FINAL TECHNICAL REPORT

Project Title: Integration of New and Existing Marine Geophysical and Geological Data Offshore Western and Southern Puerto Rico into a GIS Database: Implications for Improved Earthquake Hazard Assessment

NEHRP Grant number: 02HQGR0051

Principal Investigators: Nancy R. Grindlay and Lewis Abrams
University of North Carolina Wilmington
Center for Marine Science
5600 Marvin K. Moss Lane
Wilmington, NC 28409,
Tel: 910 962-2352, FAX: 910 962-2410
Email: grindlayn@uncw.edu

Program Element: NI (National- International)

Key words: Neotectonics, GIS database, Quaternary faults, geophysics

Research supported by the U.S. Geological Survey (USGS), Department of the Interior under USGS NEHRP award number 02HQGR0051. The views and conclusions contained in this document are those of the authors and should not be interpreted as necessarily representing the official policies, either or implied, of the U.S. government.

TECHNICAL ABSTRACT

During the one-year time period of this grant, we have integrated digital marine geophysical data collected in May 2000 offshore western and southern Puerto Rico with existing analog marine multichannel and single-channel seismic data, bathymetry sidescan sonar imagery, sedimentologic, lithologic and earthquake seismicity data into a geographical information systems (GIS) database. Numerous never-before published multichannel seismic (MCS) lines have been incorporated into the database along with recently acquired high-resolution sub-bottom profiler data. Neither seismic dataset by itself can completely constrain fault distribution; the MCS lines have deep penetration but low resolution; the sub-bottom profiler data have high-resolution but only image to depths of 20-30m. However, taken together, these datasets allow us to identify active faults and have a better understanding of the crustal structures that are being reactivated and may be capable of generating earthquakes. The integrated database is used to generate a fault compilation map to enhance scientific visualization of active offshore faults, their surface and subsurface geometries, and characterize the style of recent faulting offshore western and southern Puerto Rico. The GIS database is available to scientists and relevant government agencies in Puerto Rico by request. To date this database has been incorporated into a regional Caribbean geologic database (Mann et al., 2003).

NON-TECHNICAL SUMMARY

We have integrated recently acquired high-resolution digital marine geophysical data from offshore western and southern Puerto Rico with existing (circa 1972) never-before-published analog marine geophysical data, sedimentologic, lithologic and earthquake seismicity data into a geographical information systems (GIS) database. Taken together, these datasets allow us to identify active faults and to have a better understanding of the crustal structures onland and offshore Puerto Rico that are being reactivated and may be capable of generating earthquakes. The GIS database is available to scientists and relevant government agencies in Puerto Rico by request.

PROJECT OVERVIEW AND SIGNIFICANCE

The island of Puerto Rico is located within a diffuse and complex plate boundary zone between the North American and Caribbean plates. The dominant motion along the plate boundary is left-lateral strike-slip but lesser amounts of compression and extension are locally significant (Sykes et al., 1982; Mann and Burke, 1984; Byrne et al., 1985; Stein et al., 1988, Mann et al., 1990; Deng and Sykes, 1995.

Seismicity data and marine geophysical and geodesy studies of the easternmost portion of the North American-Caribbean plate boundary suggest that Puerto Rico is part of a microplate which also includes the Virgin Islands (Byrne et al., 1985; Masson and Scanlon, 1991, Grindlay et al., 1997; van Gestel et al., 1998; Lopez et al., 1999). The Puerto-Rico Virgin Island platelet (PRVI) is defined by the Puerto Rico Trench to the north, the Muertos Trough to the south, and the Anegada passage to the east and south. On the basis of side-scan sonar imagery and single-channel seismic data Grindlay et al. (1997) and van Gestel et al. (1998; 1999) have identified extensive normal faulting of the Oligocene to early Pliocene carbonate platform in the central and western portion of the Mona Passage, the marine strait separating Puerto Rico and the Dominican Republic. This localized extension of the platform strata reflects the differential eastward relative motions of the island of Puerto Rico and Hispaniola. Recently published GPS geodetic measurements collected during a 10-year period in the region support these findings and suggest the amount of differential motion is about 5 mm/yr (Dixon et al., 1998; Lopez et al., 1999, Jansma et al., 2000).

