STRATIGRAPHIC AND MORPHOLOGIC EVIDENCES OF HISTORIC AND PRE-HISTORIC TSUNAMI IN NORTHWESTERN PUERTO RICO

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Executive Summary

Sand laminations of marine deposits in the swamp, rock impacts of tossed boulders in the cliff zone, broken dunes with fan-delta type structures, and corals on the beach carried from the sea, are here presented as evidence of historic and pre-historic tsunami. Radiocarbon dating has been used to suggest two pre-historic seismic events accompanied by tsunami. An event yielded a date of 1270-1410 AD and other of 820-400 BC.

Due to the morphological effects of tsunami in the coast of Western Puerto Rico have not been ever conducted, this study is very significant because the historic earthquakes in Puerto Rico (1867 and 1918) generated great tsunami [Reid and Taber, 1919]. Future seismic events accompanied with tsunami are expected in the future in the northeastern portion of the Caribbean Plate as evidenced by historic records. Here it is suggested that at least 8 km of coastal retreat occurred in the Quaternary in the region caused by tsunami impact, lithologic controls, and tectonic subsidence. Also, it is suggested here that northwestern Puerto Rico is tectonically controlled, and responds directly to the active tectonics of an extensional zone being developed in western Puerto Rico, the Mona Passage, and Eastern Dominican Republic.
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Introduction

In 1918 an earthquake of magnitude M7.3 affected western Puerto Rico. This seismic event produced an important tsunami which killed various people [Reid and Taber, 1919]. These authors described evidence for a run-up of up to 5 meters and possibly higher in some places. The earthquake was associated with the rupture of the Mona Canyon Fault which according to its Seismic Moment ($M_0$) had a rupture of 3.5 meters of vertical displacement with an approximate length of 70 km [McCann and Mercado, 1997]. This earthquake is just one of the examples of the potential that many faults in the Mona Passage have to generate tsunami along the coast of western Puerto Rico.

This work contributes to the earthquake and tsunami hazards in Puerto Rico and in the northeastern portion of the Caribbean Plate. Data related to the evidence of the 1918 tsunami is presented, including long- and short-term effects of tsunami in the northwestern coast of Puerto Rico. Analysis and interpretation of pre-historic seismic events is also presented, plus a discussion of future events associated with the oblique subduction and the extension occurring in Mona Passage, western Puerto Rico, and eastern Dominican Republic.

Objectives

This study has been focussed on northwestern Puerto Rico between Aguadilla and Rincon, because was the most affected area by the 1918 tsunami (Figure 1). This investigation has been developed on suggested evidence of pre-historic and historic tsunami in this region, and has analyzed the potential effect of future seismic events accompanied by tsunami as a contribution to a response plan in the island. Pre-historically, it is presented an interpretation of previous earthquakes generating tsunami based on the stratigraphic records of these events,
registered by earthquake induced sedimentation. Finally, this study includes some interpretations related to tsunami effects taken from the descriptions of Reid and Taber, [1919], supplemented by the modeling investigations developed by McCann and Mercado [1997], interviews from survivors of the 1918 tsunami, and geologic and geomorphologic analysis of the evidence left by the 1918 tsunami. This is the first attempt to define the importance of tsunami in the evolution of the coastal morphology of northwestern Puerto Rico.

Stratigraphic and morphologic records of tsunami

Tsunami can leave evidence in different environments depending on the local characteristics of each zone [Minoura and Nakaya, 1990; Bryant and Young, 1996]. Stratigraphically, the best places to look for tsunami evidence are those where sudden geomorphic and sedimentologic changes occur after and during a tsunami [Minoura and Nakaya, 1990; Minoura et al., 1997]. One of the best places, are those where inputs of sand and marine organisms are carried from the sea and deposited in a low energy coastal environment, such as swamps or tidal zones.

Geomorphologically the search of tsunami is different. Bryant, et al. [1992, 1996] and Bryant and Young [1996] have described structures and morphologies observed in areas where tsunami have impacted coastal cliffs and coastal dunes. Rock impacts produced by tossed boulders could be common evidences of tsunami in many cliff areas. Also, marine rocks, corals, marine shells and organisms which were ripped out by the sea waves, can be carried along creeks, rivers, or water paths located close to the coast, reversing the sedimentation process from the sea toward land.
In sandy coasts, historical descriptions from tsunami mention that long-term formed coastal dunes have been broken by sea waves [Minoura and Nakaya, 1990]. These dunes have formed fan-delta morphologies associated with the disintegration of these dunes. So, these sedimentologic [Minoura and Nakaya, 1990] and geomorphologic features [Bryant et al., 1996] have been the main criteria applied to the search of tsunami evidences in the study zone.

In northwestern Puerto Rico, the presence of low energy environments on the swampy areas in the low lands close to the beach, sand dunes, and cliffs with loose boulders capable to be carried out by tsunami, have presented good conditions for these types of investigations.

Methodology

This study was based on four main lines of evidence. First, the compilation of the historic descriptions of the 1918 tsunami [Reid and Tabor, 1919]. Second, with the support of the Sea Grant Program in the University of Puerto Rico at Mayaguez, Mr. Kevin Acevedo of the Department of Social Sciences at University of Puerto Rico at Mayaguez, Mr. Martin Concepción of the Civil Defense Office of Aguada, and this author, conducted interviews with 14 survivors and witnesses of the 1918 tsunami. The interviews helped to define among other things, the most affected areas where this event was catastrophic and where geomorphologic changes were observed during the event. Third, based on the information of step one and two, the data was compared with the tsunami run-up model prepared by McCann and Mercado [1997]. Fourth, the geomorphologic and geologic characteristics of the coast were analyzed and field and photographic (aerial) investigations were conducted searching for the evidence of the tsunami. From the sources mentioned, it is confirmed that the most affected area by the 1918 tsunami was the zone between Punta Higuero (in Rincon) and La Bajura (in western
Isabella and eastern Aguadilla), so field investigations were focused on these areas in northwestern Puerto Rico (Figure 1).

The field investigations consisted in the search of tsunami evidence in: the swamps, the beach, and the cliffs. From the swampy areas, some cores were extracted in the low lands, close to the beaches of Aguada and Aguadilla, searching for possible deposits left in the swamps by the tsunami as observed in other regions in the world [Minoura and Noyaka, 1990; Atwater, 1997]. From the stratigraphy obtained, correlations were made based on sedimentologic descriptions of swamp and different deposits, following the criteria of Minoura and Nakaya [1990] and Alan Nelson [personal comm.]. To support the work in the swamp on the coastal plain of Aguada at Carrizales, a 60 meters long trench of about 2.5 meters deep was also open searching for stratigraphic record of the 1918 event and maybe older ones.

