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EARTHQUAKE VULNERABILITY STUDY OF THE MAYAGUEZ AREA, WESTERN PUERTO RICO

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ABSTRACT

Historically the Mayagüez area in Western Puerto Rico has been affected by damaging earthquakes. The vulnerability of Mayagüez has been studied by evaluation of five shallow earthquake source regions. Three of the source regions are relatively distant from Mayagüez and, therefore, their potential impacts are only moderate. One source region close to Mayagüez presents the highest potential for severe damage. Primary earthquake and tsunami effects, as well as geologically induced earthquake hazards have been identified for a model earthquake. The presence in some areas of recent beach and swamp deposits, landfills on saturated alluvium, and naturally unstable slopes caused mainly by weathering, as well as heavy rains and land use could exacerbate the earthquake hazard by the triggering of ground shaking amplification, liquefaction, and landslides. There is a high probability of a tsunami accompanying a major submarine earthquake. Accordingly, the coastal zone should be considered one of multiple geologic hazards in case of a major earthquake.

INTRODUCTION

Western Puerto Rico, is one of the most seismically active regions within the island of Puerto Rico. In 1918, the area experienced the effect of a magnitude $7.5M_S$ earthquake whose epicenter was located in the northern part of the Mona Passage, west of the town of Aguadilla. The earthquake caused a significant amount of damage to life and property. The impacts were reported by Reid and Taber (1919a, b) which mentioned that this event killed 114 persons and caused 4 million dollars in damage.

The present study investigates the potential earthquake hazards near Mayagüez, west-central Puerto Rico (Figure 1). The area is bounded by latitude 18° 07′ 30" N and 18° 15′N

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and longitudes 67° 05′ W and 67° 15′ W and lies some 110 kilometers WSW of San Juan. Different earthquake sources are considered and the diverse aspects of potential geologic hazards induced by earthquakes are examined. These include ground shaking, ground rupture, liquefaction, ground shaking amplification, landsliding and tsunami. Following the methodology used by Molinelli (1985 and 1988), the Mayagüez Quadrangle and the westernmost part of the Rosario Quadrangle will be described in terms of three levels of susceptibility to a particular hazard as determined by the geologic, hydrologic, geomorphic, and tectonic characteristics of the area. The resulting maps are designed to be a useful tool to planners and decision makers to provide essential information for earthquake preparedness and planning response, land use planning, estimation of economic loss, and implementation of mitigation strategies.

SEISMOTECTONIC SETTING

The tectonics of Puerto Rico have been described in some detail for both offshore and onshore regions (Western Geophysical Research, 1974; Asencio, 1980; McCann, 1985 and 1987; Geomatrix, 1988; McCann et. al., 1991).

Offshore Characteristics- Seismic activity near Puerto Rico results from the moderately complex tectonic activity produced by the oblique convergence between the North American and Caribbean Plates (Sykes et al., 1982). The rate of movement between the North American and Caribbean Plates has been estimated to be as high as 37 mm/yr or as low as 20 mm/yr (Sykes et. al., 1982). The island of Puerto Rico has been described as one of a series of narrow, linear tectonic blocks trapped between these two plates, thereby subject to a convergent shearing stress (Asencio, 1980; Byrne et al., 1985). More specifically,

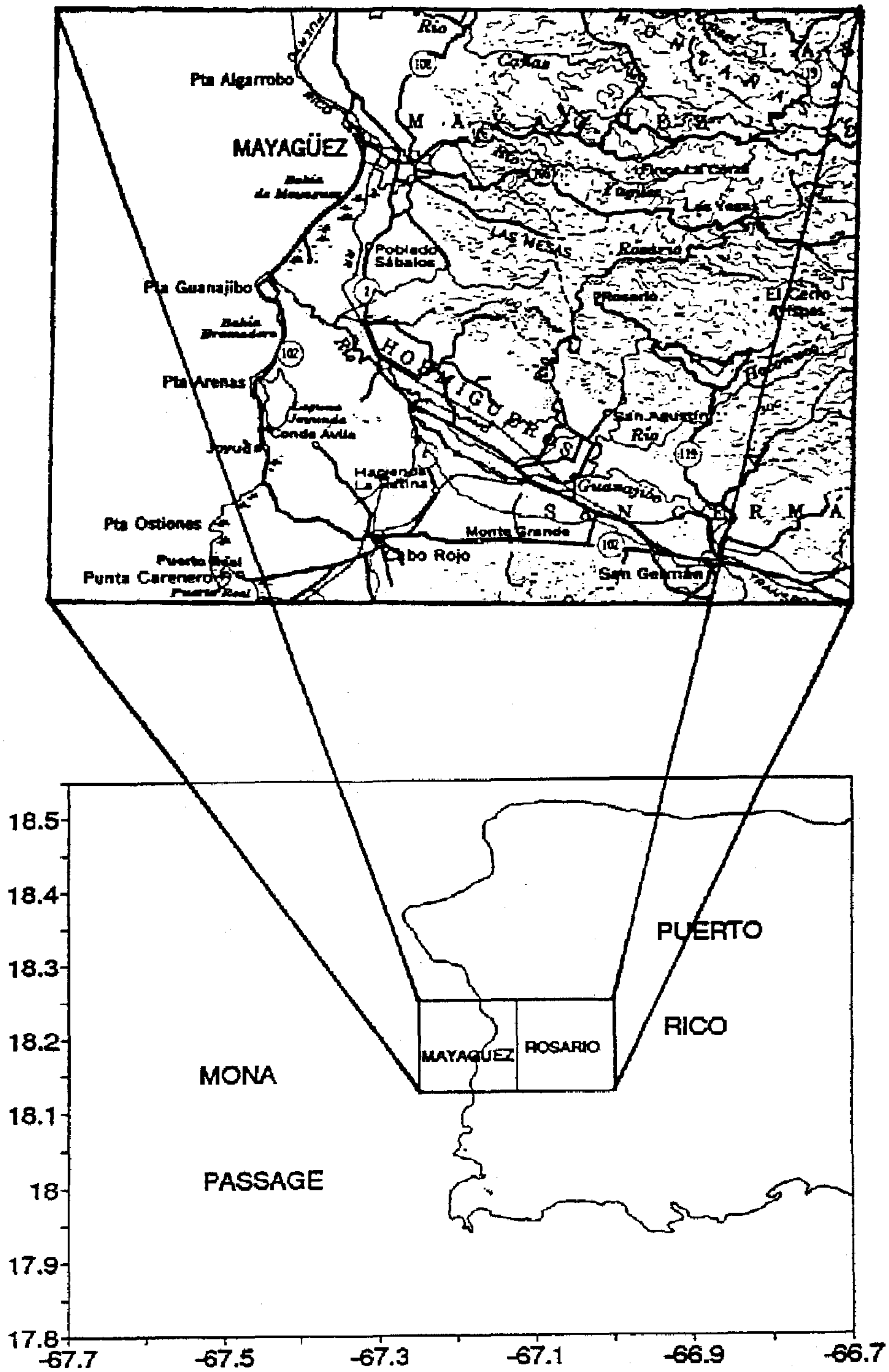

Figure 1. Location of The Mayagüez Zone in relation to Western Puerto Rico.

