

Earthquakes and Tsunamis in Puerto Rico and the U.S. Virgin Islands

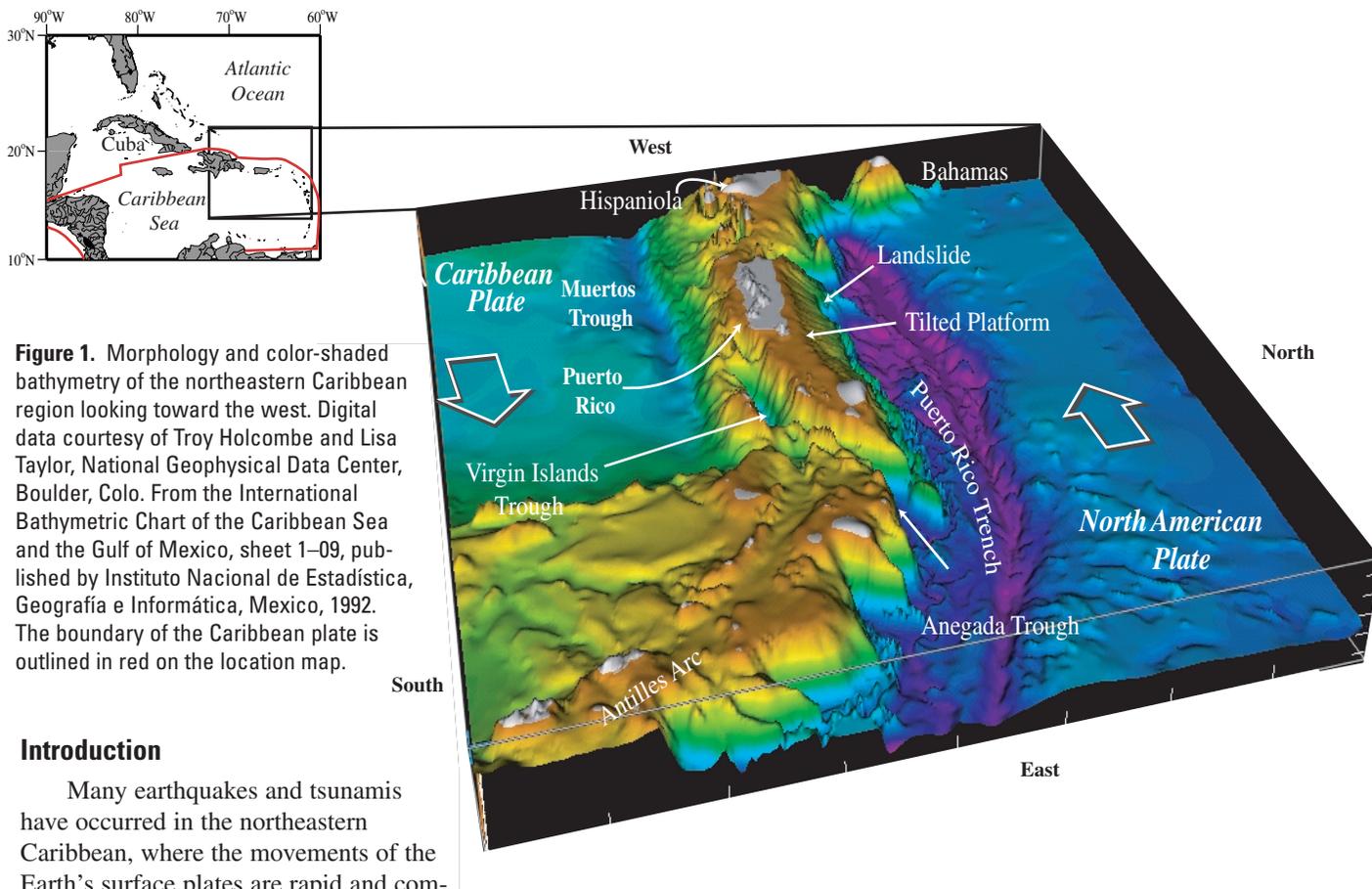


Figure 1. Morphology and color-shaded bathymetry of the northeastern Caribbean region looking toward the west. Digital data courtesy of Troy Holcombe and Lisa Taylor, National Geophysical Data Center, Boulder, Colo. From the International Bathymetric Chart of the Caribbean Sea and the Gulf of Mexico, sheet 1-09, published by Instituto Nacional de Estadística, Geografía e Informática, Mexico, 1992. The boundary of the Caribbean plate is outlined in red on the location map.