On the cliffs of Aguadilla, evidence of the tsunami runup was also searched, focussed on the possible impact structures generated by the tossed rocks moved by the sea waves, as have been observed also in other areas of the world [Bryant and Young, 1996]. This part was conducted because Reid and Taber [1919] described boulders that were carried out of the beach zone, and left on the railroad train tracks on the cliff of Aguadilla. This type of investigation was also conducted in areas where the historic description [Reid and Taber, 1919], interviews, and the run-up models [McCann and Mercado, 1997] have suggested that the run-up was very high.

In the areas with high run-up, the high-energy wave could very easily bring many rocks and corals from the sea to the beaches and the cliffs. Based on the interviews and descriptions of Reid and Taber [1919], some of these rocks were also tossed out against some
of the beaches. Taggart et al., [1993] reported for Isla de Mona similar boulders which were suggested to be associated to tsunami or hurricanes.

Finally, due to the presence of dunes in the coast of Aguadilla, field check was conducted searching for the evidence of the path of the tsunami in the sand dunes located in front of the coast, as suggested by Minoura and Nakaya [1990]. With these criteria were defined all the potential geologic and geomorphologic indicators of tsunami in this area.

**General Tectonic Setting of Puerto Rico**

Puerto Rico is located in the northeastern portion of the Caribbean Plate. The Caribbean Plate slowly advances to the east with respect to the North and South American Plates. Puerto Rico and other Caribbean islands occupy the easternmost part of a 2000-km long, 100-250 km wide Plate Boundary Zone, absorbing very oblique-sinistral convergence between the Caribbean and North American Plates (Figure 2). The island is part of the Puerto Rico Microplate [Byrne et al., 1985; McCann, 1995], the easternmost of the blocks in the Plate Boundary Zone. It is bounded by four different tectonic elements (Figure 3) [McCann et al., 1996; Moya and McCann, 1996]. To the north lies the subduction zone where the North American Plate descends into the mantle along the Puerto Rico Trench. To the south the Muertos Trough, a structure of probable oblique compressional origin, is the contact between the Caribbean Plate with the Puerto Rico Microplate. To the east and southeast is the Anegada Passage, a zone of active extensional deformation. To the west is an ill-defined zone of extension affecting the western part of the island of Puerto Rico (Puerto Rico Microplate), the eastern portion of the El Seibo Microplate in the Dominican Republic, and the Mona Passage [Moya, 1998].
Northwestern Puerto Rico is located within the extensional zone, developed by the separation of Puerto Rico from Hispaniola at a rate of about ~5 mm/yr, as suggested by GPS data interpretation [Calais, 1999]. This separation is considered fast in island arcs in the world. This separation also includes offshore and onshore zones (Figure 4) as defined by Moya [1988]. In the east, the extension involves the western portion of the Puerto Rico Microplate, which also includes northwestern Puerto Rico. On the western portion of the extensional zone, is located El Seibo Block, which corresponds to the eastern portion of the Dominican Republic [Moya, 1998]. In Western Puerto Rico and Eastern Hispaniola, the extension is being developed mainly onland. However, in the center of the region, the extension is occurring on the Mona Passage including the Mona Canyon.

This extensional zone has produced important earthquakes, such as the 1918 earthquake occurred on the Mona Canyon Fault [McCann and Mercado, 1997]. These authors have showed the importance of many faults located in the Mona Passage as tsunamigenic sources, which present an important hazard for western Puerto Rico. All the faults in the zone of extension present important source of earthquakes for Puerto Rico and many of the important sources for tsunami.

Seismicity

The northeastern Caribbean is one of the most seismically active segments of the Caribbean Plate boundary as expressed by the historic data [McCann, 1985; Papadopulos, 1995]. Large earthquakes have been fairly frequent in this island arc segment during this century. Recent seismicity shows the distribution and limits of the small microplates composing the Plate Boundary Zone. West of the Puerto Rico Microplate in the eastern part of
the Dominican Republic, is a vast area that is nearly devoid of shallow seismicity. This quiet region is the El Seibo Microplate as defined by McCann et al. [1996], and Moya and McCann [1996]. To the north, higher levels of activity reflect motion along the subduction zone and faults at the northern flank of the platelet. To the west, the seismic activity reflects motion between the El Seibo Microplate and the Gonave Microplate (Figure 3).

Also, data on recent seismicity [Moya and McCann, 1991; McCann et al., 1996] shows that southwestern Puerto Rico and Mona Passage have higher level of microearthquakes than surrounding areas. Asencio [1980] and Moya and McCann [1991] show that for Puerto Rico many events can be identified in the historical record as having originated mainly in Mona Passage. The 1918 earthquake was located in the Mona Canyon now known as the Mona Rift, west of Aguadilla, with an assigned Richter Magnitude of 7.3 in 1918. One hundred and fourteen people died with damage of $4 million (1918 dollars). These events show the importance of the seismic activity in the region associated to the separation between El Seibo and Western Puerto Rico.

**Geology and geomorphology of northwestern Puerto Rico**

The geology of northwestern Puerto is documented by Cretaceous-Paleocene volcanoclastic sediments and volcanic rocks, deformed in the Eocene and Early Oligocene. The zone more affected by the 1918 tsunami is the area between Aguadilla and Rincon in northwestern Puerto Rico. Here, the geology consists of Eocene and Post Oligocene rocks (Figure 5) [Monroe: 1967, 1979, 1980].

The geomorphic characteristics of the coast along northwestern Puerto Rico consists of a series of different flat swampy and low lands beaches, separated by prominent cliffs. The swampy low lands are associated with older courses of rivers, as is the case of the Culebrinas
River. This river has had different paths in the Late Quaternary as expressed by abandoned meanders, which are observed in aerial photos and maps. The coastal plain at the mouth of this river consist of Holocene beach, alluvial, and swamp deposits [Monroe, 1979]. At least in the Late Holocene, the morphology of this area has been associated to a fluvial-coastal interaction as expressed by the morphological and sedimentological features.

