximum amplitude was 88 plus mm. The intensity of the shock was III or IV, and the distance to the epicenter approximately 475 miles, in the northerly direction".

REID (1917) states: "(08h01m44s, G.M.T.) quite a heavy earthquake was felt here, and from later reports its center must have been in this immediate neighborhood. In some houses it knocked over glasses, pitchers sitting in bowls turned over, as did a few other articles, but practically no damage resulted. It was however the heaviest shock experienced here during the last eight years."

THE STAR & HERALD (1916a) reports from David, Chiriquí in western Panamá: "On the night of Monday April 24. (. . .). The first I knew of the earthquake was a feeling that my bed was being shaken violently. Bouncing up, I saw a figure, which proved later to be that of Stockelberg standing at the foot of the bed. 'Say, what are you shaking my bed for. I yelled'.....the movement ceased, so its continuance was all on a minute. The motion was a slow weaving back and forth. Nearly all of the visitors were aroused and got up, but the native population paid it no attention, not even coming to their doors."

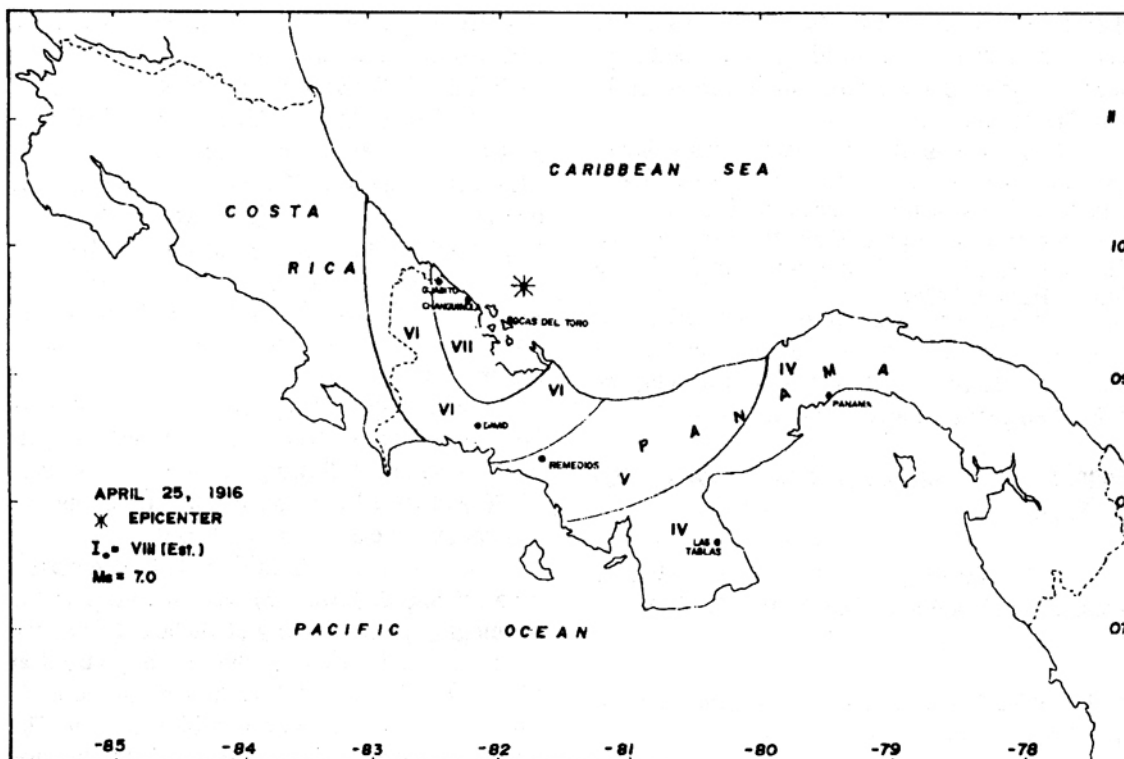


Fig. 5: Macroseismic map for the April 25, 1916 event (adapted from VIQUEZ & TORAL, 1987). The proposed epicenter is indicated by a black star.

1916, APRIL 25, 9:30 p.m., 9.6°N, 82.0°W (V-T, 1987), $M_s = 7.0$

This event was located by the Old Dominion Observatory of Ottawa, Canada at 9.5°N and 82.6°W. GUENDEL (1986) proposes 9.33°N, 82.00°W as its epicenter. VIQUEZ & TORAL (1987) propose 9.6°N, 82.0°W as its epicenter. GUTENBERG & RICHTER (1954) calculated a $M_s = 7.3$ for this event, while ABE & NOGUCHI (1983) calculated a $M_s = 7.1$.

In a letter issued to Colonel Morrow on April 26, 1916 the Chief Hydrographer of the Panamá Canal Co., at Balboa Heights, F. Wilson informs that: "Five distinct seismic disturbances were recorded by the seismographs last night. The first began at 9h22m 36s and ended at 9h 44m 00s p.m.(.....) This shock was distinctly felt by a number of persons, and was severe enough to stop the clock in the Requisition Bureau, and in the telephone Office at Colón. (..) and the movement was also

recorded by the waterstage registers at Gatún, Pedro Miguel, and Miraflores".

THE PANAMA CANAL RECORD (1916a) informs that: "in the night of April 25-26, five separate shocks were recorded. The most perceptible had an intensity of V."

Referring to the night of April 25, 1916 at David, Chiriquí THE STAR & HERALD (1916a) reports that: "Another earthquake of greater intensity and much longer duration occurred here at 8:50 tonight. This time the people did not hesitate in seeking the streets and parks, even those living in the single story adobe shacks..(..).... Movable articles in rooms were all rocking to and fro and in some instances were overturned, but as far as could be learned tonight no damage of consequence resulted. According to the writers watch the movement lasted very nearly two minutes. The disturbance was characterized by the same rocking or weaving motion of Monday morning, but after the heavier movements there appeared to be many smaller ones; in fact the ground trembled

for a full minute after the first and severe disturbances...”

