Survey Explores Active Tectonics in Northeastern Caribbean

PAGES 537, 540

There is renewed interest in studying the active and complex northeastern Caribbean plate boundary to better understand subduction zone processes and for earthquake and tsunami hazard assessments [e.g., *ten Brink and Lin,* 2004; *ten Brink et al.,* 2004; *Grindlay et al,* 2005]. To study the active tectonics of this plate boundary, the GEOPRICO-DO (Geological, Puerto Rico-Dominican) marine geophysical cruise, carried out between 28 March and 17 April 2005 (Figure 1), studied the active tectonics of this plate boundary.

Initial findings from the cruise have revealed a large underwater landslide, and active faults on the seafloor (Figures 2a and 2c). These findings indicate that the islands within this region face a high risk from tsunami hazards, and that local governments should be alerted in order to develop and coordinate possible mitigation strategies.

The cruise collected multibeam bathymetry, gravity, magnetic, high-resolution seismic, deep seismic sounding, and multichannel seismic reflection data, which are currently being processed and interpreted (Table 1).

In early November 2005, 10 ocean-bottom seismometers (OBS) that had been deployed northeast of Puerto Rico and the Virgin Islands (Figure 1) during the cruise were recovered. These OBS recorded data during the cruise and the local seismicity between April and October 2005.

Tectonic Settings and Study Areas

There are three different tectonic settings of interest south of Dominican Republic: the triple junction of the Muertos Trough subduction/thrust zone, the Enriquillo strike-slip fault zone, and the aseismic Beata Ridge [*Biju-Duval et al.,* 1982; *Mauffret and Leroy,* 1999] (Figure 1).

Where the aseismic Beata Ridge (trend southwest-northeast) intersects with Muertos Trough and Enriquillo Fault Zone (both trend east-west), the deformation regime changes from underthrusting in the Muertos Trough to convergence and left-lateral strike slip in the Enriquillo fault zone. This change is observed in the abrupt bathymetry: the Muertos Trough becomes narrower and shallower, and it is deflected northwestward just at the intersection with the Beata Ridge (approximately 70ºW).

The aim of this study was to understand why this change occurs, by exploring possible correlations between the onland structures in Hispaniola and offshore structures in the Muertos zone, and analyzing the role of the Beata Ridge. In the Muertos deformed belt/accretionary wedge and Muertos Trough (Figure 1), the Caribbean plate is possibly being thrusted or subducted under Puerto Rico and Hispaniola [*Ladd et al.,* 1977].

In the Muertos Trough, a striking bathymetric feature of >5500 meters in depth, the convergence rate is less than ~3 millimeters per year [*Calais et al.,* 2002] and decreases eastward until about 65ºW, where the deformation front seems to disappear [*Manson and Scanlon,* 1991]. The global positioning system (GPS) data and data on earthquake orientations (focal mechanism solutions) are consistent with a convergence stress regime. Here, an active compressive deformation is taking place that can generate submarine landslides, a potential source of tsunamis (Figure 2a) [*ten Brink et al,* 2004].

This study also sought to understand the tectonic regime northeast of Puerto Rico and the Virgin Islands (Figure 1), where the Puerto Rico Trench is the main tectonic and bathymetric feature (8340 meters in depth, -350 milliGal free-air gravity anomaly). The motion along this trench is predominantly a left-lateral strike slip with only a small component of subduction, where the North American plate slides beneath the Caribbean plate [*Calais et al.,* 2002; *Mann et al.,* 2002].

The present motion of the Caribbean plate relative to the North American plate, based on GPS measurements, is N70ºE at a rate of 18–20±3 millimeters per year [*Mann et al,* 2002] (Figure 1). Currently, there is discussion about a potential tear or deformation in the downgoing North American slab in this area [*ten Brink,* 2005]. This survey will help to understand the reason for the high seismic activity (e.g., southwest-northeast swarm trend in October 2001, recorded by the Puerto Rico Seismic Network) and its potential hazard to nearby, densely-populated Puerto Rico and the Virgin Islands.

Preliminary Findings

A multibeam bathymetric digital model of the seafloor (Figure 2a) south of Hispaniola and Puerto Rico (Figure 1) shows the Muertos Trough and the Muertos deformed belt/accretionary wedge associated with the active subduction/thrust zone [*Ladd et al,* 1977; *Biju-Duval et al.,* 1982; *Byrne et al.,* 1985]. The deformation front at the base of the slope is more clearly defined in the west than in the east—the width of the deformation zone decreases greatly east of 68°W, and the trench depth becomes shallower. A sub-bottom profile generated with echo-sounder within the deformed belt (Figure 2c) shows active deformation in recent sediment beds, perhaps of Holocene origin.