Bathymetry

One of the possible causes of the high impact of tsunami on the northwestern part of Puerto Rico is the presence of a small canyon formed by a secondary fault which connects with the Mona Canyon Fault [McCann and Mercado, 1997; Moya, 1998] (Figure 6). This secondary canyon points out directly towards the northwestern part of Puerto Rico, which causes that the seismic induced waves (tsunami) coming from the Mona Canyon or from the Mona Passage, can arrive faster and directly to the Aguadilla beach, as predicted by the model of McCann and Mercado [1997]. The bathymetry of this canyon goes from 4000 m in the Canyon to zero along the coast in less than 15 km (Figure 6). The bathymetry of the rest of the Mona Passage to the south is shallower, mainly south of Rincon is shallower. Apparently during 1918, the impact of tsunami waves was less on western Puerto Rico, south of Rincon. This could be caused, between other things to the dissipation of the energy by the roughness of the sea floor at the moment of the wave arrival, and by the wave diffraction [McCann and Mercado, 1997].
Interpretation of the 1918 earthquake

Observed Run up

During the 1918 tsunami, according to Reid and Taber [1919], there was a big difference in the behavior of the runup height in different areas of northwestern Puerto Rico. These authors described characteristics of the tsunami such as the time arrival, the runup, and its penetration, which has been also defined from the people interviewed (14 survivors of the 1918 earthquake and tsunami), some of those people still alive in Aguada, Aguadilla, Rincon, and Mayaguez. These people were living on the beach or close to it at the moment of the earthquake, and some were witness of the tsunami [Acevedo, 1997]. Results of the run up highs from Reid and Taber [1919] and survivors are presented in figure 7.

The interviews almost totally corroborated the data reported by Reid and Taber [1919] concerning the impact on the coastal zone. The people interviewed who mentioned that the sea receded, came and receded, and came again a few times. It was not a single wave, but a set of waves, sometimes with more than five minutes of difference in the arrival time. In some areas survivors described that the sea water was ponded in the plains and swamps for days. In the Aguada beach at Carrizales, for example, human bodies were taken later from the swamp, after the water receded. Bad odors remained in the zone for more than a week, associated with dead marine organisms and dead bodies, particularly in the area of Espinar and La Bajura. One person interviewed showed where in Carrizales the sea wave affected his family property and killed some relatives. There, the tsunami penetrated in the swamps at least 50 m and in some areas by more than 150 meters.

For some of the survivors, the sea level receded about 500 to 700 meters before the first wave arrived, the sea came back with a runup of up to 3 to 5 meters high. From different
sources was established that the church of Aguadilla was not affected by the wave as has sometimes been stated. However one block to the west, the streets were flooded with ponded water. According to the Civil Defense Office in Aguada, after the 1918 tsunami event, some storms (called locally Bravatas) have had the energy enough to affect the coast with high waves. These storms have not been strong enough to penetrate in the swamps of Aguada or as far as the 1918 tsunami in the city of Aguadilla. So the possibility of recent storm deposits located on these swamps after the 1918 tsunami has been eliminated. However, in 1928 the eye of Hurricane San Felipe, a Hurricane with category 5, crossed the area when was leaving Puerto Rico. In the interviews, nobody mentioned that the effects of the storm surge during this event penetrated the swamps in Aguadilla and Aguada. It is important to mention this, mainly because tsunami effects could be similar to storm surge effects, something that will be considered later.

**Predicted run up**

*Mercado and McCann* [1997] have generated a model, related to the potential run up that another event similar to the 1918 M7.3 earthquake, could generate in the western part of Puerto Rico. At least for the area of the City of Aguadilla, the model suggests that run up waves with heights up to 4 meters occurred during the 1918 tsunami. This is almost consistent with the data observed by *Reid and Taber* [1919]. Their model also predicts several important sets of waves and not a single one. From the people interviewed and from the model, it is suggested that each wave delivered important quantities of sand and marine organisms as observed for the local people in the beach and in the swamp after the tsunami. So, several waves meant several inputs of sand and marine organisms during the 1918 event.
Field Investigations

Cores in the swamps

In the swamps of Aguada and Aguadilla (Figure 8), 8 cores were taken following the technique suggested by Alan Nelson [pers. comm.] for investigations on tsunami evidence. Aluminum pipelines of 8' long and 3'' of diameter were used to collect the cores (Figure 9), which were pushed into the ground with a wood hammer. For deepest sampling in Espinar, the services of a geotechnical company were hired to use portable drills. The aluminum pipelines were later cut with an electric saw in order to see the materials collected inside (Figures 10 and 11). The materials were analyzed using a binocular 30X microscope, and the presence of marine deposits were classified by Mr. Pedro Quiñones, a former marine biologist from the Department of Natural Resources of Puerto Rico. The generalized stratigraphy is presented in Figure 11.

Trenching at Carrizales

Two trenches were also dug on the coastal plain of Aguada, searching for stratigraphic markers of the tsunami. Mr. Martin Concepción, Director of the Civil Defense office of Aguada and his team supported the work. One trench was about 40 m long and the other about 15 m long. They were dug looking for the signal of the deposits associated with the 1918 event. According to Mr. Aibot Ramos the owner of the property, this swampy area has been used intensely for cattle in the last 50 years, reworking the first feet of the surface materials. Also, this is the place pointed out by one of the survivors, who mentioned that the seawater was ponded for days in the area and that about 4 people were killed by the wave.
Aguada Plain at Carrizales. Two aluminum pipeline cores were taken in the area known as Carrizales (Figure 8) to a depth of almost 8' deep. One was located about 50 meters from the actual beach and the other about 100 meters. The sites were named Aguada-Carrizales 1 (CA1) and Aguada-Carrizales 2 (CA2) respectively.

The stratigraphy observed in the core is presented in Figure 11. Due to its soft sedimentological conditions, the most complete core was CA-2. Aguada 1 (CA1) presented strong difficulties because some layers are very cemented appearing as “beach rock” deposits, make them very difficult to analyze. For CA2, from 0 to 15 cm, coarse sandy deposits composed of 40% of quartz and feldspars are characteristics, and 40% or more of calcareous sand appears mixed with recent soil. Also, white materials composed of pieces of broken shells are part of the profile. Here, there is a sudden change in grain size and composition of the materials at about 15 to 25 cm deep. This change is characterized by about 8 cm thick, of white and gray very well defined fine calcareous sand and silt with abundance of pieces of Halimeda sp., a marine algae which lives in the bottom of the shallow marine platform on the first meters of depth. This layer appears is some areas as parallel cross bedding laminations and resembles a clear depositional event, different from the massive deposition from the layer on top and underneath.

From .25 to 1.10 m the material is composed of massive white and gray calcareous fine sand. At about 1.10 m deep, appears a thin layer composed of fine quartz sand. This layer is only 8-10 cm thick and suggests a single high-energy event. The lack of marine organisms suggests that this layer could be associated with a storm more than seismic wave or even a flood deposit. From about 1.20 to 1.30 m the layer is the same than from .25 to 1.10 m,
basically massive white and gray calcareous sand. Again at about 1.30 to 1.35 m deep, there is another layer similar to the one that appears from 1.20 to 1.30 m. This is a single layer of fine quartz sand about 4 to 5 cm thick. The similarities of the layers at 1.10 m and 1.30 m deep presenting just fine quartz sand suggest that these layers could be associated with inputs of sand as product of important storms. In these layers there is no evidence of marine organisms, so the possible source could be just the remotion of beach deposits.

