U.S. DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

THE U.S. GEOLOGICAL SURVEY MARINE GEOLOGY PROGRAM IN PUERTO RICO

by

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INTRODUCTION

The shallow marine shelf surrounding Puerto Rico has an area of about 3,500 km^2 within the 200 m isobath, or nearly two-thirds that of the land area of the Commonwealth. On an island where more than 85 percent of the population lives within 7 km of the sea and is dependent on the tourism that its beaches and coral reefs attract, it is necessary that high-quality scientific data be available to planners, engineers, and other scientists to help formulate public policy regarding residential and commercial development along the coast, beach replenishment, and future utilization of marine resources. In an attempt to meet these needs, the U.S. Geological Survey (USGS) in cooperation with the Puerto Rico Department of Natural Resources, maintains a field office in San Juan whose objectives are to: (1) produce reconnaissance marine geologic maps of the insular shelf and upper slope surrounding Puerto Rico; (2) conduct geologic research on processes operating on the coastal zone, insular shelf, and upper slope surrounding Puerto Rico; (3) conduct mineral resource appraisals, notably for sand and gravel and economically important minerals on the insular shelf; and (4) assist in the education and professional development of Puerto Rican marine geologists and marine science technicians. This report provides a description of the program, results of previous investigations, ongoing activities, and future plans.

The USGS field office in San Juan is an integral part of the USGS Branch of Atlantic Marine Geology's Exclusive Economic Zone (EEZ) Geology and Sedimentary Processes Program, centered in Woods Hole, Massachusetts. The USGS Puerto Rico Marine Geology Program began in 1968 and has stressed systematic reconnaissance mapping covering the entire insular shelf as its prime directive. This offshore mapping initiative continues to be the primary function of the program and has been expanded to include the entire Puerto Rico EEZ (EEZ-SCAN 85 Scientific Staff, 1987). More recent concern with the erosion of Puerto Rico's coastline has led to a series of investigations related to coastal zone processes, which is rapidly becoming the principal focus of the program. The program in Puerto Rico will maintain its flexibility so that it can provide timely responses to future requests from the Puerto Rico Department of Natural Resources or other Commonwealth/Federal agencies and remain committed to assist in the education and professional development of Puerto Rican marine geologists through programs such as the Minority Participation in the Earth Sciences Program.

The USGS Puerto Rico Marine Geology Program can be divided into two

main investigations: (1) Insular Shelf and Coastal Sedimentologic Processes; and (2) Tectonic and Stratigraphic Evolution of the Insular Margin. The coastal and insular shelf sedimentologic investigations include studies of sedimentary processes (erosion, transport, and deposition) acting in the coastal zone and insular shelf/upper slope. This component of the program is supplemented by a cooperative program between the USGS and Duke University. Investigations related to the tectonic and stratigraphic evolution of the insular margin include studies of the geologic evolution of the island and the assessment of offshore geologic hazards.

INSULAR SHELF AND COASTAL SEDIMENTOLOGIC PROCESSES

Insular Shelf Reconnaissance Mapping Project

There is a need to improve our understanding of the dynamic sedimentary processes affecting the Puerto Rico insular shelf because of the impact that these processes have on coastal erosion, water quality, pollutant dispersal, resource distribution and preservation (coral reefs, construction materials, heavy mineral deposits, and living resources), and other aspects of sea-floor utilization. Offshore mineral resources, especially sand and gravel, used for construction and beach replenishment, are of major importance because of their potential for low-cost development and because suitable onshore sources have been depleted. Sand and gravel are presently the most economically important non-hydrocarbon marine mineral resource worldwide. The unusually high construction costs of island states and territories are reduced somewhat by the availability of these resources. Sand and gravel are ubiquitous on beaches around Puerto Rico, but widespread availability does not mean that this resource can be extracted without severe economic and environmental penalties. For example, mining of beach sand has resulted in significant erosion and loss of beaches and dunes (Rodríguez 1984); these are major concerns for tourism and residential development in some areas of Puerto Rico. A complete understanding of the extent and worth of insular shelf sand deposits requires a systematic mapping of the shelf and a full understanding of the sedimentary processes contributing to their deposition and redistribution.

Data collection, which includes single-channel seismic-reflection profiling and sediment sampling has been completed over approximately 80% of the shelf around Puerto Rico (see attached list of references). This insular shelf mapping project is presently the top priority of the Puerto Rico Marine Geology Program. The entire insular shelf reconnaissance map series is due to be completed by the end of 1996 (Fig. 1). These data provide reconnaissance information about the composition and distribution of

sediment on the insular shelf. Potential sites for offshore resource development such as three sedimentary deposits with a combined volume of about 178 million cubic meters of sand and gravel have been identified (Fig. 1). The dynamic environment surrounding these deposits have also been studied thus insuring proper, environmentally sound management if they are to be exploited in the future (Grove and Trumbull,1978; Trumbull and Trías, 1982; Rodríguez and Trías, 1989; Trías, 1991, and Delorey and others, 1993).