Most geophysical and geological data sets including GPS geodesy indicate that the deformation zone extends onshore within western Puerto Rico (cf. van Gestel et al., 1998; Jansma et al., 2000). The onshore and offshore region of southwestern Puerto Rico is one of the most seismically active regions near the island of Puerto Rico. During the past five years alone over 70 earthquakes with a magnitude of 3.0 or greater have been recorded by the local seismic network in the western region of Puerto Rico (Seismic Network, 1998). Several large to great historical earthquakes have occurred within the nearby Puerto Rico Trench (McCann and Sykes, 1984). There is also historical evidence of at least 40 strong events originating in the Mona Passage or northwest Puerto Rico between 1524 to 1958 (Asencio, 1980). One of the best known large events (M=7.3) to significantly affect the west coast of Puerto Rico occurred in 1918. The epicenter of this event was located in the northern part of the Mona Passage, approximately 50 km west of the town of Aguadilla. The earthquake caused a substantial amount of damage to life and property on the western coast of Puerto Rico due to effects of ground shaking and tsunami. This event, as reported by Reid and Taber (1919), killed at least 116 persons and caused four million dollars (adjusted to current equivalence) in damage. At the time of the 1918 earthquake the population of Mayagüez was about 17,000. Today, western Puerto Rico is heavily populated and the Mayagüez metropolitan area alone now has a population of more than 132,000.

This intense seismic activity associated with crustal and lithospheric deformation along an active plate boundary within 50 km of the west coast of Puerto Rico poses a serious threat to

the growing population in the region. In May 2000, a systematic sidescan sonar mapping and high-resolution sub-bottom profiling effort on the shallow insular shelf of western and southern Puerto Rico was conducted by the investigators, Grindlay and Abrams, P. Mann (University of Texas, Austin), two University of North Carolina Wilmington graduate students (J. Backstrom and L. DelGreco) and one University of Puerto Rico undergraduate student (D. Lao). The main objective of the mapping program was to identify and characterize active faulting on the insular shelves of western and southern Puerto Rico and to link these offshore faults with active faults onland. These results confirm the presence of seafloor scarps interpreted to be late Holocene in age along the trends of the Cerro Goden, Mayagüez, and Great Southern Puerto Rico Fault zones. We have presented the preliminary interpretation of these data at the 2000 Fall American Geophysical Union meeting (Delgreco et al., 2000, Grindlay et al., 2000) and are in the process of writing up these results (Grindlay et al., submitted, Mann et al., in submitted).