From about 1.35 to 1.70 m deep, the layer is again massive as the others between .25 and 1.10 m and 1.20 to 1.30 m deep, suggesting similar coastal plain (beach) sequences interrupted by single events. At about 1.70 m deep, there is a layer of dense sand with some preserved pieces of Halimeda Sp. In some pockets even is observable some deposits of magnetite but without any defined sedimentary structure. The Halimeda Sp. and the magnetite, which are at present distributed on the shore, suggest that these deposits were carried from the beach about 100 meters to this place. Below this layer, the materials are composed mostly of coarse to medium gray calcareous sand and broken pieces of shells though 2.40, the depth of the end of the sample.

The presence of Halimeda sp. as a massive layer located at about 15 to 25 cm deep, is interpreted as the signature of a tsunami as well as the layer at about 1.70 m deep which contains magnetite. The changes in color and grain size are significant, and the presence of the Halimeda sp. eliminates the possibility of river flooding.

*Trenching and Logging Results at Carrizales*

The two trenches dug in the area on the property of Mr. Aidot Ramos, were subdivided in two sections. One section of about 40-50 meters-long (Trench A) and a second
one of about 10-15 m (Trench B) and were oriented perpendicular to the beach (Figures 12 and 13). Each trench was located about 10 meters from the logs of CA1 and CA2 respectively. The stratigraphy found in the trenches presents is in some aspects, some differences respect to some units observed in the logs (Figure 14). Standardized profiles are presented here. The Trench A presents different variation of horizontal sedimentation. Trench B represents better the stratigraphy due that these are has been less affected by agriculture.

At top of trench B, as in log CA2, appears the same reworked soil with quartz and calcareous sand. Then at about 25 cm deep, a thick layer of about 12 cm of gray calcareous coarse sand and shells defines the possible evidence of the tsunami observed in the Core CA2 (Figure 15). This layer present some well preserved shells and oysters, which were deposited in this area, but were not broken when were deposited. Variations of different layers of sandy materials appear in the profile from about 0.35 cm through about 1.80 m deep. At about this depth, appears a gray layer of sand with Halemida Sp., marine shells, and magnetite. This layer presents a sharp change with only 5cm thick. The rest of the column is basically sand with different amounts of broken shells and sand with quartz and feldspars as in the CA2 log. Both layers, the one at 2.5 cm and the other at about 1.80 m present abundant presence of very well preserved Halemida Sp. The presence of well preserved Halemida Sp. in these layers suggest a sudden sedimentation event which brought these materials from the sea to this swamp-type environment. Here is suggested that the well-preserved layers of Halemida Sp. could be indicators of a tsunami. Broken or reworked pieces of Halemida Sp. or marine shells would be associated to a storm or storm surge due to the time with high energy generated by a storm, destroying or braking the hard parts of these organisms.
As in the trench B, the deposits of CA2 on the layers at 15 and 25 cm have been interpreted as deposited by the 1918 tsunami respectively. The differences between the information obtained from the logs and from the trenches suggest that lateral variations in sedimentation are present in the zone. Even when the area where log CA2 was taken and trench B was opened have not been too affected by human activities since 1918, this area do not represent a good environment for tsunami record. This is due to the different changes in land use and land modifications.

In general, the main point here has been to try to define the signal for the tsunami record, and it is suggested again that the presence of Halemida Sp., and magnetite distributed in laminations may be good indicators of tsunami records.

_Aguadilla Swamp at Espinar_

For sampling, three (3) aluminum pipeline cores were also collected in the swamp of the area known as Espinar in Aguada, about 1200 meters east of the Culebrinas River. Espinar is another sector in Aguada where the people said that the houses of some fishers where ripped out by the tsunami. In the Espinar area, according to local people, the swamp has receded about 20 to 50 meters since 1930. Also, about 50 meters of coastal erosion have made the coast to retreat, so the swamp is now about 40 to 30 meters closer to the beach than 1918. Here, the sampling technique was difficult, just one pipeline got a good sample (ES1), and the other two had the problem of sand compression at the mouth of the cores. To resolve this problem, the sampling was developed by a geotechnical company (ES2).

First, at the log obtained at ES1, from 0 to 25 cm, a beige organic material appears covered by a thin soil. This organic material is composed of silt and fine sand. From about 25
to 30 cm deep, there is a layer composed of 5 to 6 laminations of magnetite, and gray and white medium to fine sand, which contrast with the beige color of the organic material. Then from about 30 cm to 1.2 m, appear again the beige silty-sand materials of the swamp environment (Figure 11).

At about 10 meters from the same place, a geotechnical company took a 4.0 meter deep, 2 inches thick core with almost no perturbation in the swampy area of Espinar (Figures 8 and 11). Here the author has trusted in the samples obtained by the firm, because he was not there at the moment of the sampling. From 0 to about 50 cm, the log showed that a fine silty sand gray-brown organic layer appears at the surface. At about 50 to 55 cm deep, there is a layer of gray and black coarser sand with high content of magnetite. This layer is about 5 cm thick and presents about just 5 oxidized laminations and very small broken pieces of shells and small pieces of preserved organic relics, possible roots. There is an important difference between the laminations between ES1 and ES2. In the laminations of ES1 no oxidation is observed, however, at ES2 the oxidation and the presence of small pieces of organic material, mainly roots, and less laminations suggest that the ES2 laminations are different. Oxidation could be an indicator of time acting on the magnetite. An organic piece located in the laminations mentioned on ES2 was taken for radiocarbon dating.

Continuing with the ES2 description, from 55 to about 100 cm appears again the fine sandy gray-brown organic layer, pretty similar that the one above the laminations. No data was collected in the log from −1 to 1.8 m, possibly due to sand liquefaction, or any other problem with the sampling. From 1.8 to 2.43 meters deep in the core appears a gray-clear-beige silty-clay organic mud. Then from about 2.43 to 2.50 meters appears again a sandy-silt zone of oxidized laminations of medium sand with magnetite. This layer is about 4 cm thick similar to
the one located at 50 cm. These laminations contain important amount of magnetite and small pieces of broken shells and tiny pieces of organic tissues. There, another organic piece was taken for radiocarbon dating. This author admits that the sampling in the log could generate important errors in the interpretation. The lack of sample from ~1 m to 1.8 m could give different alternatives in the interpretation of the data, plus the sampling obtained. As mentioned before, sampling was taking without the author supervision, so the author has trusted in the geotechnical firm and do the interpretation “as is” in the log.