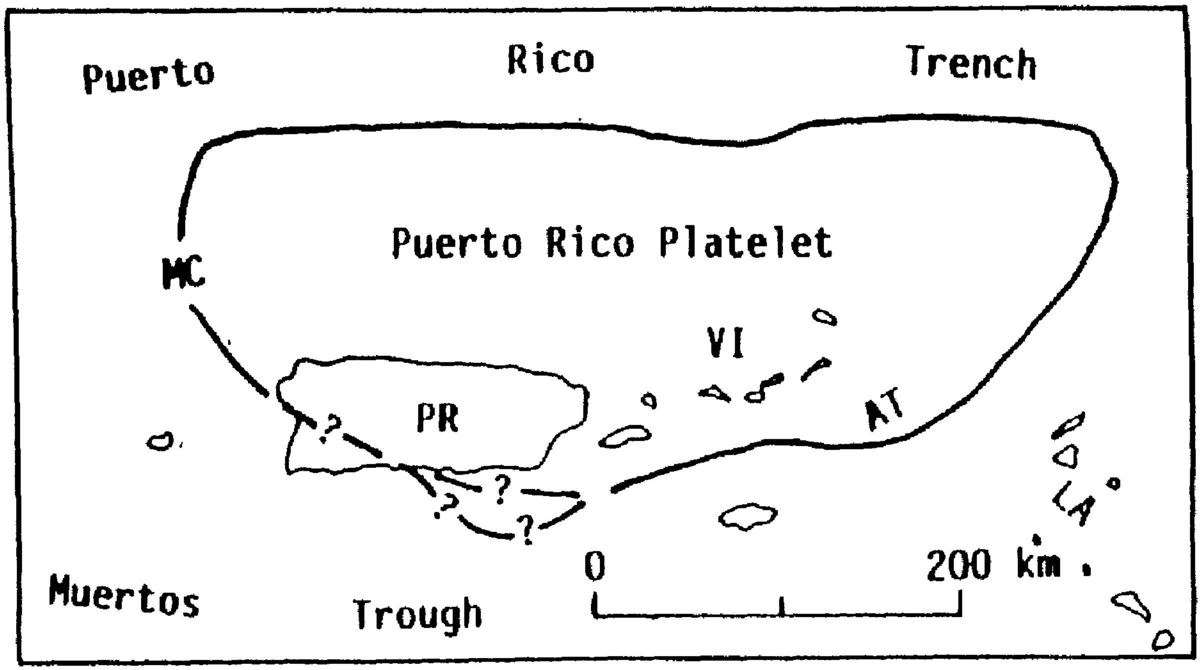

Figure 2. Approximate limits of the Puerto Rico Platelet. From Byrne et. al. (1985); McCann et. al. (1987); and Geometrix, (1988).

geophysical data demonstrates that most of the island of Puerto Rico lies on the Puerto Rico Platelet (Figure 2; Byrne et al.,1985; McCann et al., 1987). Four active tectonic areas bound the Puerto Rico Platelet. They are: the Puerto Rico Trench, the Anegada Trough, the Muertos Trough, and the Mona Passage and Western Puerto Rico. Each one has distinct morphological, tectonic and seismological characteristics (Figure 3). Only the Anegada Passage is of lesser importance because of its great distance from western Puerto Rico.

Puerto Rico Trench- The main axis of the Puerto Rico Trench lies approximately 100 km north of the island of Puerto Rico where it reaches a depth of more than 8 km. The trench is the site of oblique subduction of the North American Plate beneath the Puerto Rico Platelet (Sykes et al., 1982 and McCann et al., 1991). The historic and instrumental record demonstrate that strong earthquakes have occurred in the trench in the past (McCann, 1987).

Muertos Trough- The Muertos Trough lies about 75 km south of Puerto Rico. This tectonic feature reaches a depth in excess of 5 km and represents the southern limit of the Puerto Rico platelet. The Muertos Trough has all the characteristics of a subduction zone. Seismicity suggests that the relative rate of motion here is much lower than in the Puerto Rico Trench and that the largest earthquakes are smaller than those in the Puerto Rico Trench (McCann, 1985). No historic earthquake has yet been associated with the trough.

Mona Passage- The Mona Passage is located between Hispaniola and Puerto Rico. Seismicity in this area threatens all the west coast, including the city of Mayagüez. The tectonics of the area is complex, consisting of a series of grabens and horsts probably undergoing oblique extension (Asencio, 1980; McCann, 1985, McCann et. al 1987; Joyce et

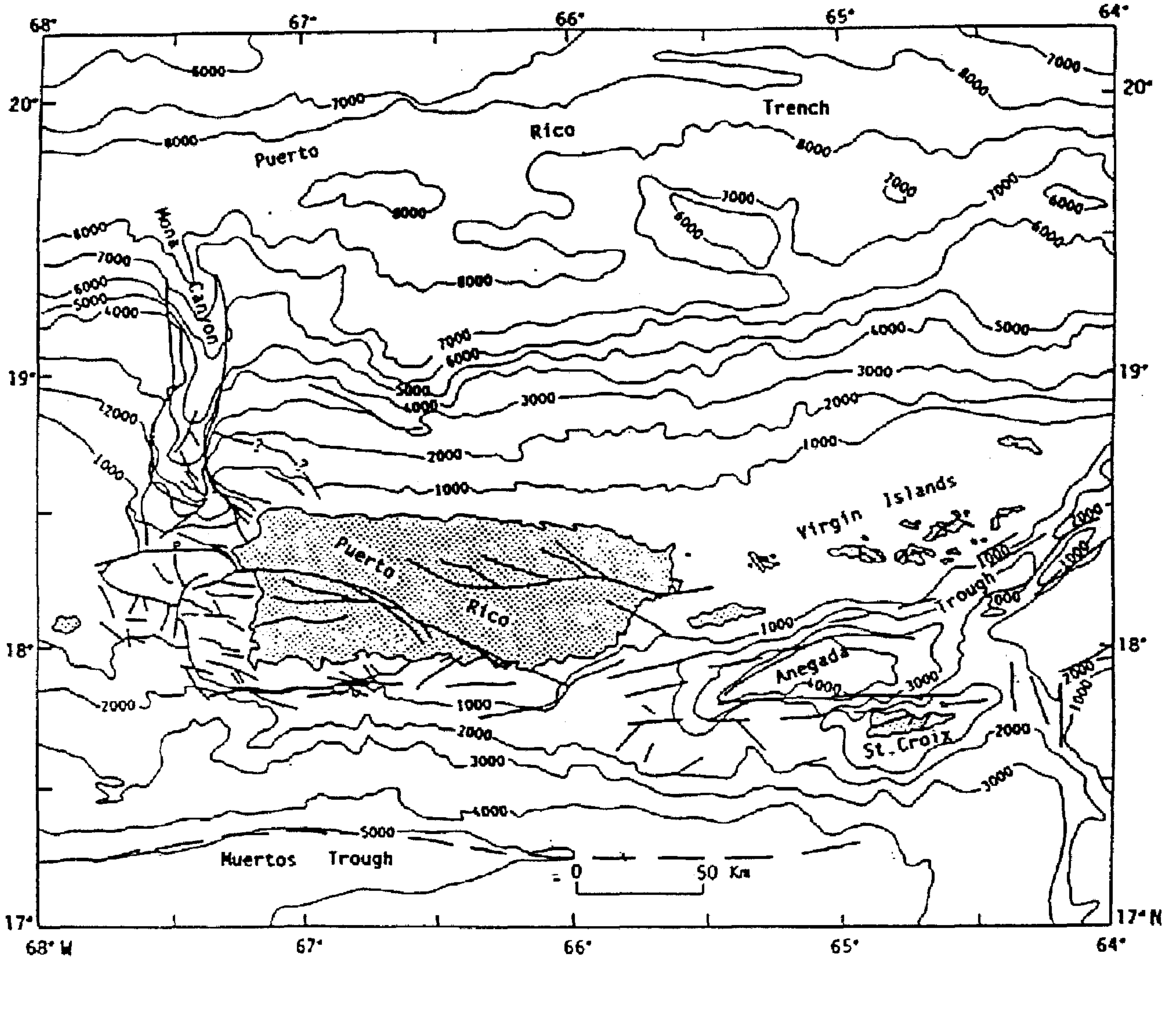

Figure 3. Bathymetry and tectonic zones around Puerto Rico. From Geometrix (1988).

al. 1987; and McCann et al., 1991).

The 1918 earthquake (7.5M_S) was felt in western Puerto Rico, and originated on one of the faults that bound the Mona Canyon in the northeast part of the Mona Passage (Reid and Taber, 1919a; Asencio, 1980; and McCann, 1985). Asencio (1980) established two sources of seismicity inside of the Mona Canyon: the east and west Mona Canyon fault zones. The West Mona Canyon Fault truncates the Great Southern Puerto Rico Fault Zone (GSPRFZ).