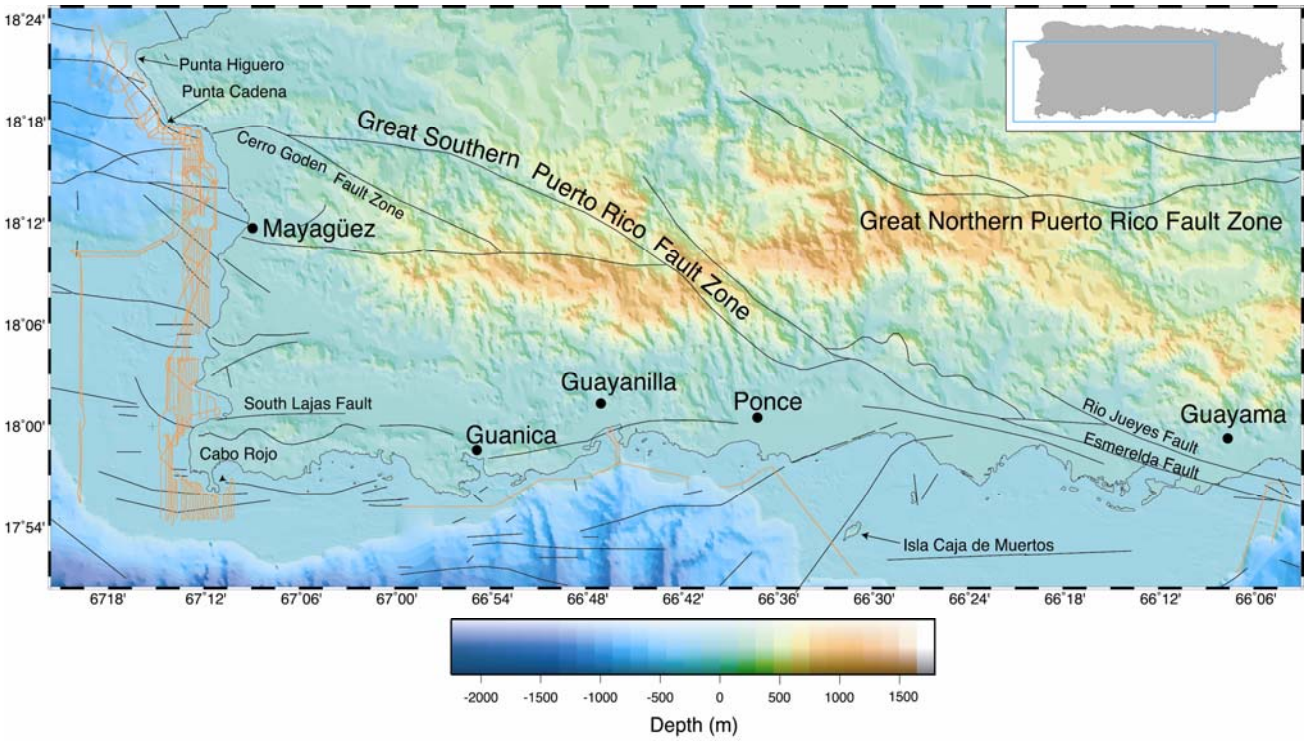

Figure 1. A DEM of Puerto Rico and insular shelves showing the location of the May 2000 marine geophysical survey (orange lines). Black lineations represent faults interpreted by Furgo, Inc. and Western Geophysical Co. from multichannel seisimc data collected in 1972. The interpretation did not distinguish between active and inactive faults. Comparison of these fault locations with high-resolution sidescan sonar and sub-bottom profile data collected in May 2000 show that many of the faults do not break surface sediments. The fault locations do, however, provide information about the past tectonic history of the region and locate regions of potential crustal weakness where reactivation could occur.

One result of our offshore survey and the coordinated onland trenching and mapping studies (Prentice et al., 2000; Lao et al., 2000) is to show that areas of late Holocene faulting are widespread through the west and south coasts, and that many of these faults appear to reactivate older WNW trending basement structures. In addition to our newly acquired data, a considerable amount of marine geophysical and geological data has been collected by various institutions over

the past 25 years offshore the island of Puerto Rico. Much of these data are in analog format (e.g. paper copies of MCS lines) and are part of geophysical data reports commissioned by Puerto Rican Governmental agencies. The reports have not been published and therefore have not been widely distributed within the scientific community. As individual data sets they have limited scientific value, but as an integrated GIS database they have proven invaluable to the assessment of neotectonics and seismic hazards within the region and to planning future marine geophysical investigations. Unlike previous GIS studies conducted in the region which have dealt with terrain or infrastructure databases (e.g. Marcari, 1997; McCann, 1995; Scanlon and Briere, 2000; Torres-Pulliza et al., 2000), to our knowledge, no GIS database has been compiled for marine geophysical and geological data of the region.

We have augmented the analysis of the newly acquired side-scan sonar imagery and sub-bottom profiles by an extensive data set of existing marine geophysical and geological data that includes the following:

- a dense grid of MCS profiles on the insular shelf and slope of western and southern Puerto Rico (Western Geophysical Company and Fugro, Inc., 1973). The grid of MCS profiles separated by 5-10 km surrounds the island and were collected as part of a geological-geophysical reconnaissance for citing of power plants in Puerto Rico. Seismic data obtained imaged the entire sediment column and the top of volcanic basement. Analog records and maps of selected seismic lines were made available through the Seismic Network at the University of Puerto Rico. These MCS profiles have never been published. Integration of the deeper penetration MCS data have allowed us to have a better understanding of the crustal structures that are being reactivated, and thus are structures that are most likely capable of generating earthquake (Digitally scanned and loaded as geotiff files)

- NOAA/NOS digital bathymetric database of nearshore area of Puerto Rico and Virgin Islands (Mercado, 1994) and elevation data from USGS 1:250000 Digital Elevation Models (DEMs). (gridded with 2 arc sec interval)

- Earthquake epicenters from the local Puerto Rico seismic network and the USGS NEIC (database files).

- Analog maps of sediment distribution and core locations distributed by the USGS as Miscellaneous Investigations Series Maps (Grove, 1993: Morelock et al., 1994; Beach and Trumbul, 1981; Trias, 1991). (Digitally scanned and loaded as geotiff files)

- Onshore and offshore fault traces from a variety of sources (Glover, 1971, Joyce et al. 1987, Lao et al., 2000, McCann et al., 1987, Meltzer et al., 1998; 2000, Curet, 1986, Volckmann, 1984a; 1984b). (shape files)

Various data layers listed above have been projected into a true cartographic projection and seamlessly integrated into an ArcView GIS database. The digital database allows us to make overlays of different data sets at the same scale and effectively integrate a wide range of data types (Fig 2). In addition, hot links have been developed in the GIS database to access georeferenced seismic profiles and sidescan sonar mosaics (Fig. 3a, b, and c).