Following the time arrival of the run-up presented by McCann and Mercado (1997), the sand laminations of magnetite have been interpreted as the evidence of each marine wave coming to the coast and penetrating in the swamp and as mentioned by the people interviewed. It is here suggested again that the thin laminations observed in the core represent the inputs of the marine sediments, and heavy minerals located in the beach which were brought to the swamp by the tsunami. Based on the oxidation presented on ES2, it is here suggested that the laminations found in ES1 and ES2 in the first upper meter correspond to different events in time whatever could be the origin of these laminations.

Aguadilla Swamp at Parque de Aguadilla

In the Parque de Aguadilla area four cores were taken in the mangrove along the channel that is located behind the park where a few years ago an entertainment train used to be located. The samples were located on the tide channels and called AG1, AG2, AG3, and AG4 (Figures 8 and 11). On AG3 and AG4 logs, all the material obtained from 0 to 80 cm was beige and clear gray silty sand and clay deposits. On the AG1 and AG2 cores, the top of the samples is composed of beige and clear gray silty sand and clay deposits associated with this
low energy environment. At about 39 and about 50 cm deep, we can observe in these two cores a set of about 6 to 7 laminations characterized by fine and medium gray and white sand layers stratified with fine sand composed of magnetite, and very scarce pieces of broken marine shells. This layer is similar to the layer found in Espinar, but no clear oxidation is observed. Here the laminations are more clear and spectacular. So it is again suggested here that these laminations are the evidence of the 1918 tsunami, as are the deposits found in Aguada. The lamination layers are common in both logs at almost the same depth and similar to the one in ES1.

Evidence in the cliffs

The field investigation included the search of tsunami evidence in the cliffs of Punta Agujereada and Punta Borinquen using the criteria of Bryant and Young [1996].

Punta Agujereada

The zone between Punta Borinquen and Punta Agujereada presented evidence of a run up with up to 6 meters high (Figure 7) [Reid and Taber, 1919]. Reid and Taber [1919] mentioned that some rocks that were ripped out from the sea, carried out by the seismic wave, and were left on the beach at the moment of the event. Field evidence showed that along the coast there are boulders up to 10 meters in diameter located on the beach. The rocks are composed of limestones that have fell out from the cliffs. Marine erosion has eroded the base of the cliffs and the rocks came down due to the gravity as rock falls.

The field evidence suggests that these rocks fell down from the cliffs to the sea and were later tossed out against the cliffs or were taken laterally along the coast until they reached
the beach, as mentioned by a survivor in Aguadilla and as described by Reid and Taber [1919].

According to the Civil Defense Office in Aguada, during important storms or "bravatas", storm surges in northwestern Puerto Rico have caused remotion of the sand in the beaches, so mainly sandy coasts have retreated, some times up to 10 meters (Martín Concepción, personal communication). So, at least in the last 20 years storms have not taken materials from the sea to the beach. Instead erosion of the beach has occurred during storms.

In Punta Aguajera, just underneath of the US Army Base on the beach, possible rock impacts of more than 1 meter in diameter can be observed in the cliffs, in areas where boulders of this diameter are abundant along the coast (Figures 16a and 16b). Figure 8 presents the area where the evidence of these possible impact structures can be observed. In this case because the rocks are limestones, the lack of weathering, dissolution, and the formation of secondary carbonate in the exposed surface of a rock make the impact recognizable. This evidence consists of semi-circular broken surfaces in the rocks, following the contour of the rock shape. Similar structures have been observed by Bryant and Young [1986] in Australia, and have been associated with tsunami as well. The impact is about 4 m above the sea level.

A close up of the impact shows that the dissolution in the zone of impact is less than the dissolution in the surrounding area as evidenced by the change in color on the secondary carbonate in the limestone (Figure 16b). In the same area, but on the beach, many rocks with diameters between 50 and 100 cm were found about 50 meters from the coast, which could be also rocks that have been carried by the sea wave.
Punta Borinquen

The area of Punta Borinquen was also visited where a small creek comes to the sea, close to the old lighthouse. At about 70 meters from the beach inside the creek (Figure 17), there is a zone where a group of piled rocks with diameters of about 50 to 100 cm appear isolated. Piled rocks have been observed in zones where tsunami have penetrated on land in zones that present steep rivers or creeks Bryant et al., [1992], and Bryant and Young [1996]. These piled rocks which are limestones, were piled in the same area, suggesting that those rocks could be the evidence of the tsunami penetration limit in the area. The creek has not enough energy to carry out these rocks from the land to the sea because the water infiltrates in the karst. The presence of these rocks makes them very suspicious as indicators of tsunami penetration.

La Bajura

East of Punta Agujereada, in the area known as La Bajura, a coral of about 200 to 250 pounds and 100 to 120 cm in diameter is observed behind the natural sand dune that protects the coastal plain (Figures 8, 18a, and 18b). There are indicators that in some areas in the dune, which is a Holocene dune, has been washed out. Minoura and Nayaka [1991] have described this as a common process generated by tsunami (Figure 19). In this area, the coral was deposited behind the dune, after it was broken. This coral is located almost 50 meters from the beach behind a depression in the dune, at the front of a sandy fan-delta like feature (Figure 19). This coral is here also suggested as one carried from the sea by the tsunami and that the area removed from the dune, which is indeed a depression, is also the fossil path of the tsunami. Other paths can be observed also in other areas as well on the dune belt. The storm
surge in the area has been very strong during storms, but never strong enough to remove or
cross over the coastal dune in the area, and carry big pieces of corals, as observed by the
people living in La Bajura. People living in this area, about 1-2 km east of the coral location,
have not experienced a storm surge or inundation since 1918. This area appears in the historic
records of the Civil Defense office as one of the areas where the penetration of the tsunami was
more catastrophic, and the community was destroyed by the 1918 tsunami.

Historical records from other tsunami around the world show that boulders from
different origin and corals have been carried out from the sea to the coast. This is the case of
the 1996 Indonesia Tsunami, and the 1996 Nicaragua Tsunami (NOAA, 1999), so the
similarities of the coral in La Bajura and the boulders in Punta Agujereada and Punta
Borinquen are not too different from the evidences found in other regions of the world. So it is
suggested here that many of the boulders and the coral in the beach could be carried by
tsunami during seismic events.

Radiocarbon Dating

From the log ES2, two radiocarbon dates were obtained, assuming preliminarily that
the laminations found are associated to tsunami deposition. It is here assumed that combined
with log ES2, the logs of AG1, AG2, and ES1 have helped to define a possibly stratigraphic
definition of tsunami in a swamp environment in northwestern Puerto Rico. Table I show the
age of the radiocarbon samples and Figure 11 shows the stratigraphy and the location of the
samples.
After the calibration of the radiocarbon dates as presented by Sauvier and Kra [1986] using the program Oxcal, the age of the upper event at Espinar 1 (ES2) was dated about 1270-
1410 AD. However, the deeper event was dated about 820-400 BC. The events at AG1,
AG21, and ES1 have been assumed to be associated to the 1918 tsunami.