Onshore Characteristics- The GSPRFZ dominates the tectonic structure of Western Puerto Rico (Figure 4). It has been described as an extensive system of northwest-trending high-angle faults with predominantly left-lateral offsets (strike-slip) throughout their history. The fault zone onshore extends 112 km from Punta Higüero in northwest Puerto Rico to Bahía de Jobos in south central Puerto Rico (Asencio, 1980). The Great Southern Puerto Rico Fault Zone (GSPRFZ) lies generally to the north of the Western Puerto Rico seismic zone and in terms of recent tectnonics may be less important than its extension offshore;. (Briggs, 1964; Garrison, 1969; Seiders et. al., 1972; Asencio, 1980, Trumbull, 1981; and McCann, 1985). One of the most important faults in this system is the Cordillera Fault. It appears to have had the most recent movement since it cuts other faults in the same system. Another important fault is the Mayagüez fault, the details of which will be discussed later.

REGIONAL SEISMICITY

McCann and Sykes (1984) and McCann (1987) estimate the long-term activity of shallow focus along the Caribbean-North American plate boundary. They identify potential seismic sources around Puerto Rico and estimate maximum magnitude for these as wel as

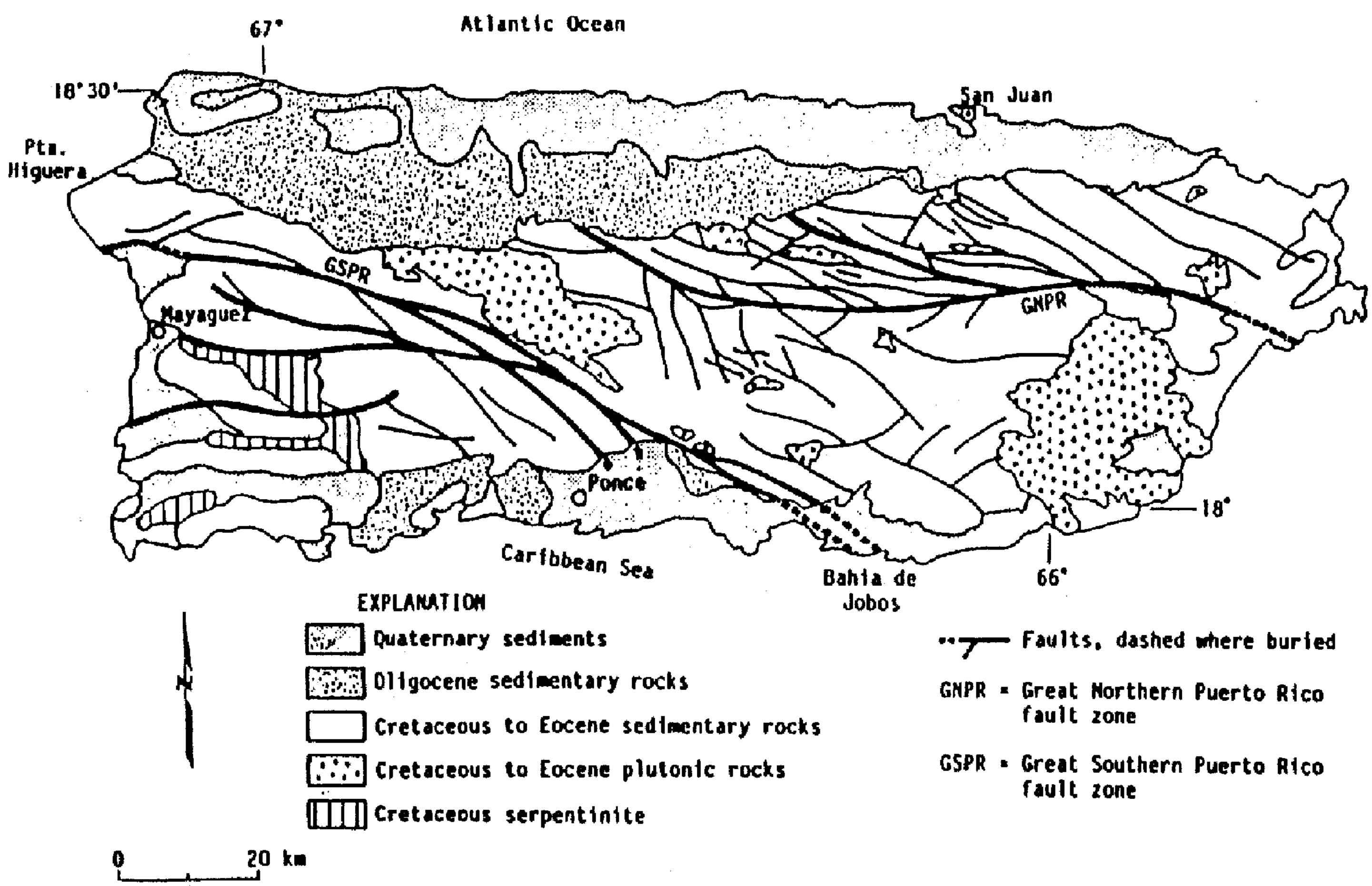

Figure 4. Generalized geologic map with fault zones in the Puerto Rico Area: GSPR is Great Southern Puerto Rico Fault Zone. From Geomatrix (1988).

and their long-term activity (Figure 5). Although Puerto Rico region has historically has been shaken by strong earthquakes (≥ 7.0) on average twice every century (McCann, 1987), in terms of Modified Mercalli Intensity (MM), the island experiences on average an intensity of VIII (MM) or more only once every hundred years (Molinelli, 1985). The three most important earthquake potential sources that could produce significant ground shaking in the Mayagüez Region are the Puerto Rico Trench, the Muertos Trough, and the Mona Passage and the Western Puerto Rico seismic zone (Reid and Taber, 1919a; Asencio, 1980; Trumbull, 1981; McCann and Sykes, 1984; McCann 1985; Geomatrix, 1988; and McCann et al. 1991).

Historical Earthquakes- Asencio (1980) shows that at least 40 events can be identified in the historical record as originating in Mona Passage or northwest Puerto Rico. The same author also mentions the Central and SW Mona Passage as the locus of several strong, intermediate depth earthquakes. The most important events felt on the island in the past 400 years are shown in table 1. Numerous historical accounts exist for earthquakes in the Mayagüez area. The Catalog of Regional Seismicity for the Mayagüez area from 1524 to 1958 as compiled by Asencio (1980) is included in Appendix A.

The 1918 earthquake affected the Mayagüez region and is the best documented large event in Puerto Rico (Reid and Taber, 1919a). It was located in the Mona Canyon west of Aguadilla and was assigned a Richter Magnitude of 7.5. This event has been considered the most damaging in the history of the Island. During the 1918 earthquake, local variations in damage caused by ground shaking amplification occurred as a result of local geological