Introduction

Many earthquakes and tsunamis have occurred in the northeastern Caribbean, where the movements of the Earth's surface plates are rapid and complicated. Future such events pose serious hazards to the 3.7 million people who live in Puerto Rico and the U.S. Virgin Islands.

Plate Movements

The Caribbean is one of the smaller surface plates of the Earth. The approximately rectangular plate extends from Central America on the west to the Lesser Antilles on the east, and from just south of Cuba on the north to South America on the south (fig. 1). Earthquakes occur all around its periphery, and volcanoes erupt on its eastern and western sides. This plate remains at a fixed spot relative to the deep Earth, while the North American plate, which includes the continent of North America and the western North Atlantic ocean basin, is being shoved

westward. The motion between these plates is rapid for a geological process, at about 2 centimeters/year (about 1 inch/year).

The Puerto Rico/Virgin Islands region is located at the northeastern corner of the Caribbean plate where motions are complex. The westward-moving North American plate is being driven under the Antilles Arc where volcanism is active. On the north side of the plate corner, the North American plate slides past the Caribbean (fig. 1), but irregularities in the plate boundaries cause stresses that result in a complicated underthrusting of plate fragments. The interaction of plates causes the volcanism of the Antilles Arc on the eastern boundary of the Caribbean plate and creates major stresses all along the northern boundary.

North of Puerto Rico is the Puerto Rico Trench, the deepest part of the Atlantic Ocean and the place where the pull of gravity at sea level is less than anywhere else on Earth (free-air gravity anomaly). The stresses are holding part of the North American plate down to form the trench. The collision has also caused the tilting of the limestone platform deposits of northern Puerto Rico during the last 3.3 million years. These formerly horizontal layers, deposited near the water surface, now are tilted strongly to the north and have subsided to depths of more than 4.5 kilometers (2.8 miles). Sea-floor images collected by the U.S. Geological Survey (USGS) show that great slabs of limestone, as much as 70 kilometers (43 miles) wide, have broken off and slid into the Puerto Rico Trench.