Assuming that the laminations in ES2 are associated as well with tsunami sedimentation, then with this data it is possible to preliminary suggest the first pre-historic record of tsunami in northwestern Puerto Rico (Figure 21). In this figure is presented the possible historic and pre-historic events around and in Puerto Rico obtained from this investigation.

It is important to mention that on other paleoseismic studies in western Puerto Rico, this author found liquefaction features expressed as sand injections on an archeological site on Rio Yaguez. The analysis of this site is out of the scope of this study, but two radiocarbon dates and paleoseismic interpretation of the site suggest that there was an important seismic event between 1300 and 1511 AD (Moya et. al., In prep). This is important due that the dates of the assumed tsunami deposits on ES2 in the upper laminations, overlap with the data in the archeological site at Rio Yaguez. This is another point that supports that these laminations on ES2 could be associated to a pre-historic seismic event occurred close to northwestern Puerto Rico.

Discussion

This study has presented some field investigations associated with the 1918 tsunami and previous tsunami. The evidences suggested here to be associated with this event were
compiled from historic, and field geologic and geomorphologic investigations, plus interviews from survivors developed by Mr. Kevin Acevedo, Mr. Martin Concepción, and this author.

It is accepted the limitation of the field techniques applied to the search of tsunami sedimentation in the swamps of Aguada and Aguadilla and this study should be considered preliminary. However, there is a repetition of sand laminations in different levels on the logs, which suggest that at least for the samples in logs AG1, AG2, ES1, and ES2. These sand laminations may be the indicators of different sea wave periods coming from the sea and bringing inputs of sandy magnetite and *Halemaida* Sp., to the low energy environment in the swamps. These sand inputs could be associated with seismic induced waves.

The data from log CA2 where it was composed of calcareous sand suggests that the sedimentation was different in this area. The layer interpreted as being associated with the 1918 tsunami, shows that there was not an unique stratigraphic signal left by tsunami in northwestern Puerto Rico. Local variations such as local sedimentary environment, sources of sediments, wave behavior, and geomorphic conditions in the local area, could change the stratigraphic record of tsunami. However, for the logs in the swamp of Aguadilla, sand laminations were common.

The laminations on ES2 are sedimentologically similar to the others at AG1, AG2, and ES1. However, the oxidation in the layers on the magnetite suggest that the possible 1918 event, was missed in the core and that the upper event according to radiocarbon dating, corresponds to an event occurred between 1270-1410 AD. An older event has been suggested here to have occurred about 820-400 BC, as suggested also by radiocarbon dating. Then, the events at AG1, AG21, and ES1 have been assumed as associated to the 1918 tsunami.
The date suggested by the radiocarbon date on the upper laminations on ES2 is very similar to the dates obtained from other two independent sources of liquefaction. This suggests that an important seismic event could occur between 1300 and 1511 AC, as suggested as well by archeological interpretations on the Spanish occupation in western Puerto Rico [Rivera and Silva, 1997]. The overlap in the dates on the archeological site at Rio Yaguez [Rivera and Silva, 1997; and Moya et al., in prep], and the date on ES2 are suggesting very strongly the existence of this important seismic event in western Puerto Rico between these dates.

The field investigations on the cliffs of Punta Agujereada and Punta Borinquen suggest that rock impacts observed on the cliffs have been associated with tsunami, mainly boulders located on the beach and far way from rock fall sources. The best evidence of boulders carried by the tsunami is for this author are, the coral observed in La Bajura, which is presented in figures 18a and 18b, and other boulders as presented in figure 22. There are good conditions in northwestern Puerto Rico for rocks or corals that will be tossed by future tsunami against the coast.

*Long-term geomorphologic changes and tectonic controls on the northwestern coast of Puerto Rico.*

The morphology of the northwestern Puerto Rico resembles a big embayment with a long “C shape”, which is concave toward the sea including beaches and cliffs. There are not other places like this around the entire island, so this morphology is indeed unique. Other bays with similar morphologies are composed mainly of sediments. From the field conditions observed, three main controls have been defined as the ones that have contributed to the morphological development of this region: tectonics, lithology, and tsunami.
First, active tectonic controls are very important for northwestern Puerto Rico. This can be observed onshore on the faults that are located just close to the beach in the marine canyon of Aguadilla [McCann and Mercado, 1997]. There, two active normal faults have contributed to the development of this important tectonic depression also called tectonic graben. These faults are the Borinquen and the Borinquen South Branch faults [McCann and Mercado, 1997]. Combined with the Mona Canyon or Mona Rift fault, these tectonic features have contributed to the development of a natural depression in Quaternary times. This graben points out directly to northwestern Puerto Rico, developing the conditions for a natural waveguide or natural tunnel, which contributes to the fast arrival of tsunami, and developing local conditions which are favorable for the impact of tsunami.

Observing the general geology of the marine platform north of Aguadilla and west of Rincon, and the active normal faults in the zone, it is here suggested that a minimum of 8 km of coastal retreat has occurred in the northwestern portion of Puerto Rico during the Quaternary. This is the result of tectonic subsidence forming the Aguadilla Canyon, which is connected with the Mona Canyon.

The second important condition is the presence of limestones. The karstic landscape in the area does not allow to the rivers to mature and develop a good alluvial or coastal plain, so the contribution of sand to the beach is poor. Only the Culebrinas river is the main source of sediments to the beach, but the concave morphology of the bay suggest that the sand balance is not enough to keep a sandy beach. Also, on the cliffs, the dissolution generated by the seawater on the limestones is very important. This dissolution at the contact of the limestones with the seawater at the base of the cliffs, creates a good conditions for the formation of rock falls. Figure 23 shows the importance of rocks falls in the cliffs of Aguadilla.
If the conditions for rock falls to occur are important on the cliffs, every time that an earthquake shakes the coast, the lateral forces generate many rock falls and landslides as described by Reid and Taber [1919] and as observed in the field (Figure 22). Combined the rock fall activity in the cliffs plus the lack of sand inputs from the rivers, we can expect an important geomorphic retreat in the long-term on the coast.

Finally, the last control of the coastal is the tsunami itself. Even with the limitations of two radiocarbon dates for the possible tsunami deposits, but two dates from the indirect observation of the liquefaction at Rio Yaguez, we can estimate preliminarily the impact of tsunami in northwestern Puerto Rico. The data on historic and prehistoric tsunami suggest events in 1918, other possible seismic event between 1300 and 1511 AC, and another about 820-400 BC. Based on just two dates the 1918 and the previous event about 600 years ago, we have at least 2 events in the last thousand years. Considering that there other faults in the Mona Passage capable to generate tsunami [McCann and Mercado, 1997], and considering that the tsunami wave traveling in the Passage will impact the northwestern portion of Puerto Rico due to the local conditions. Then, we can expect to receive tsunami in this region whatever could be the source in the region.