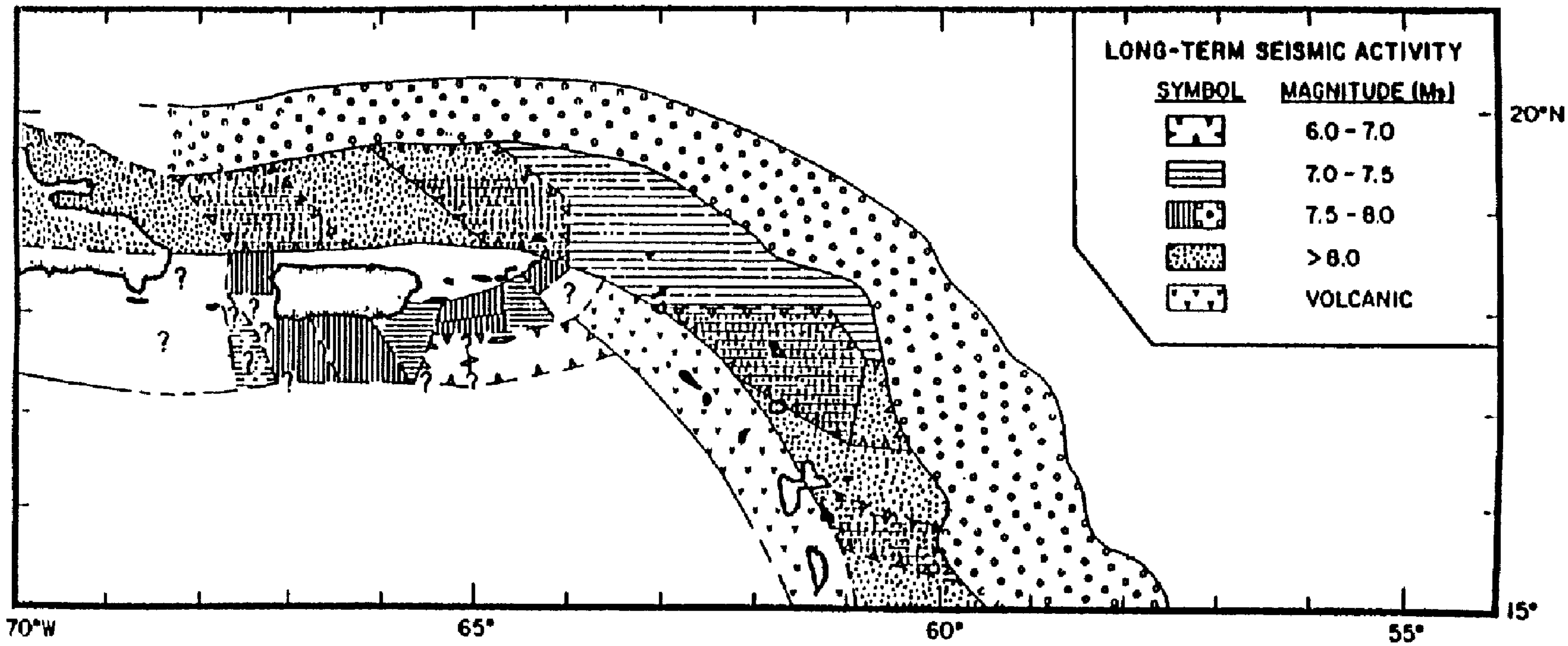

Figure 5. Estimate of long-term activity of shallow focus along the Caribbean - North American plate boundary. From McCann and Sykes (1984).

Table 1. Most significant historical earthquakes in Puerto Rico, (After Asencio, 1980)

1524 - Data is not clear, the home of Ponce de Leon was destroyed in Añasco either by a storm, indians or an earthquake.

1670 - Damage in San German, felt in San Juan, three months of aftershocks (probably more than magnitude (M) 6.0 to have three months of aftershocks).

1787 - Damage in different zones on the island. The source could be from the Puerto Rico Trench with magnitude as large as 8.0.

1867 - Damage in eastern Puerto Rico. Generated in the Anegada Trough, M = 7.5 (Reid and Taber, 1919a).

1918 - This event is the best known large event in Puerto Rico. The damage was greater in the west coast of the island. The epicenter was located in the Mona Canyon with M = 7.5 (Reid and Taber, 1919a).

conditions. Major damage occurred in areas built on alluvium. Aguada, Añasco and Mayagüez suffered the most building damage mainly because of ground motion amplification in the alluvium. The range of isoseismal intensity in Mayagüez was between VII and VIII (Rossi-Forel adapted scale).

Based on the historical data, it is clear that historically large events located around Puerto Rico have not repeated in the same place. The data show that zones with seismic potential are spread around and throughout the island. Any zone that has not yet generated significant earthquakes could very well be the next source: This includes areas within Puerto Rico and the Virgin Island platform, as well as the surrounding submarine areas. In the case of source zones located on land, historic data are poor and are not sufficient for the definition of source zones.

Shallow Earthquakes- Seismic activity varies strongly across the western part of Puerto Rico (figure 6). The northern region is nearly aseismic, with significant seismic activity onshore only apparent south of about 18° 15´ N. Seismic activity is not evenly distributed throughout the active region. In Figure 6 one can see the regions of relatively high seismic activity. Contours enclose regions in which at least one event was found within a region with a radius of 2.5 km and whose region connected with those of at least 4 other events. This method tends to define regions of concentrated seismic activity (i.e. SW Puerto Rico seismic zone) and exclude those of low-level activity (the aseismic area on northern Puerto Rico). The seismic zone is probably more completely defined in the onshore region because the detection threshold of earthquakes is lower there. Therefore, large breaks in the seismic zone in the marine area are probably due to an incomplete seismic record.

A large aseismic region is found in the shallow platform off the southern part of the west coast. It is bounded on the north by the edge of the platform and a westerly trending group of earthquakes. The lack of earthquakes in the platform is remarkable when compared to the regions to the north and east of it. There is also the suggestion of events aligned NNW along the western flank of the platform as defined by the 100 m bathymetric contour. The northeastern edge of the seismic region trends NW from about Añasco in the northwest, to about Salinas in the southeast. Paralleling that aseismic-seismic border, but in the area of seismic activity, there is an aseismic strip extending almost from Mayagüez to the southern coast outside the study area. The strip of outlying seismicity coincides, at least in part, with the GSPRFZ.

McCann et al. (1991) define three major faults near the coastal region of west-central Puerto Rico. These are the: Mayagüez, and Guanajibo Faults and the Desecheo Fault