In the new data, a large submarine landslide has been identified southwest of Puerto Rico (Figure 2a). Other large submarine landslides have been described in the Puerto Rico Trench and Mona Rift areas [*Grindlay et al.,* 2005; *ten Brink et al.,* 2004], which have been correlated with historic earthquakes and tsunamis.

A preliminary stack of the multichannel seismic reflection profile L3R (Line-seismic-Reflection-Three) (Figure 2b), across the Puerto Rico Trench (Figure 1), shows more clearly than previous profiles [*Larue and Ryan,* 1998] the subduction of the North American plate under the Caribbean plate. In the profile L3R area, the subducting slab is faulted, with tilted crustal blocks, and the trench is a narrow deep graben filled with more than 1500 meters of sediments.

Table 1. Acquisition systems and surveyed area

Techniques	*Surveyed Area*	*Technique Features*
Multibeam bathymetry	all surveyed area (2.868 total miles)	Simrad EM-120/EM-1002 Multibeam
Gravity	all surveyed area (2.868 total miles)	Bell Aerospace Textron BMG-3 Marine Gravimeter
Magnetic	all surveyed area (2.868 total miles)	SeaSPY Marine Magnetometer
High-resolution seismic	all surveyed area (2.868 total miles)	Topographic Parametric Seismic System (TOPAS)
Deep seismic sounding	three profiles south of Dominican Republic (276 miles) five profiles northeast of Puerto Rico and Virgin Islands (281 miles)	3680 cubic inch airgun array; 90 second shot interval; 29 land seismometers; 10 short-period ocean-bottom seismometers, which were left on the seafloor to record local seismicity and were retrieved in November 2005
Multichannel seismic reflection	four profiles northeast of Puerto Rico and Virgin Islands (252 miles)	2700 cubic inch airgun array; 50 meter shot interval; 2.4 kilometer, 96-channnel hydrophone streamer