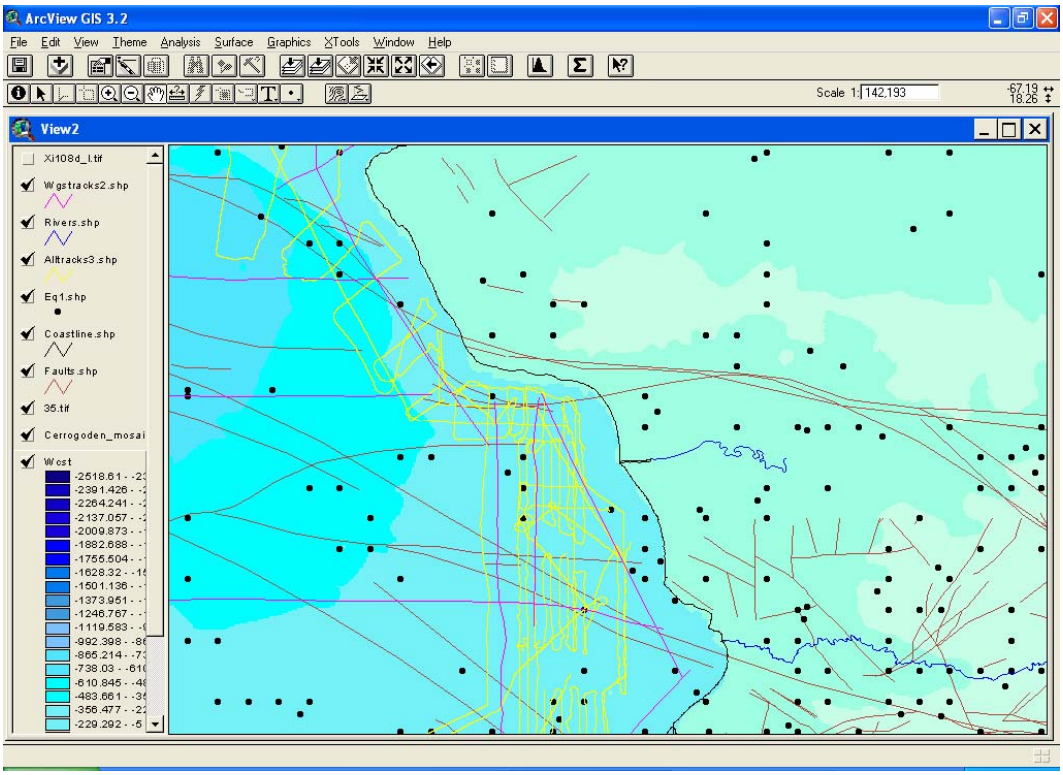

Figure 2: ArcView GIS project showing integration of multiple data sets.