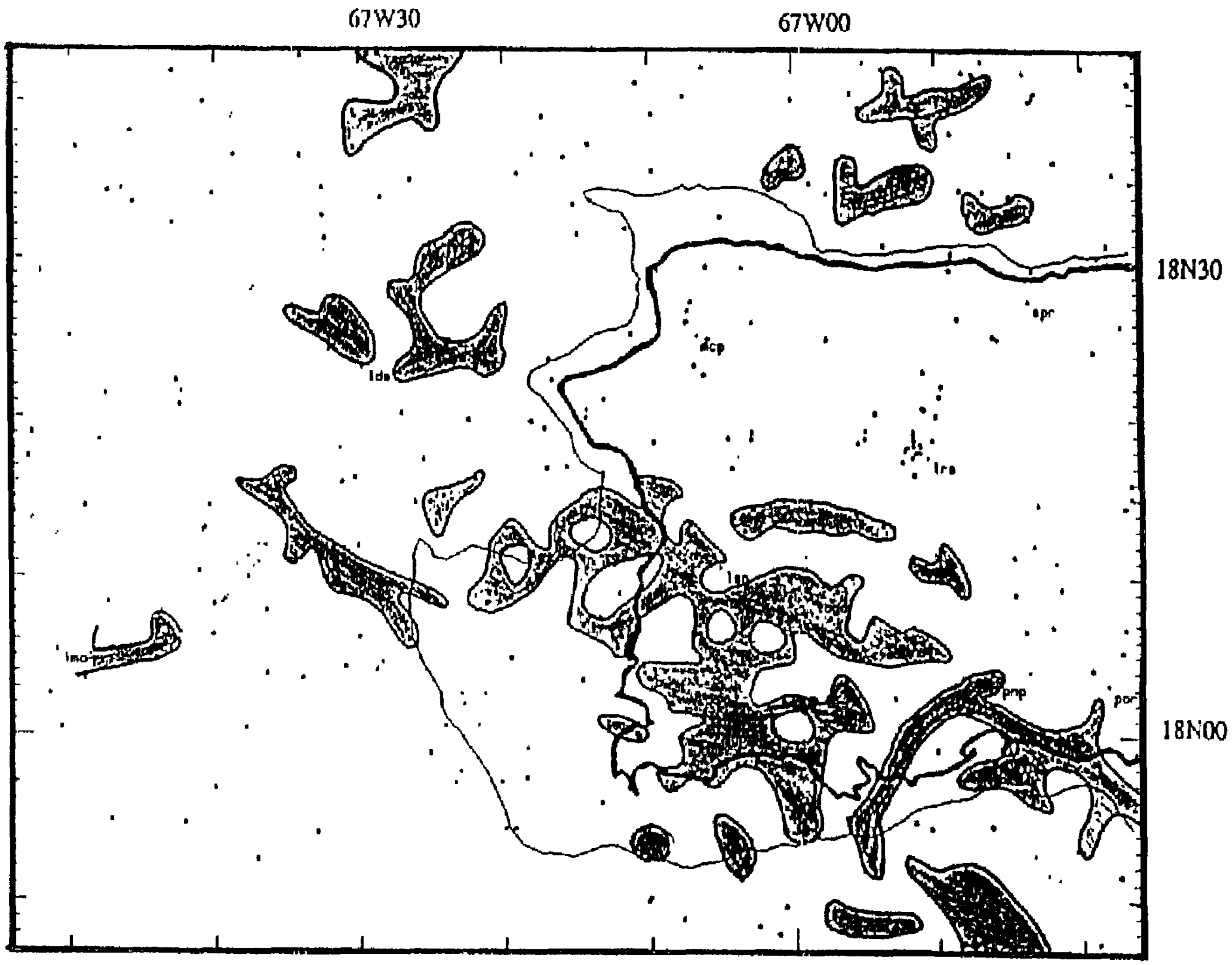

Figure 6. Western Puerto Rico seismic Zones. From McCann 1991.

system. The Desecheo Fault System is composed of the La Cadena, Ensenada and Higüero fault segments. All of these faults appear to be associated with extension and some (as yet undetermined) quantity of strike-slip motion. The extensive shelf off the southern part of the west coast is mostly free of major faults. Other major faults appear off the coast of northwest Puerto Rico, and are associated with the well-known Mona Canyon fault system (Western Geophysical Research, 1974).

Using the data available, a series of studies have been made to identify potential seismic sources in Western Puerto Rico. Based on interpretation of aerial photographs and SLAR (Side Looking Airborne Radar) imagery (Figure 7a,b) some geomorphological and structural lineaments with tectonic landforms preserved such as truncated spurs, fault scarps, linear creeks, offset of currents and drainage anomalies were defined. These features were checked in the field and could be considered as possible Quaternary faults.

La Cadena and Other Possible Faults- Offsets of streams and trucated drainage at the front of the La Cadena Ridge to the north of the study area were found. This evidence led us to consider the likelihood of a strike-slip system with a normal component along the south side of the ridge. This evidence must be analyzed in detail to determine if the origin of these features is completely tectonic. Two other features were observed in Western Puerto Rico, a lineament with truncated spurs in the Sabana Grande area, and small but continuous lineaments and possible segmentation of faults and ridges (en echelon patterns) in the Lajas and Guánica area, to the south of the study area.

Using the seismological and morphological data onshore and offshore Western Puerto Rico, and following Asencio (1980), McCann (1987), Geomatrix (1988), and McCann et al.

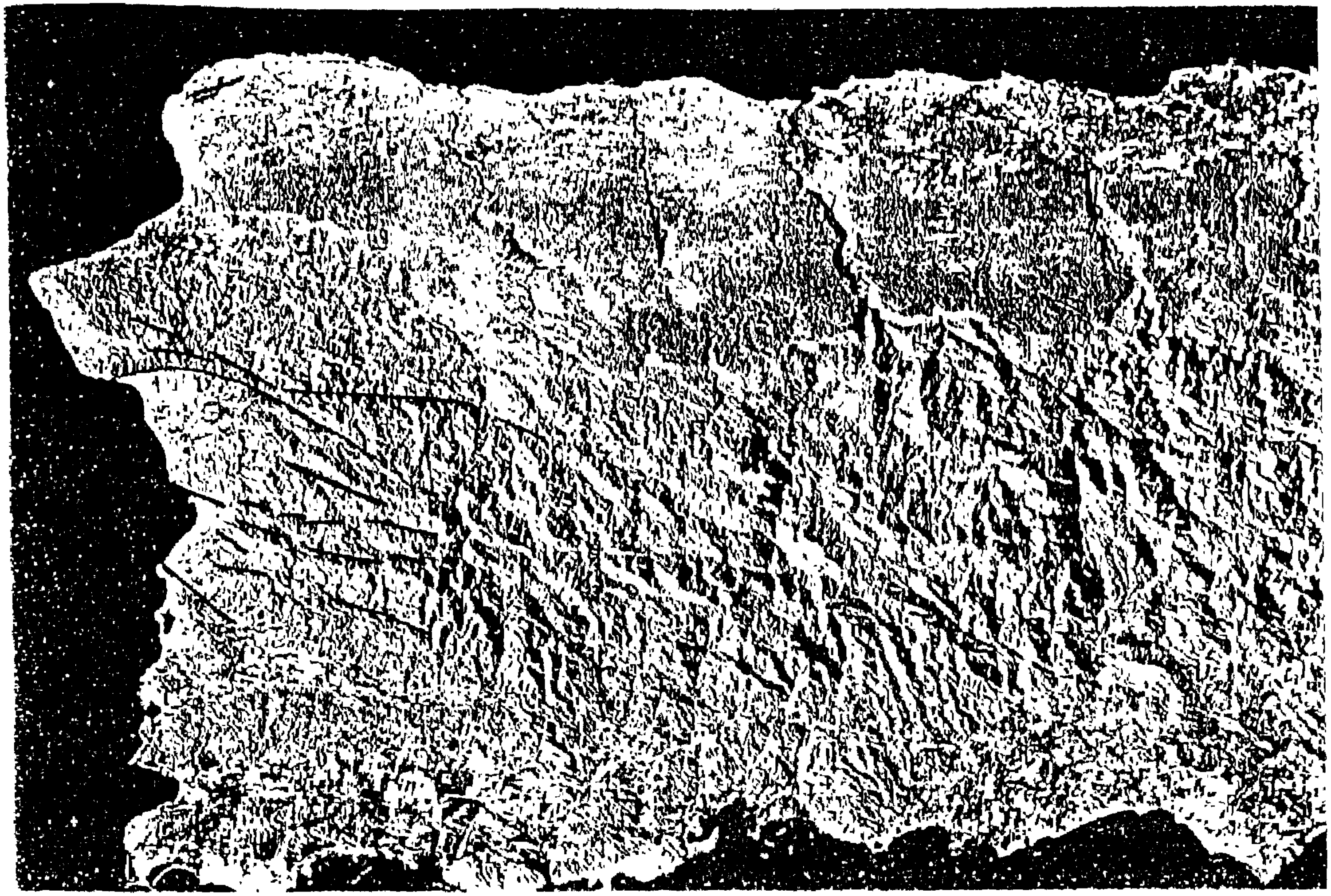

Figure 7a. SLAR Imagery. Areas Showing lineaments associated to possible faults in wester Puerto Rico.