THE STAR & HERALD (1916b) also informs that: “This earthquake was particularly strong in Almirante and Bocas del Toro. In Almirante it was hard for people to stand up. Unstable objects in shops and warehouses were thrown out from their places with a considerable loss of property. A total of 89 houses were shifted from their foundations. Many windows were broken and water tanks fell down. The railroad tracks were bended in many places. The water service and electricity was temporarily interrupted. There were six fires, but they were rapidly suffocated. The telephone cable between Almirante and Bocas del Toro got broken. The pier in Bocas del Toro was damaged and some houses shifted from their supports and the United Fruit Co. general office, storehouse and workers camp suffer considerable damage. A small tsunami throw litter and canoes some two hundred meters ashore. This wave came from the northeast. The phenomenon of liquefaction was reported.”

THE STAR & HERALD (1916c) informs that in Bocas del Toro, capital of the Province of the same name “large fissures, which subsequently closed were made and sea flowed over knee deep into the land. The Henriquez aerated water factory at 46 North Avenue came to grief, the large tanks were washed away around the shore and the plant was damaged so badly...(..)

Many dwelling houses were thrown off their blocks, furniture and adornments were damaged...(..).in Almirante the earth opened in many places far wider than in Bocas...(..)

At Bastimentos, Old Bank, the sea flowed beyond the usual limit for some time...(..)

The shock was also felt at Changuinola, Guabito and elsewhere, but no damage nor casualties have been reported.”

The General Engineer of the Province of Bocas del Toro reported on April of 1916: “Before concluding I want to recommend some urgent reparations needed by the Cedar Creek bridge in Almirante, whose columns collapsed by effect of the April earthquake.(..)

At the National Police headquarters at Bocas del Toro the following urgent repair work

was performed: the roof and the ceiling were fixed, the staircase, the baths and the floor of the guard room, whose concrete have subsided, were completely replaced. A concrete column was built to support the staircase, the windows of the building and the walls were fixed.” (S.F.O.P., 1916)

On THE PANAMA CANAL RECORD (1916) is reported that: “The aftershocks that followed were of much less severity, though two were of sufficient intensity to be felt.

It is probable that all the disturbances this month, with the exception of the tremor on April 17, were of common origin.....This and the similarity of the records, in that the movement was stronger, on the north-south components of the seismographs, would indicate that the seat of the disturbances was to the northwest of the observing station.”

REID (1917) reported that this earthquake was:”the heaviest shock experience here during the last eight years...(..)

At Bocas a slight tidal wave carried canoes and debris two hundred meters in land. Sweet water was found in one of the cracks in the street, and still causing considerable speculation. Near this spot several years ago an artisan well was driven twelve hundred feet no water, either salt or fresh, was encountered.

Frame houses set up on underpinning are not yet very stable; it does not require a destructive shock to overthrow the pins and let the houses down.”

REID (1980) comments that: “In 1916 when the great earthquake shook the whole province and nearly destroyed Careening Cay, two young men, Nahum Martínez and myself, were out on the little lonely Zapadilla Cay, fishing. That night, at 9:30 we were in our hammocks, talking and laughing...(..). Then came the greatest surprise of our lives. The whole Cay trembled and shook.....We got down on our knees. I prayed..... Shortly after, there was a lull; everything was quiet again.

Ephraim Alphonse was a young dandy..... He was at a dance hall in Careening Cay the night the earthquake shook the whole province. Careening Cay was severely affected, and parts of

it were completely covered by water. The same place where he had been standing was submerged and covered by the sea.".....

An isoseismal map for this earthquake is on figure 5. We have estimated an epicentral intensity I_0 of VIII MM. and from this value we calculated a surface wave magnitude $M_s = 7.0$. This last value is very close to $M_s = 7.1$ (ABE & NOGUCHI, 1983), $M_s = 6.9$ estimated by DUDA (1990) and $M_s = 6.9$ obtained by using CAMACHO (1991) duration magnitude formula. We assigned a $M_s = 7.0$ for this event for consider it more reliable.

1930, MARCH 7, 10:45 p.m., 9.67°N, 78.83°W, $M_s = 6.2$

This event was strongly felt in the cities of Colón and Panamá where people fled into the streets (STAR & HERALD, 1930). Some cracks opened in the Administration Building of the Panamá Canal Company at Balboa (BHPF, 1930). BHP assigned an intensity of VI R.F. to this event.

CONCLUSIONES

1. The events in the Caribbean region of Panamá historically and instrumentally have been located in the eastern and the western segments of the North Panamá Deformed Belt.

2. There is an amazing absence of strong historical events in the central segment, between 80.0 and 81.4°W, and almost no seismicity have been instrumentally recorded originating there. This seismic quiescence could be explained by the possible regional absence of overthrust of the Panamá Block in the Caribbean plate as has been proposed by BOWLAND (1984).

3. Major events from the North Panamá Deformed Belt seem to be characterized by multiple ruptures and for causing local tsunamis.

4. The Western Segment of the NPDB is at least conformed by two subregions which have independently ruptured in historical times.

5. In the Western Segment of the NPDB the events of 1798, 1822, 1904 and 1991 seem to have originated at the western subregion. Large events located in this subregion seem to have

been accompanied by coseismic vertical deformation of the coast. While the events of April, 1916 and probably the one of 1867 originated at the eastern subregion.

6. In the Eastern Segment of the NPDB historically there has only been a major destructive event $M_s = 7.5-8.0$ on September 7, 1882. But the instrumental seismicity is much higher than in the Western Segment.

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