For example, it is reasonable to estimate that at least 2 seismic tsunamogenic events occur every one thousand years. This could be considered an estimate based in a rate of 4–5 mm/year of separation between Puerto Rico and Eastern Hispaniola [Calais, 1999]. The probability of more earthquakes with tsunami from different sources in the Passage, other than the Mona Canyon fault is real. There are several active faults capable to induce tsunami during seismic events in the Mona Passage [McCann and Mercado, 1997].
Considering the age of the Aguadilla and the Mona Canyons at least as Quaternary (at least formed in the last million of years), two tsunami events per thousand years in the last million of years, that means at least two million tsunami. This is considering that the conditions have been the same for the time suggested. Even just with one event every thousand year means about one million tsunami arriving to the coast in the last million years.

Then the combination of tectonic subsidence in the Aguadilla Canyon, the lack of renewal in the sand sources in the beach, the rock fall activity in the cliffs, which is traduced in cliff retreat, and the recurrence time of tsunami in the northwestern coast (at least one each thousand years), have made these factors very important in the coastal evolution of northwestern Puerto Rico. Again, if the physiographic conditions have not changed in the last million of years it is logic to think that in the long-term the impact of tsunami has been very important, enough to make a significant change in the morphology of the coast.

Conclusions.

Northwestern Puerto Rico has the conditions to be affected by future tsunami. The separation of about 4-5 mm/yr occurring between Puerto Rico and Hispaniola has generated a zone of extension occurring mainly on the Mona Passage, Eastern Hispaniola, and Western Puerto Rico. This means that potential seismic events associated with the faults in these areas could generate important earthquakes and tsunami. All the seismic sources located around Puerto Rico could induce important tsunami in northwestern Puerto Rico due to the submarine canyon coming from the Mona Rift to this area. Naturally, exist the features to generate seismic induced marine waves as occurred in the 1918 seismic event and the associated
tsunami. Also, any important submarine landslide could induce and develop an important tsunami for northwestern Puerto Rico.

The evidences proposed here of past tsunami, suggest that these events have produced important geomorphologic changes to the coast of Puerto Rico, as well as modifications to the environments, and marine sand inputs to the swamps. More detailed studies should be conducted to define more the signal of the tsunami in different environment to develop a very realistic hazard plan against these events, and of course the definition of pre-historic tsunami to establish the recurrence time of these events in northwestern Puerto Rico.

In general for northwestern Puerto Rico, the model of Mercado and McCann [1997] agrees with the description of Reid and Taber [1919], the interviews, and the field data. The areas to be more impacted by a future tsunami, will be exactly the areas reported by these sources. Important attention should be focused on the Aguadilla and Aguada beaches, and mainly on La Bajura.

It is not necessary to have another event of M7.3 as the event in 1918 to generate a catastrophic tsunami. As observed in other parts of the world, earthquake with magnitudes of about M7 or less could be also catastrophic if submarine slides are generated. The conditions in the Mona Canyon and its secondary canyons present the conditions for the generation of submarine slides because of its steep slopes. The problem here is that historic information is too scarce to fully make the public aware of the potential hazard.

Preliminary, it is suggested here that another tsunami as the 1918 event occurred between 1270 and 1410 AD, and other previous event at could occur about 820-400 BC. These data is not enough to define a recurrence time of tsunami, and has to be verified and validated with more field data based on detailed investigations. This work is only the beginning
of this investigation. This author accepts that the data presented here is incomplete and has to be improved with better stratigraphy. The sand laminations need to be confirmed as associated with tsunami sedimentation. However, the main conclusion is that northwestern Puerto Rico is controlled tectonically and has responded to the separation of Puerto Rico and Hispaniola, being tsunami one of the effects of this separation.

Acknowledgements.

The Sea Grant Program in Puerto Rico, under its Seed Money Grants granted this investigation. The support from Dr. Manuel Pizzini, Dr. Kurt Grove, and Dr. Aurelio Mercado is appreciated. Special and important support was provided for Mr. Martin Concepción from the Civil Defense Office in Aguada and his group. Also, logistic support was received by Mr. Mariano Vargas from the State Civil Defense Office in San Juan. Mr. Kevin Acevedo developed part of the interviews to the survivors of the 1918 tsunami and helped to improve the field investigations. Mr. Richard Webb from the U.S.G.S. in Puerto Rico supported the log analysis. Dr. William McCann provided data on seismic and tsunami sources. Mr. Pedro Quiñones analyzed the marine organisms. Special thanks are mentioned for Mr. Aibot Ramos from Aguada. Also to Dr. Carol Prentice from the USGS office in Menlo Park, Ca., for making possible the two radiocarbon dates for this project. Special thanks for the people that in many ways supported this investigation.
References.

Figure 1. Location of the Study Area in Northwestern Puerto Rico between Aguadilla and Rincon
Figure 2. Tectonic Setting of Western Puerto Rico in the Caribbean-North American Plate Boundary Zone.
PR: Puerto Rico; M: Mona Passage; BR: Beata Ridge; AP: Anegada Passage; and H: Hispaniola. Arrows indicate the direction of the tectonic plates movement.
Figure 3. Tectonic Units around Puerto Rico. BB: Bahamas Bank; SB Septentrional Block; ES El Seibo Microplate; MP: Mona Passage; and AP: Anegada Passage. [After McCann et al., 1998, and Moya, 1998].
Figure 4. Zones under extension between Puerto Rico and the Dominican Republic
[From: Moya, 1998].
Figure 5. Geology of Northwestern Puerto Rico. [From Jolly, et al., 1995]
Figure 6. Bathymetry, geologic faults, and morphologic features of the Aguadilla Canyon. A: Mona Canyon; B: Borinquen Fault; C: Borinquen South Branch Fault [From McCann and Mercado, 1997].
Run up heights in meters:
2 From Reid and Taber (1919)
2 From Survivors and witnesses

Figure 7 Run up observed by Reid and Taber [1918] and survivors ad witnesses from the 1918 tsunami.
B - Boulders carried out from the sea
C - Coral carried out
* - Marks of impacted rocks on the cliff
S - Sandy sediments in the swamp