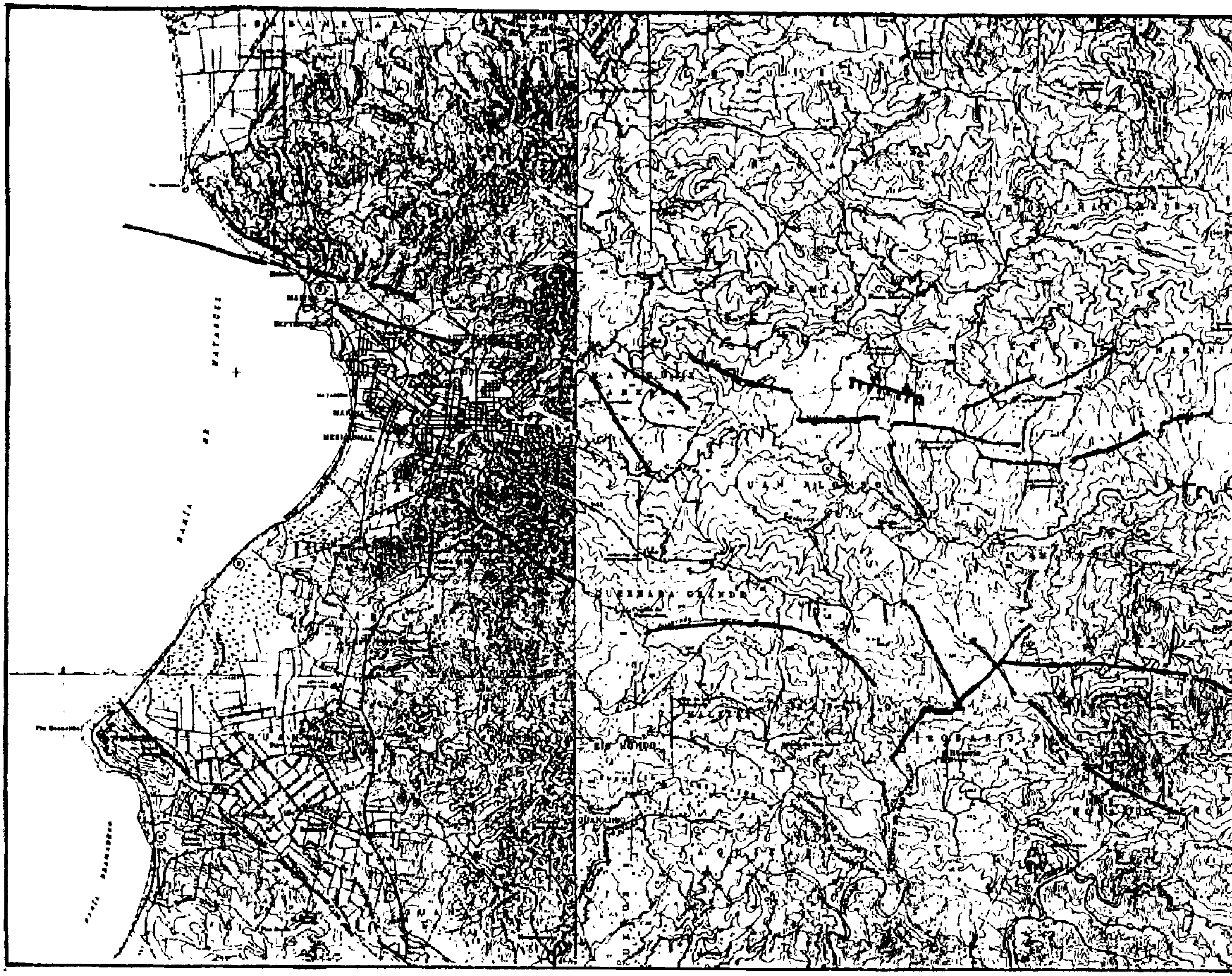

Figure 7b. Morpholineaments better expressed in the Mayaguez Area.

(1991), two features were considered as potential seismic sources.

Mayagüez Fault- This feature appears as a seismically active fault zone that extends from the offshore zone to the onshore zone in Mayagüez. McCann et. al. (1991) have defined a length of about 15 km and a depth of 20 to 25 km, giving it the potential to produce a maximum event of about 6.5. The fault strikes 300° and dips SW85° (Figure 8). Asencio (1980) has defined some geophysical aspects of this fault such as: spatial hypocenter distribution, scarps in the offshore, the focal mechanisms, and the depth distribution of hypocenters (figures 9, 10, and 11). Some Quaternary landforms associated with the apparent easterly extension of this fault were found in the field. These are: an apparent small pull apart in the "El Recreo" area, linear valleys, aligned swale, knots of fractures, triangular facets, fault scarps modified by landslides and ponded alluvium. Webb (pers. comm., 1991) found Holocene features in marine sediments in Mayagüez Bay and fractured coral associated with the offset of the Mayagüez fault, suggesting recent fault activity affecting nearshore morphology.

Cordillera Fault- Using microearthquake locations, McCann et al. (1991) defined a seismotectonic feature with a length of approximately 18 km, azimuth of 281° and a dip of SW80° (Figure 12). Moya (unpub. data) found geomorphological irregularities associated with this fault such as scarps, faceted ridges, linear valleys, ponded alluvium, and troughs. A tectonic and geomorphologic analysis of all evidence for the existence of the Mayagüez and Cordillera faults are outside the scope of this study because the specific purpose of this work is earthquake induced geologic hazards.

Intermediate Depth Earthquakes- Subcrustal earthquakes could also be strongly felt in

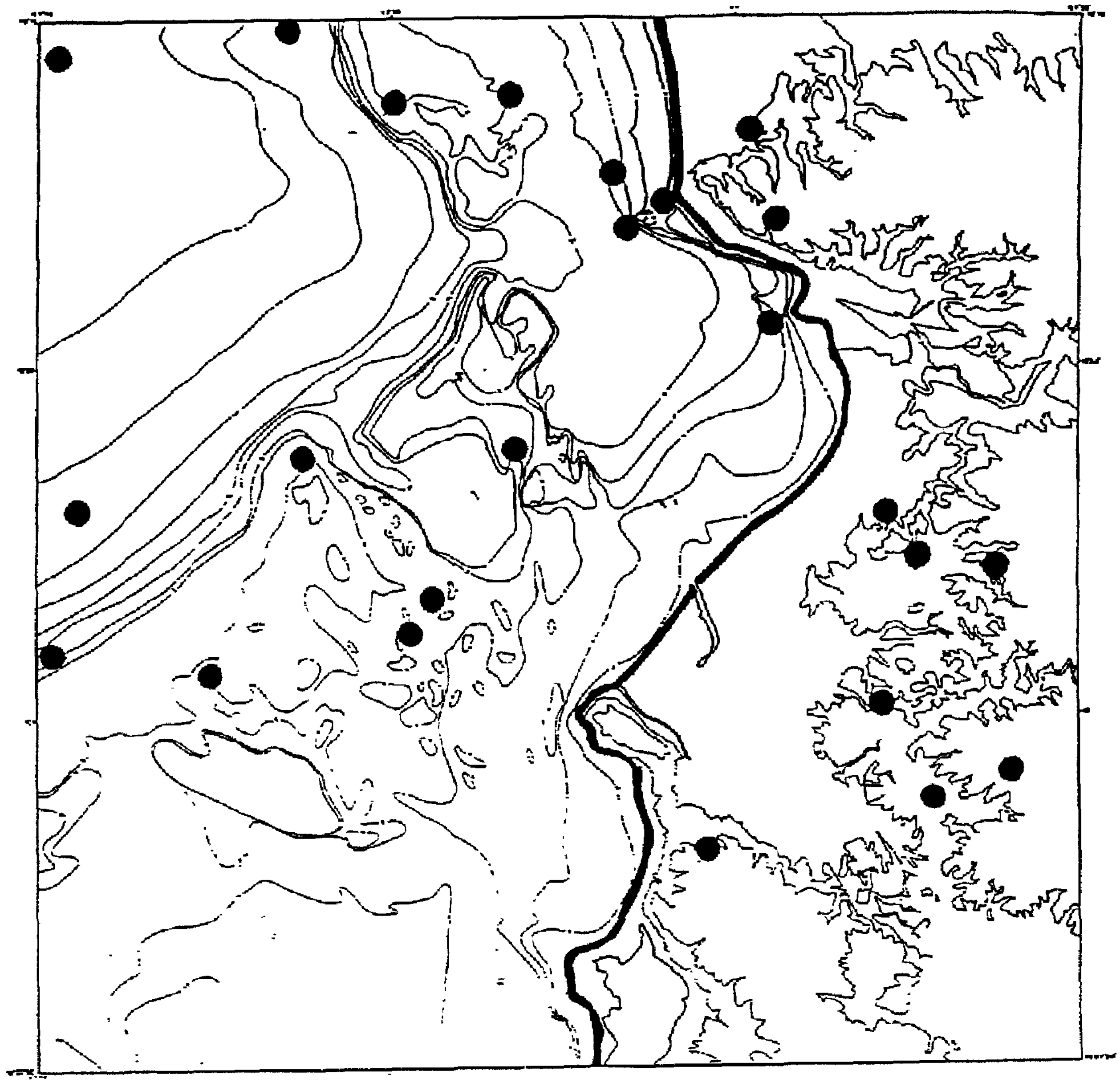

Figure 8. Earthquake epicenters in the Mayagüez quadrangle. From McCann 1991.