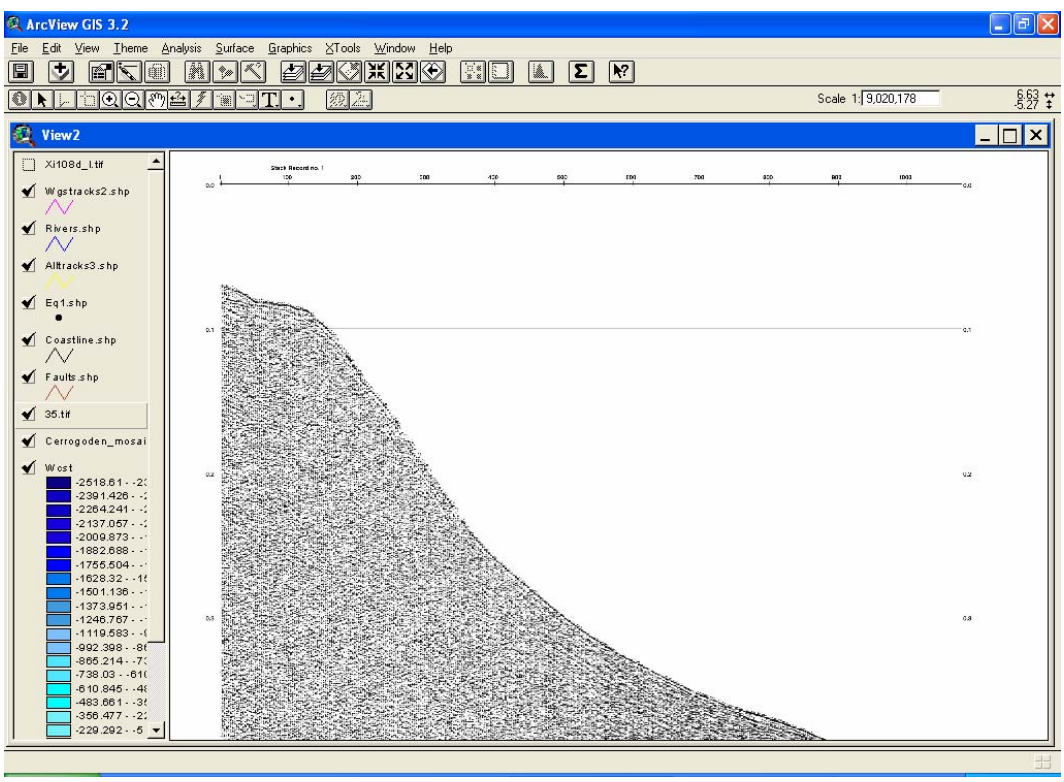

Figure 3a: ArcView GIS project showing integration of multiple data sets. Hotlink to georeferenced high-resolution single channel seismic line collected in 2000.

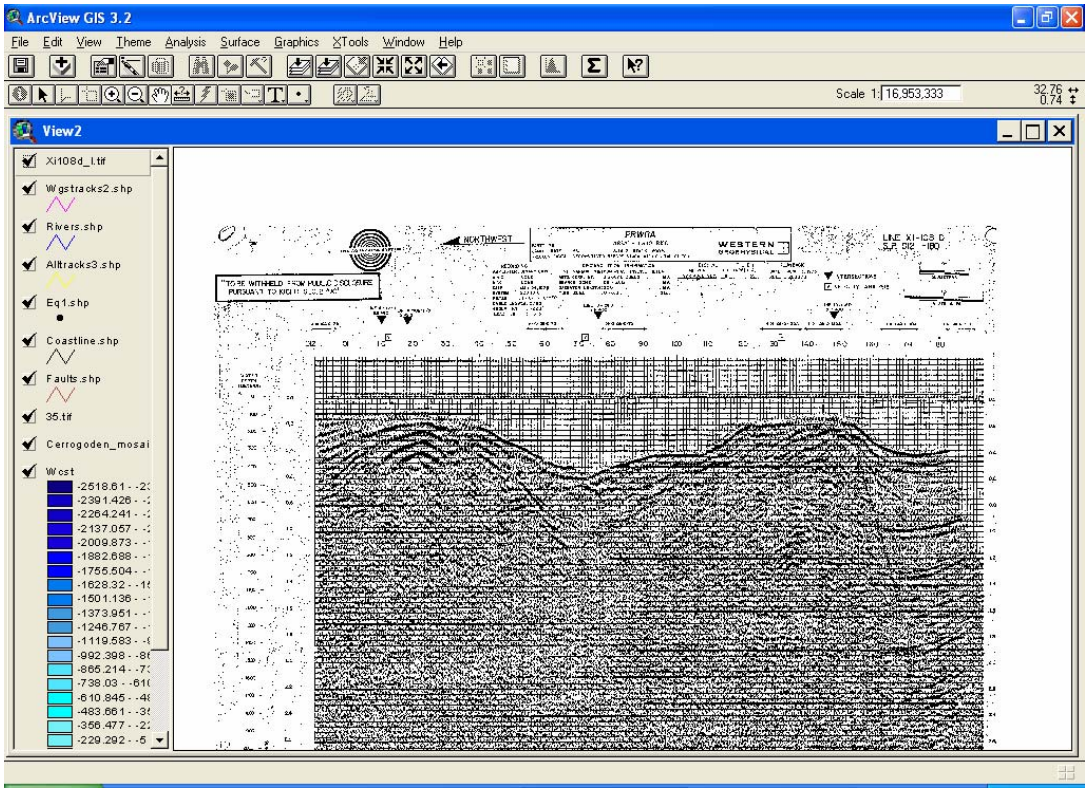

Figure 3b: ArcView GIS project showing integration of multiple data sets. Hotlink to georeferenced digitized Western Geophysical multichannel seismic line.