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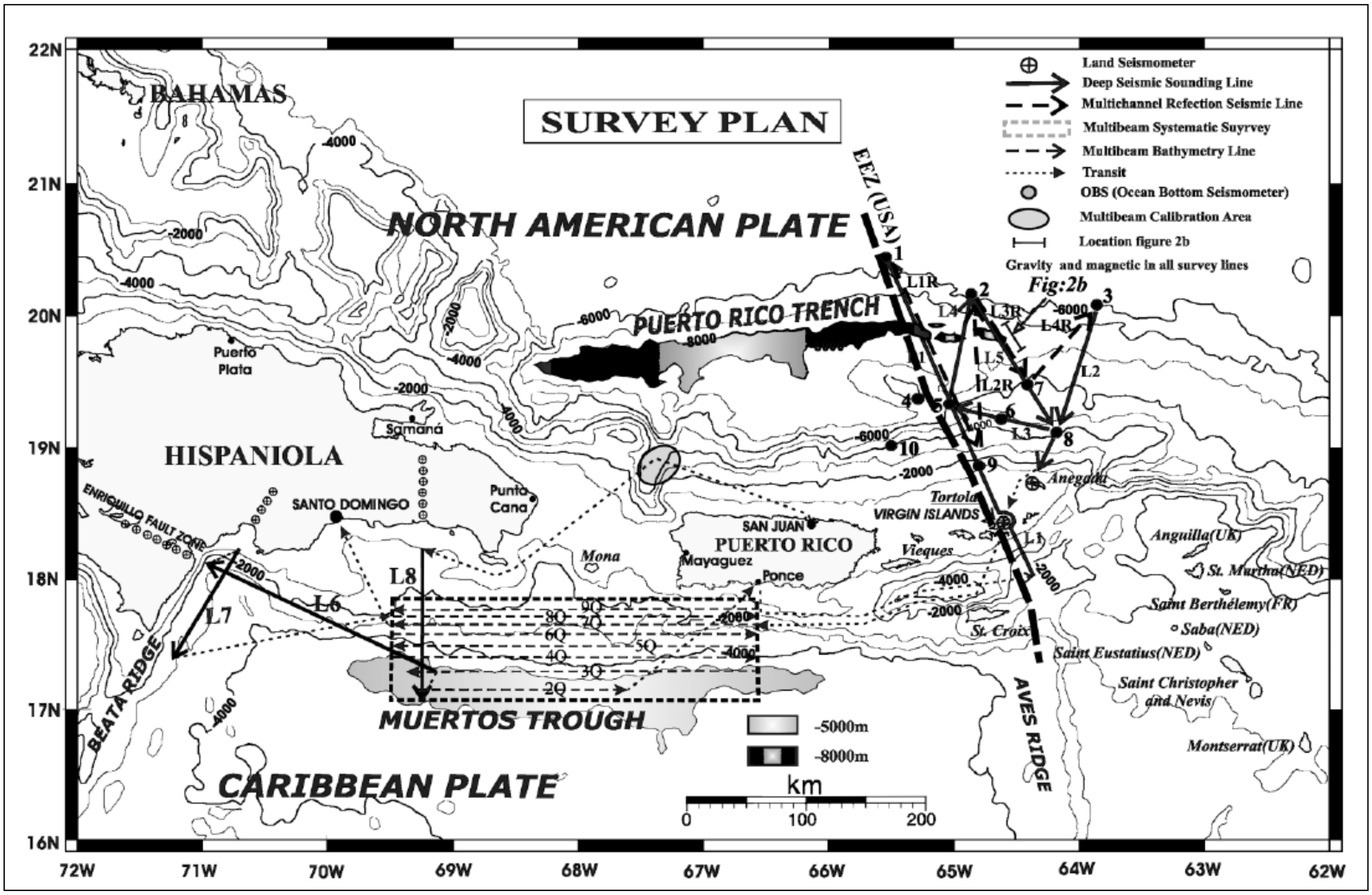
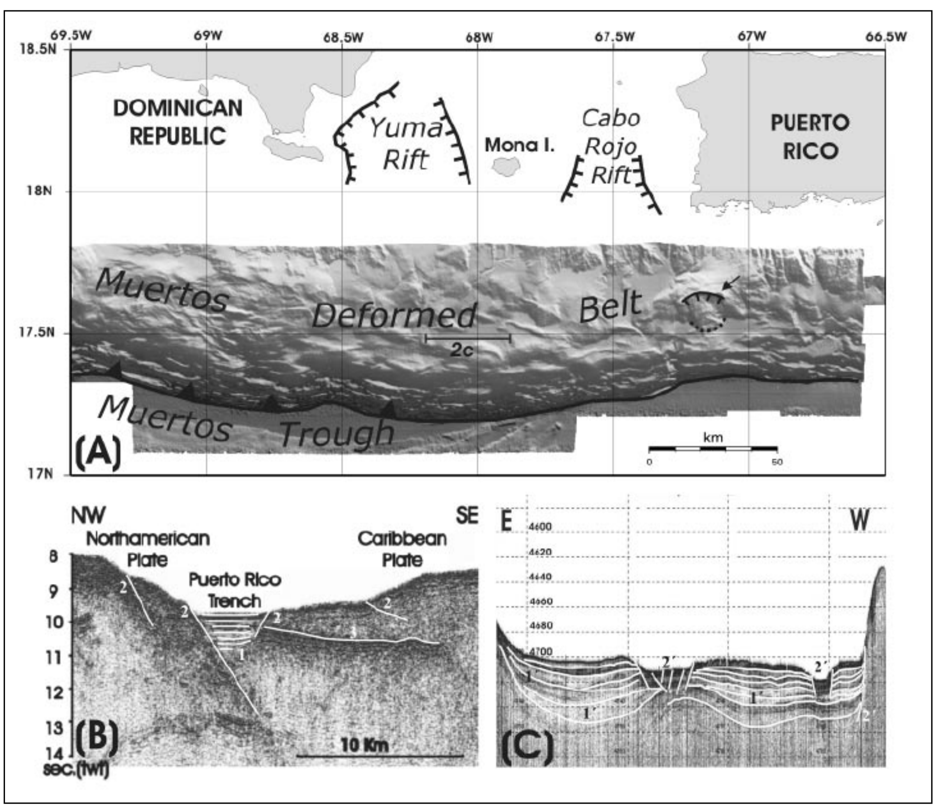


Fig. 1. Location and track lines on a map of the surveyed area. L1R through L4R are a series of Line-seismic-Reflection surveys. L1 through L8 are Line-seismic-Refraction surveys. All the track lines included combine multibeam data, potential fields data, and chirp sub-bottom data. The numbered points indicate the number of the deployed OBS.