Figure 8. Location of the results of the tsunami field investigations in Northwestern Puerto Rico.
Figure 9. Examples of some coring in the swamp of Aguada at Espinar.
Figure 10. Opened core showing the deposits in the swamp. Note the gray laminations composed of hematite and quartz.
Figure 11. Stratigraphy obtained from the cores.
Figure 12. Photo of the trench opened in Carrizales, Aguada.
Figure 13. Photo of part of the stratigraphy observed in the trench at Carrizales.
Figure 14. Generalized stratigraphy observed in trenches A and B.
Figure 15. Photo of suggested tsunami deposits on Carrizales, Aguada.
Figure 16a. Rock impact on the cliff observed in Punta Agujereada.
Figure 16b. Close up of rock impacts observed in Punta Agujereada.
Figure 17. Piled rocks observed in a creek located close to the old lighthouse in Aguadilla.
Figure 18a. Boulder of coral found behind the dune in Punta Agujereada, close to La Bajura. This coral is suggested to be carried by a tsunami.
Figure 18b. Close-up of a boulder of coral found behind the dune in Punta Agujereada, close to La Bajura. This coral is suggested to be carried by a tsunami.
Figure 19. Delta-fan structure observed in Punta Agujereada, close to La Bajura. This fan-delta is suggested to be formed by a tsunami.
<table>
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<th>AA#</th>
<th>Material</th>
<th>Sample ID</th>
<th>Mass (mg)</th>
<th>d13C</th>
<th>14C Age (BP) ± 1σ</th>
<th>2σ Calendar Age Range</th>
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<td>1270 - 1410 AD</td>
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<td>2,515 70</td>
<td>820 - 400 BC</td>
</tr>
</tbody>
</table>

Table 1: Radiocarbon calculations.
Figure 2.0. Historic earthquakes around Puerto Rico [After Moya, 1998].
LARGE AND IMPORTANT EARTHQUAKES OCCURRED IN PUERTO RICO

CALENDAR YEARS

- 1943
- 1918 Tsunami
- 1867
- 1787(?)
- 1640

- 1270AD-1410AD
- Tsunami

- 820BC-400BC
- Tsunami

Radiocarbon dates from suggested Pre-historic Tsunami deposits
Historic Events

Figure 21. Dates of historic and pre-historic earthquakes in NW Puerto Rico.
Figure 22. Rock falls in Punta Borinquen. These falls are suggested to be developed mainly during earthquakes by ground shaking.
Kurt Grove

From: Aurelio Mercado <a_mercedo@RUMAC.UPR.CLU.EDU>
To: Kurt Grove <k_grove@rumac.uprm.edu>, Dr. Manuel Valdes Pizzini <m_valdes@RUMAC.UPR.CLU.EDU>
Sent: Tuesday, January 12, 1999 1:31 PM
Subject: Fw: Tsunamis-Reporte Final

Informe de Juan C. Moya.

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-----Original Message-----
From: Juan Carlos Moya <jcmoya@hotmail.com>
To: a_mercedo@rumac.uprm.edu; a_mercedo@rumac.uprm.edu
Date: Tuesday, January 12, 1999 12:12 PM
Subject: Tsunamis-Reporte Final

>Te escribo para informarte que finalmente después de tanto tiempo las
>datocones de los terremotos y maremotos del noroeste llegaron. Es una
>pena que llegaron después de mi defensa. Pero aquí están. Tenemos
>eventos en:
>A. 1918
>B. 1270-1410 AD (Antes o en la época en que llegó Colón)
>C. 820-400 BC (Antes de Cristo)
>
>Aun menos es lo que dieron los fechamientos. Del fechamiento de la
>ubicación de arena en el yacimiento arqueológico del Río Yagüez, hay
>otro evento sísmico, aquí se tomaron dos muestras:
>1210-1390 AD
>1240-1390 AD
>
>Las muestras fueron tomadas del mismo horizonte y concián, o sea que
>posterior a estas fechas vino el evento, que pudo ser antes o en el
>1670. No hay record de otro evento después. Es probable que pudiera ser
>el mismo evento que origino el maremoto B, las fechas son algo similar a
>caen en el umbral +/-
>
>Para Yabucoa tenemos un evento de maremoto fechado en:
>D. 1310-1460 AD
>O sea que está el evento de finales del siglo pasado y otro, el D entre
>estas fechas.
>
>En general creo que el trabajo que realiza fue serio pero no creo que
>sea suficiente. La metodología aunque fue realizada la mejor posible
>no se necesita ser mejorada. El muestreo de todo el pantano de Aguadilla cerca
>del parque debiera ser una prioridad para así definir la estratigrafía
>de los maremotos de una forma mas contundente. Ya sabemos cual es la
> evidencia, así que sería más fácil reconocerlo.
>
>Creo que los resultados son bastante decentes pero aun queda muchísimo
>por hacer y datar. Con más datos se puede hacer estadística y confirmar
>si estos eventos son los unicos o si hay mas, y en el extremo de los
>casos si las dataciones están equivocadas, siempre aunque remota cabe la

9-10-99
> posibilidad.
> 
> estoy tratando de terminar el reporte final para antes del lunes. Estare
> en la conferencia de Subduccion oblicua en Puerto Plata el proximo
> lunes, durara una semana y de ahí voy a Puerto Rico al área oeste, así
> que en algun momento dentro de dos semanas pasare a visitarlos. El
> reporte ya casi esta pero quiero trabajar la interpretacion un poco mas.
> 
> la pregunta es: habra dinero de Sea Grant para continuar esto con mejor
> tecnica y con una propuesta mas robusta?
> 
> espero verte pronto y hablar mas de esto en detalle. Por favor puedes
> mencionarles a los de Sea Grant los resultados?. Pronto hare llegar el
> informe.
> 
> saludos
> 
> juan carlos moya
> 
> get your free email at http://www.hotmail.com
September 12, 1999

Dr. Kurt Grove
Research Coordinator
Sea Grant College Program
PO BOX 9011
Mayaguez, PR 00681-9011

Dear Dr. Grove:

I hope everything is fine at Mayaguez. I am sending you the final document on the Tsunamis in Puerto Rico (Seed Money Project) which was called: "STRATIGRAPHIC AND GEOMORPHOLOGIC EVIDENCES OF HISTORIC AND PRE-HISTORIC TSUNAMI IN NORTHWESTERN PUERTO RICO".

I am including you the original report and two copies. Even that I do not have receipts, my final cost to finish this report was $190.00 in office materials, reproduction, and others. The remaining money of the budget could be used to reproduction at your discretion.

I hope that this work can be considered a contribution to the tsunami studies in Puerto Rico.

Finally I want to inform you that after September 20, 1999 I will be working for the Texas General Land Office, Coastal Studies Division, out in Austin, TX. It took me so long to give you this final report because I have been packing and dealing with too many things out in Austin. As soon as I have my new address I will give it to you. You can get in contact with me until December in my same mailing address here in Boulder, CO.

Thanks for the support to this study and I hope to continue contributing to develop coastal studies in Puerto Rico through the Sea Grant College Program.

Cordially,

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