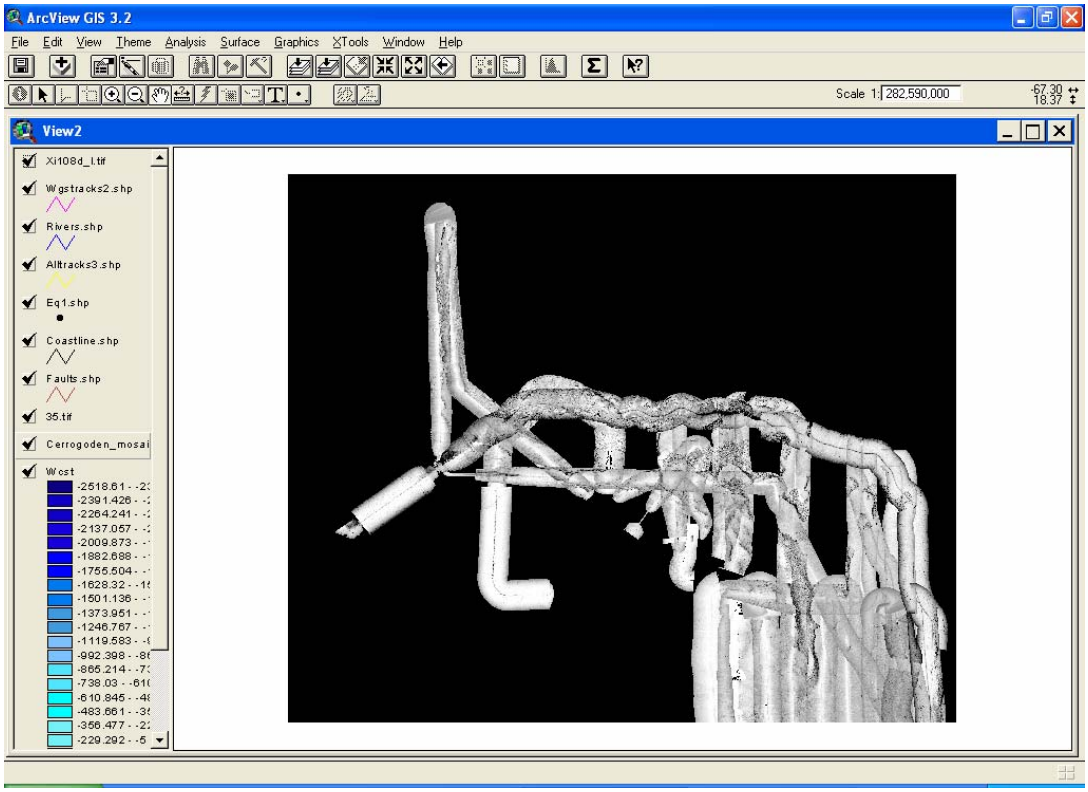

Figure 3c: ArcView GIS project showing integration of multiple data sets. Hotlink to georeferenced high-resolution sidescan sonar mosaic.

PROJECT RESULTS

The final results of the one-year project are three fold:

1. We have catalogued and made readily available in digital (GIS) format to the scientific community and local planners, important and relevant data sets that are currently only in analog format and of limited access. The GIS database is available at no-charge upon request. To date this database has been incorporated into a regional Caribbean database of active faults and earthquake seismicity presented at the 2003 Seismological Society of America conference in San Juan, Puerto Rico (Mann et al., 2003). In addition, the high-resolution seismic reflection data have been submitted to the online Marine Seismic Data Center at the University of Texas Austin, Institute for Geophysics http://www.ig.utexas.edu/sdc, and the high-resolution sidescan sonar data files and processed mosaics have been provided to NOAA/NMFS scientist José Rivera for habitat analysis;

2. We have developed a fault compilation map in GIS format that enhances the scientific visualization of the surface and subsurface geometries of offshore faults and characterize the style and geometry of recent faulting;

3. We have examined the relationship between the offshore and onshore structures of southwestern Puerto Rico to gain a regional perspective of the neotectonic setting of the Mona Passage and southwestern Puerto Rico within the North American-Caribbean plate boundary zone. We have presented these findings at the annual Seismological Society of America Conference in San Juan, Puerto Rico, 2003 (Grindlay et al., 2003) and are incorporating the results in two publications that have been submitted (Grindlay et al., submitted, and Mann et al., submitted).

.