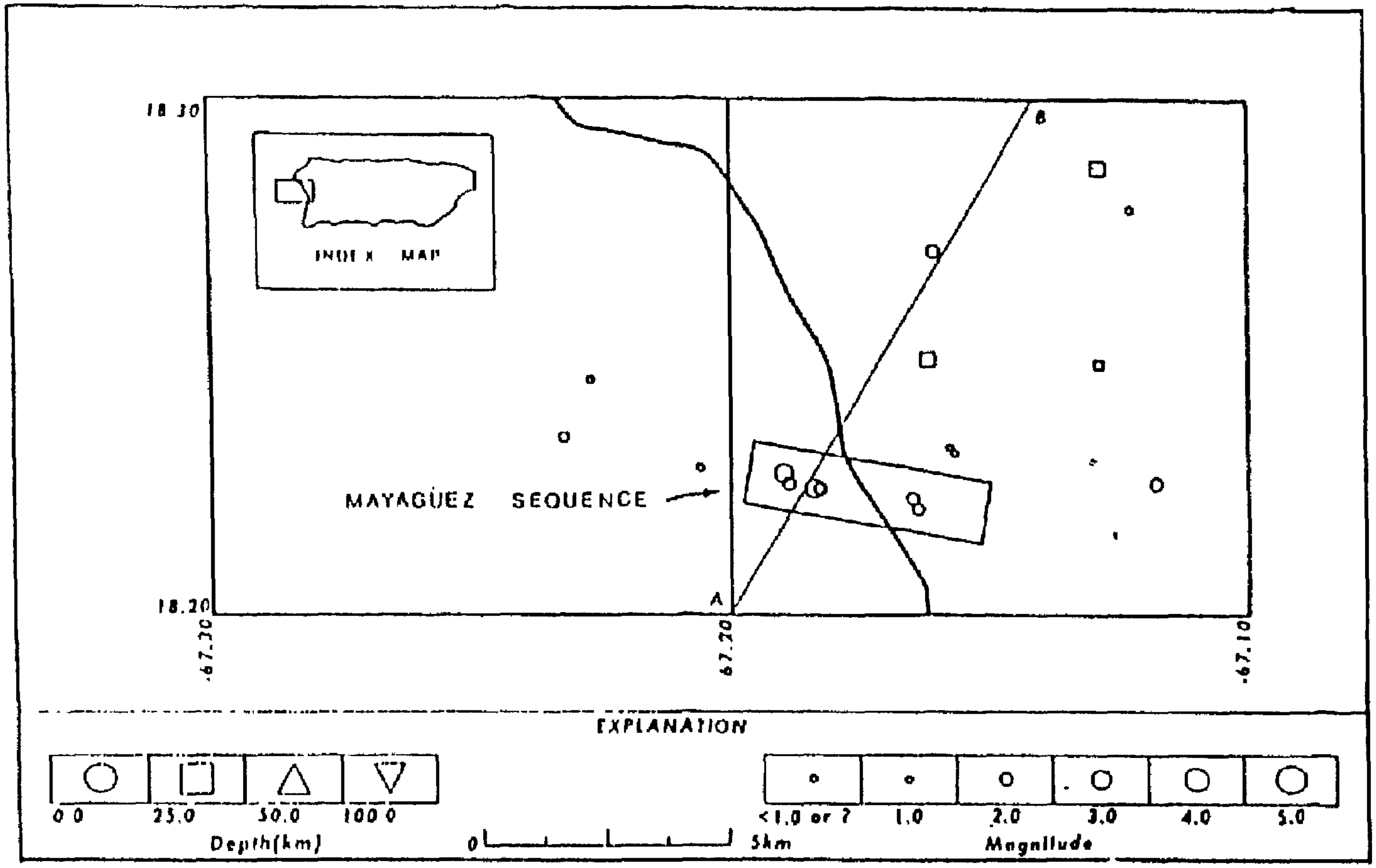

Figure 9. Spatial hypocenter distribution delineating the Mayagüez Fault. From Asencio, 1980.

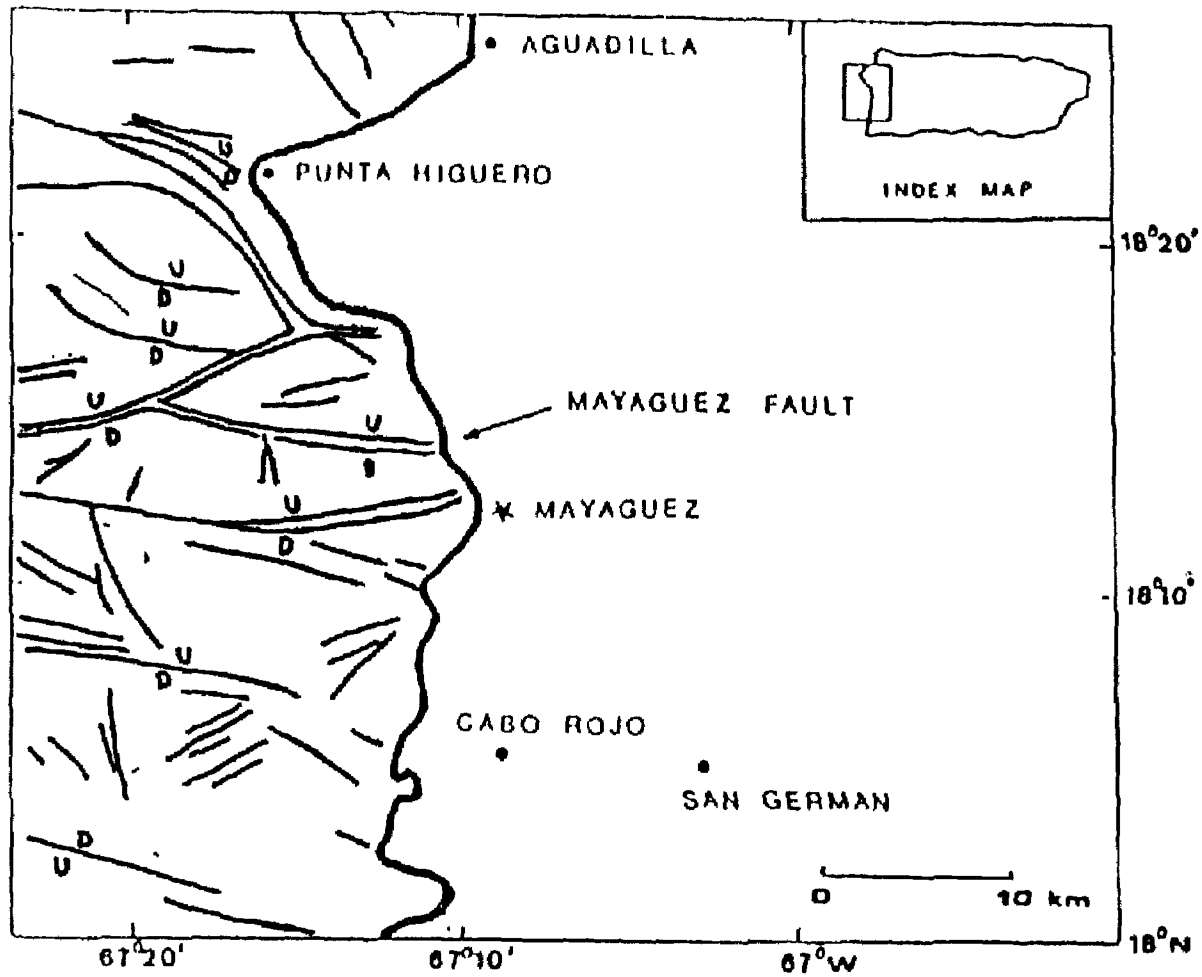

Figure 10. Offshore structural features in western Puerto Rico showing the Mayagüez fault.