A deformation front/accretionary wedge with some compressive structure (thrust fault [*Larue and Ryan,* 1998]) appears in the overriding Caribbean plate.

The complete processing of multichannel seismic data jointly with deep seismic sounding data will allow better understanding of the structure of the subduction zone and will aid local governments in developing tsunami mitigation strategies.

Data were collected aboard the Spanish research vessel *Hespérides*. The Puerto Rican

Fig. 2. Preliminary cruise results. (a) Multibeam bathymetry digital model south of Hispaniola and Puerto Rico (see Figure 1). The base of the deformation front is indicated. The black arrow shows a large landslide: escarp and toe (dotted lines). (b) Brute stacked section of the multichannel seismic reflection profile L3R in the Puerto Rico Trench axis area (see Figure 1). Vertical scale is in seconds, two-way travel time (twt). White lines correspond with reflectors of sediments beds (1), faulting (2), and top of tilted block (3). (c) Semi-interpreted section of high-seismic resolution of the line Q5 in an inter-ridge basin south of Hispaniola and Puerto Rico (see Figure 1). Vertical scale is in milliseconds, two-way travel time. White lines correspond with different sedimentary beds (1') and faults (2').

commercial tugboat *Kruger B* was used to deploy the ocean-bottom seismometers. The cruise was conducted jointly by the Universidad Complutense de Madrid (Spain), Real Observatorio de la Armada de San Fernando (Cádiz, Spain), Instituto Español de Oceanografía (Madrid, Spain), Universidad de Barcelona (Spain), U.S. Geological Survey (USGS) (Woods Hole, Mass.), the Puerto Rico Seismic Network (Mayaguez), and Instituto Sismológico Universitario-Universidad Autónoma de Santo Domingo (Dominican Republic), with the collaboration of the Dirección General de Minería (Dominican Republic) and Department of Disaster Management (British Virgin Islands).

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NEWS

Convention Sets Next Steps on Climate Change Efforts

PAGE 538

Delegates from more than 180 countries have adopted rules for implementing the Kyoto Protocol to the United Nations Framework Convention on Climate Change and also have agreed to two separate decisions that set in motion the next steps for international efforts to mitigate climate change.

More than 9000 participants discussed the future of the Framework Convention and the Kyoto Protocol at the United Nations Climate Change Conference, which was held 28 November through 10 December in Montreal, Canada.

The 1992 Framework Convention, which has been ratified by 189 countries including the United States, set the objective of reducing global levels of greenhouse gas emissions but did not include any goals or provisions for enforcement. The 1997 Kyoto Protocol, which came into effect in February 2005, sets targets for the reduction of greenhouse gas emissions for about three dozen developed countries. It has been ratified by 157 countries, and only two developed countries—the United States and Australia—have chosen not to participate.

During the conference, countries that have committed themselves to the Kyoto Protocol formally adopted the Marrakech accords, which establish operating rules for such practices as emissions trading; the Clean Development Mechanism, which allows developed countries to meet emissions targets through projects in developing countries; and crediting of carbon sinks activities. These rules also launch a system for reviewing and reporting national emissions.

These rules are "the completion of a decade of negotiation bringing the Kyoto Protocol to life," said Elliot Diringer of the Pew Center on Global Climate Change.

Two other decisions reached during the conference set the next steps for international efforts. The first decision, made under the Kyoto Protocol, starts a process to consider further commitments to reduce greenhouse gas emissions beyond 2012, when current emission targets expire.

The second decision, made under the Framework Convention, establishes a two-year, "non-binding" dialogue to "analyse strategic approaches for long-term cooperative action to address climate change" but will not lead to any negotiations of commitments to reduce greenhouse gas emissions.

The U.S. delegation, which had stated its opposition to any discussions of the post-2012 process and at one point walked out on the talks, eventually agreed to the non-binding dialogue.

Climate change science—including topics such as adaptation, deforestation, and carbon capture and storage—was highlighted in sessions separate from the government negotiations. "From the science community's perspective, we had a lot more attention to science than we have seen in previous meetings," and the science was having an impact on the dialogue and discussions at the conference, said Robert Corell, a senior fellow in the American Meteorological Society's policy program and an affiliate of the Washington Advisory Group.