REFERENCES

Asencio, E., 1980, Western Puerto Rico seismicity: USGS Open-File Report 80-192, 135 p.

Beach, D., Trumbull, J., 1981, Marine Geologic Map of the Puerto Rico Insular Shelf, Isla Caja de Muertos Area. USGS Miscellaneous Investigations Series Map I-1265, 1:40,000.

Byrne, D. B., G. Suarez, and W. R. McCann, 1985, Muertos Trough subduction--Microplate tectonics in the northern Caribbean: Nature, v. 317, p. 420-421.

DelGreco, L. Abrams, L. Grindlay, N. and Mann, P., 20000, Identification of recent faulting in Bahia de Anasco and Bahia de Mayaguez, western Puerto Rico, Eos Trans. AGU, Fall mtg. suppl., v. 181, F1181.

Deng, and Skyes, L., 1995, Determination of euler poles for Caribbean- North American plate using slip vectors of interplate earthquakes, Tectonics, v. 14, p. 39-53.

Dixon, T., F. Farina, C. DeMets, P. Jansma, P. Mann, and E. Calais, Relative motion between the Caribbean North American plates and related boundary zone deformation based on a decade of GPS observations, J. Geophys. Res., v. 103, p. 15,157-15182, 1998.

Erikson, J., Pindell, J. and Larue, D., 1990, Mid-Eocene-early Oligocene sinistral transcurrent faulting in Puerto Rico associated with the formation of the northern Caribbean Plate Boundary zone, Journal of Geology, v. 989, p. 365-384.

Glover, L., 1971, Geology of the Coamo area, Puerto Rico, and its relation to the volcanic arc-trench association, USGS Professional paper, 636, 102p.

Grindlay, N.R., P. Mann and J. Dolan, 1997, Researchers investigate submarine faults north of Puerto Rico, Eos, Trans. AGU, v. 78, p. 404.

Grindlay, N.R., P. Mann and J. Dolan, 1999, Oblique collision of the Bahama Platform in the Hispaniola-Puerto Rico area, northeastern Caribbean, GSA Penrose mtg, Subduction to strike-slip transitions along plate boundaries, Dominican Republic, abstract volume http://www.uncwil.edu/people/grindlayn/penrose.html.

Grindlay, N., Abrams, L., DelGreco, L., and Mann, P., 2000, A high-resolution sidescan sonar and seismic survey reveals evidence of late Holocene fault activity offshore western and southern Puerto Rico, Eos Trans. AGU, Fall mtg. suppl., v. 181, F1181.

Grindlay, N.R., L.J. Abrams, L. Del Greco, and P. Mann, 2003, Toward an integrated understanding of Holocene fault activity in western Puerto Rico: Constraints from high-resolution seismic and sidescan sonar data, *Seismological Res. Lett.* 74, 231.

Grindlay, N.R., L. Abrams, L. Del Greco and P. Mann, Toward an integrated understanding of Holocene fault activity in western Puerto Rico: Constraints from high-resolution seismic and sidescan sonar data, *GSA Special Paper* "Active tectonics and seismic hazards of Puerto Rico, the Virgin Islands, and offshore areas", ed P. Mann, submitted.

Grove, K., 1983, Marine Geologic Map of the Puerto Rico, Northwestern Area: Rio Grande de Anasco to Rio Camuy. USGS Miscellaneous Investigations Series Map I-1418, 1:40,000.

Jansma, P, Mattioli, G., Lopez, A., DeMets, C., Dixon, T., Mann, P. and Calais, E., 2000, Neotectonics of Puerto Rico and the Virgin Islands, northeastern Caribbean, from GPS geodesy, Tectonics, v. 19, p.1021-1037.

Lao-Davila, D., Mann, P., Prentice, C., and Draper, G., 2000, Late Quaternary activity of the Cerro Goden Fault Zone, transpressional uplift of the La Cadena Range, and their possible relation to the opening of the Mona rift, western Puerto Rico, Eos Trans. AGU, v. 181, F1181.

Lopez, A., P. Jansma, E. Calais, C. Demets, T. Dixon, P. Mann and G. Mattioli, 1999, Microplate tectonics along the North American-Caribbean plate boundary: GPS geodetic constraints on rigidity of the Puerto Rico-Northern Virgin Islands (PRVI) block, convergence across the Muertos Trough, and extension in the Mona Canyon, Eos, Trans. AGU spring mtg suppl., S77.

Macari, E., 1997, Earthquake hazard assessment of western Puerto Rico, Monograph, US Geological Survey, p. 12.