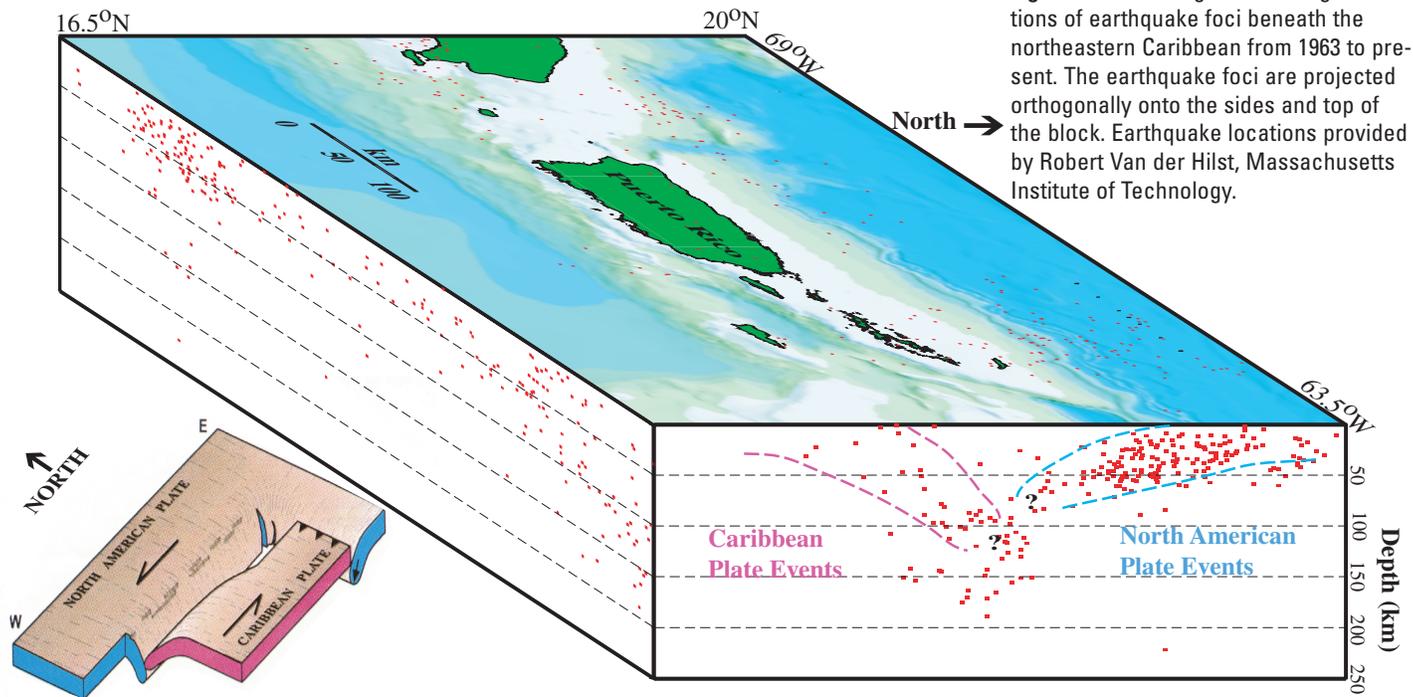


Figure 2. Block diagram showing locations of earthquake foci beneath the northeastern Caribbean from 1963 to present. The earthquake foci are projected orthogonally onto the sides and top of the block. Earthquake locations provided by Robert Van der Hilst, Massachusetts Institute of Technology.

Figure 3. Conceptual drawing of the geometry and relative motion of the major plates of the northeastern Caribbean. The microplates that form Puerto Rico and the Virgin Islands have been removed for clarity.

Earthquake Patterns

Stresses in the plates cause frequent earthquakes, and so the pattern of deep earthquakes can be used to map the locations of cold, brittle underthrust plates (fig. 2). Two groups of earthquake foci (locations of initial ruptures within the Earth) extend diagonally under the islands, one from the north and one from the south. Apparently the North American plate is bent down to the south, and the Caribbean plate is bent down to the north; they may be in contact beneath the islands. The islands are situated on a set of independent small plate fragments or microplates that are located in the V-shaped trough between the downbent parts of the major plates (fig. 3).

Large earthquakes have occurred in the Puerto Rican region (table 1). USGS research indicates an equal probability for damaging ground motion for Mayaguez in western Puerto Rico as for Seattle, Washington; other Puerto Rican cities also have substantial risk.

Table 1. Large earthquakes near Puerto Rico and the Virgin Islands.

Earthquake location	Date	Magnitude
Hispaniola	1953	6.9
Mona Canyon	1946	7.5
Hispaniola	1946	8.1
Mona Canyon	1918	7.5
Anegada Trough	1867	7.5
Puerto Rico Trench	1787	8.1

Tsunami Hazards

Tsunami waves form when large pieces of the sea floor undergo abrupt vertical movement due to fault rupture, landslides, or volcanism. Immediately after the 1946 earthquake, a tsunami struck northeastern Hispaniola and propagated inland for several kilometers; some reports indicate that nearly 1,800 people drowned. In 1918, a magnitude 7.5 earthquake resulted in a tsunami that killed at least 91 people in northwestern Puerto Rico. Eyewitness reports of an 1867 Virgin Islands tsunami give a maximum wave height of more than 7 meters (23 feet) in Frederiksted, St. Croix, where a large naval vessel was left on top of a pier.

USGS Research

The USGS is studying the geology of the region to map earthquakes, understand how they are generated, and esti-

mate where earthquakes and tsunamis will be initiated. A problem for Puerto Rico and the Virgin Islands is that sites of tsunami generation are likely to be very close to the coast, and so warning time is short, unlike Hawaii, where sites are very distant and warnings can be broadcast hours in advance. Therefore, improved understanding of the geology must be used for public education and planning for safer construction and the proper siting of structures where people congregate.

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A description of a USGS-sponsored workshop on tsunami and earthquake hazards in the region is available online at: <http://woodshole.er.usgs.gov/epubs/openfiles/ofr99-353>