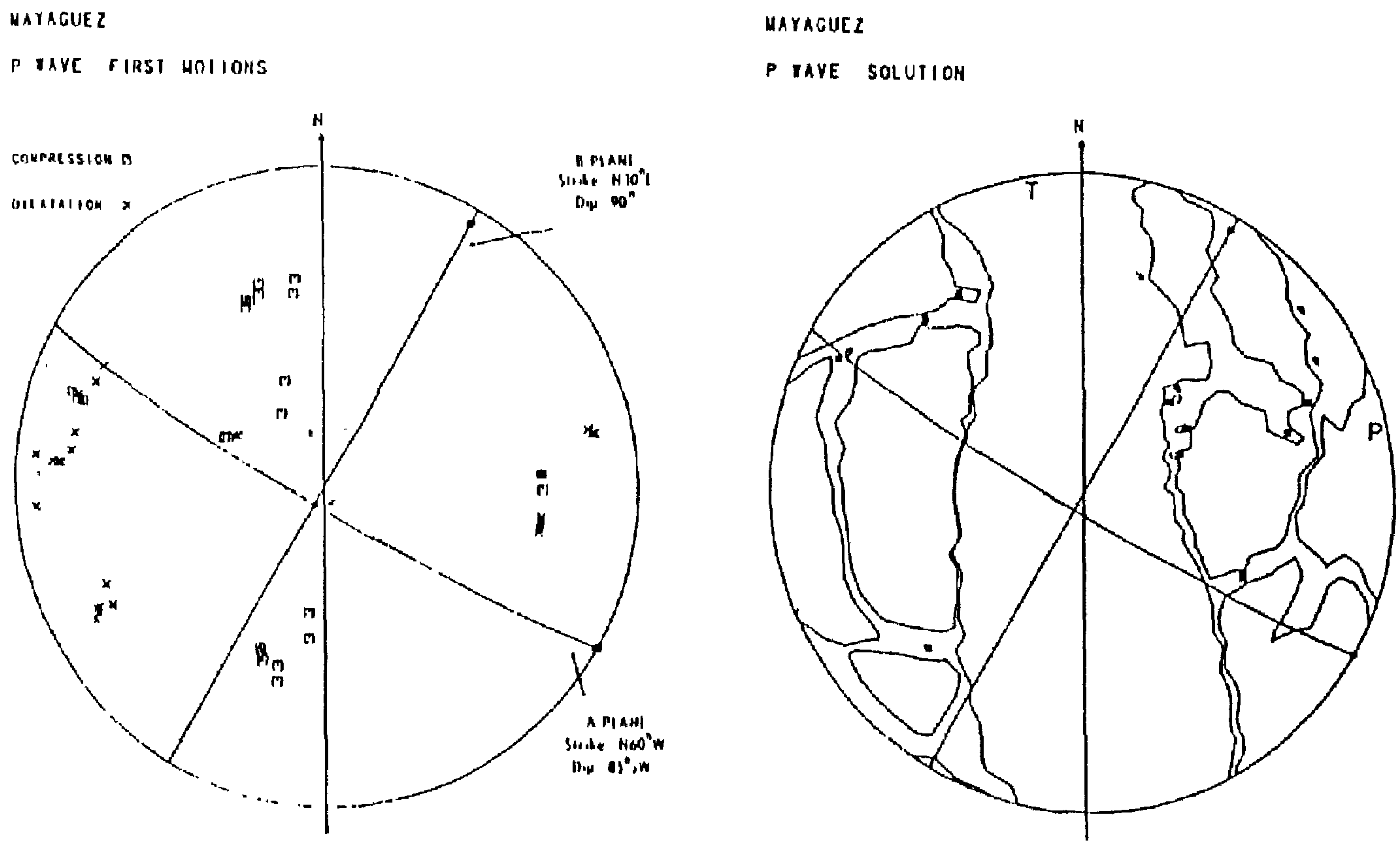

Figure 11. Composite focal mechanism solution (lower emisphere) for the Mayagüez fault region. From; Asencio, 1980.

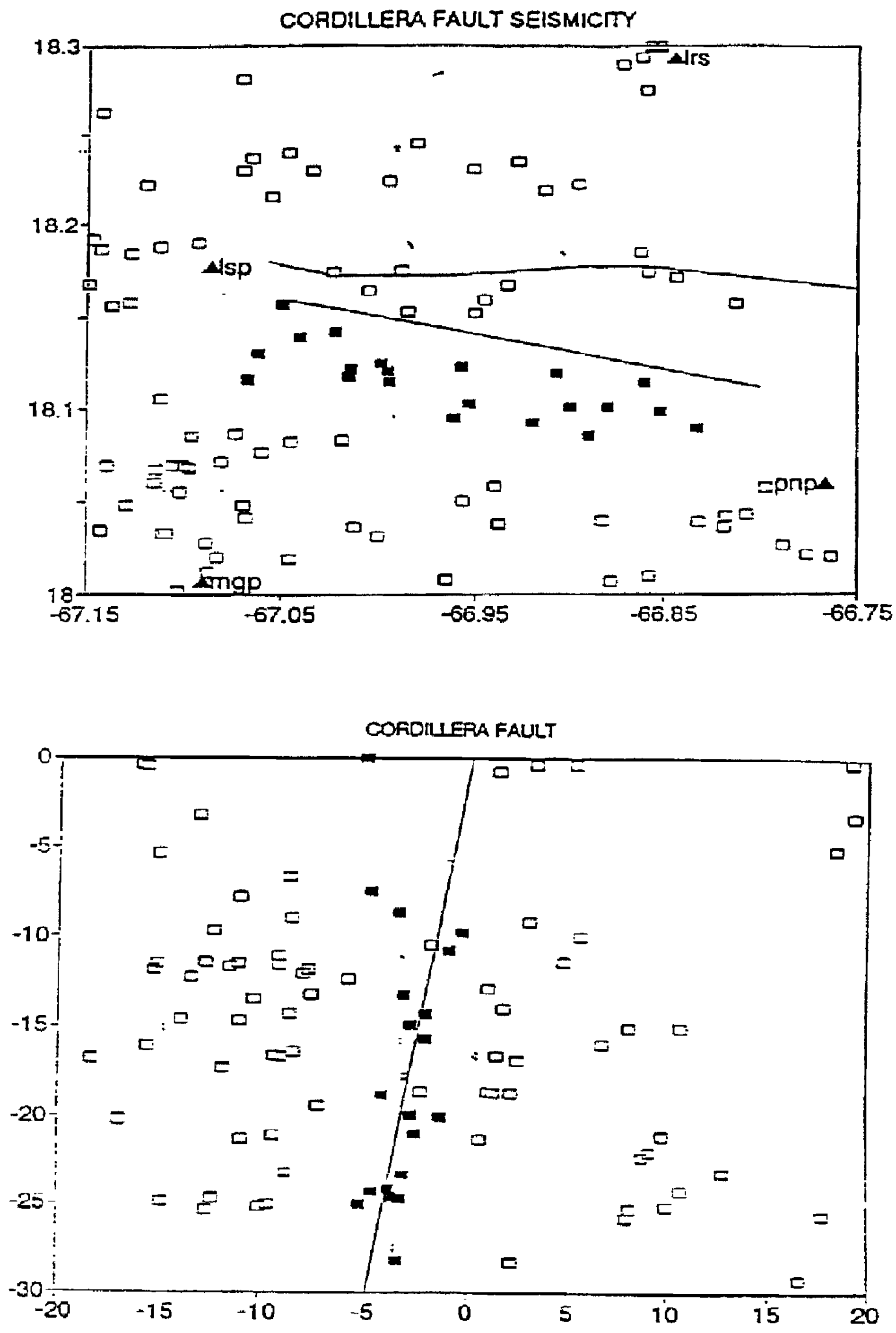

Figure 12. Horizontal and cross section showing earthquake distribution of the Cordillera fault. From McCann et. al. 1991.