Mann, P. and K. Burke, 1984, Neotectonics of the Caribbean: Reviews of Geophysics and Space Physics, v. 22, p. 309-362.

Mann, P., Schubert, C. and Burke, K., 1990, Review of Caribbean neotectonics. In: G. Dengo and J.E. Case (editors), The Geology of North American, vol. H, The Caribbean Region. Geol. Soc. Am., Boulder, CO, p. 307-337.

Mann, P., Rogers, R., and Watson, L., 2003, Neotectonics of the North America-Caribbean Plate Boundary Zone: A GIS-based Compilation of Faults, Epicenters, and Focal Mechanisms from Guatemala to the Lesser Antilles, *Seismological Res. Lett*. 74, 231.

Mann, P., J-C Hippolyte, N.R. Grindlay and L.J. Abrams, Neotectonics of southern Puerto Rico and its offshore margin, *GSA Special paper* "Active tectonics and seismic hazards of Puerto Rico, the Virgin Islands, and offshore areas", ed P. Mann, submitted.

Masson, D. G. and K. M. Scanlon, 1991, The neotectonic setting of Puerto Rico: Geological Society of America Bulletin, v. 103, p. 144-154.

Meltzer , A., 1998, Fault structure and earthquake potential Lajas Valley, SW Puerto Rico, USGS Technical Abstract, http://erp-web.er.usgs.gov/reports/abstracts/1998/ni/g2501.htm.

Mercado, A., 1994, Digitization of National Ocean Survey hydrographic survey "smooth" sheets for Puerto Rico and the U.S. Virgin Islands, Sea Grant College Program, p. 116.

Mercado, A., and W. R. McCann, 1998, Numerical Simulation of the 1918 Puerto Rico Tsunami, Natural Hazards v. 18 p. 57.

Morelock, J., Winget, A., Goenaga, C., 1994, Geologic Maps of the Southwestern Puerto Rico Parguera to Guanica Insular Shelf. USGS Miscellaneous Investigations Series Map I-2387, 1:40,000.

Prentice, C., Mann, P., and Burr, G., 2000, Prehistoric earthquakes associated with a late Quaternary fault in the Lajas Valley, southwestern Puerto Rico, Eos Trans. AGU, Fall mtg. suppl. v. 181 F1182.

Reid, H and Taber, S., 1919, The Puerto Rico Earthquakes of October-November 1918, bull. Seism. Soc. Amer., v. 9, p.95-127.

Scanlon, K., and Briere, R., 2000, Puerto Rico Marine Sediments, terrestrial and seafloor imagery, and tectonic interpretations, USGS Open File Report 00-006, CDROM.

Stein, S., C. DeMets, R. G. Gordon, J. Brodholt, D. Argus, J. F. Engeln, P. Lundgren, C. Stein, D. S. Weins, and D. F. Woods, 1988, A test of alternative Caribbean plate relative motion models: Journal of Geophysical Research, v. 93, p. 3041-3050.

Sykes, L. R., W. R. McCann, and A. L. Kafka, 1982, Motion of Caribbean plate during last 7 million years and implications for earlier Cenozoic movements: Journal of Geophysical Research, v. 87, p. 10656-10676.

Torres, P.D., Jansma, P., and Mattioli, G., 2000, Assessing the interplay of tectonics, sedimentology, and lithology in coastline development of Puerto Rico using a GIS, International Geoscience and Remote Sensing Symposium, v. 1, p. 295-297.

Trias, J., 1991, Marine Geologic Map of the Puerto Rico Insular Shelf--Guanica to Ponce Area. USGS Miscellaneous Investigations Series Map I-2263, 1:40,000.

van Gestel J-P, P. Mann, J. Dolan and N.R. Grindlay, 1998, Structure and tectonics of the upper Cenozoic Puerto Rico-Virgin Islands carbonate platform as determined from seismic reflection studies, J. Geophys. Res., v. 103, p. 30,505-30,530.

van Gestel J-P, P. Mann, N.R. Grindlay and J.F. Dolan, 1999, Three-phase tectonic evolution of the northern margin of Puerto Rico as inferred from an integration of seismic reflection, well, and outcrop, Marine Geology, v.161 p.259-288.

Western Geophysical Company of America, and Fugro, Inc., 1973, Geological-geophysical reconnaissance of Puerto Rico for citing of nuclear power plants, The Puerto Rico Water Resources Authority, San Juan, P.R., 127 p.