Coastal Processes Project

Most of Puerto Rico's beaches are presently eroding, although rates of erosion vary (Theiler, 1993). Response to coastal erosion in Puerto Rico has been crisis-based, disunited engineering of the coast. Many of the resulting engineering structures have had a deleterious impact on local erosion rates (Wright, 1989). It is apparent that solutions to erosion problems in one area of Puerto Rico cannot be applied universally to others due to the dynamic and varying nature of coastal processes active in Puerto Rico.

Preliminary studies of coastal erosion by the USGS began in 1987 with a beach monitoring program in the San Juan area and were expanded immediately after Hurricane Hugo struck the Commonwealth in September, 1989. The principal objective of these studies is to assess the impact of major storm events on the coastal environment. This is accomplished by documenting and assessing the impact of storms on three critical coastal resources of Puerto Rico, beaches, offshore sand deposits, and coral reefs and monitoring their subsequent recovery.

Changes in shoreline position around Puerto Rico have been quantified recently using aerial photographic techniques (Danforth and Theiler, 1992). Preliminary analysis of shoreline changes in the San Juan metropolitan area (Fig. 2) suggest that long-term accretionary trends have occurred within embayments between headlands (lower-energy areas where there are few or no engineering structures impinging on the littoral zone), whereas quasi-stable to slightly erosional trends have occurred at headlands that are exposed to higher-energy wave and current action (Schwab and Rodríguez, 1992). Thus, there is an apparent long-term trend of shoreline straightening through headland erosion and embayment infilling (Fig. 3). In addition, weekly coastal monitoring in the San Juan area showed that the effects of Hurricane Hugo on the sandy beaches in the San Juan area had been an erosional perturbation in the seasonal cycle (Schwab and Rodríguez, 1992). However, where engineering structures were extensively damaged because they extend too far seaward, beach recovery has been hindered. It is planned to expand these types of investigations to other coastal areas of critical

environmental or economic importance such as the southwest and northeast coasts (Cabo Rojo to Boqueron and Luquillo to Fajardo respectively) and to maintain a shoreline position digital database in the San Juan field office for future reference.

Preliminary analysis of aerial photographs also suggested that the offshore sand and gravel deposit off the island of Vieques, the Escollo de Arenas (Fig. 1) was severely affected by Hurricane Hugo (Fig. 4). However, analysis of closely spaced high-resolution seismic-reflection profiles, sediment cores, and grab samples show that large-scale changes affecting the volume and overall geographic extent of the deposit did not occur; less than 4 percent of the original volume of the Escollo de Arenas deposit was lost during this hurricane (Delorey and others, 1993).

Sediment cover on the narrow insular shelf surrounding Puerto Rico is, in general, patchy and diverse with little continuity (Pilkey and others, 1987). This sediment cover variability is a reflection of the wide range of complex physical and biological factors affecting sedimentation in this area. High-resolution mapping of sedimentary environments using state-of-art sea-floor mapping techniques can help identify areas where sediment most likely accumulates. These data can be used to assess the nearshore sand supply and the fate of the sand eroded from the shoreline; find and assess the sources and sinks of offshore sand and gravel needed for beach replenishment; and shed light on the processes controlling the distribution of the sediment. An ongoing investigation on the insular shelf off the town of Luquillo, northeast Puerto Rico (Fig. 2), was designed to document the effect of major storms in order to assess the nearshore sand supply and the fate of the sand eroded from the shoreline. Sea-floor structures and textural/compositional sedimentologic trends in this study area suggest that regional oceanographic processes result in a net cross-shelf, offshore sediment transport direction during storms (Figs. 5 and 6). However, east-west trending eolianite ridges that crop out on the sea floor act as natural dams, blocking material removed from the shoreface thereby forming sand deposits up to 20 m thick along the inner boundary of the eolianite ridges. These deposits are a potential exploitable resource because they are in shallow water and are composed of beach sediment removed from the active shoreface. This type of detailed high-resolution sea-floor mapping project, although time-consuming and technologically complex, has the potential of generating a true understanding of the processes that control the natural development of the shoreline in other critical areas. One such area is the shoreline of the northwestern towns of Rincón and Aguada, where severe erosion has hindered the expansion of the tourist industry.

Coral reefs around the island of Puerto Rico are a major source of

carbonate sand production, act as buffers to storm-wave induced coastal erosion, are sites of high biologic productivity (important to local fisheries), and are a tourist attraction. Thus, a living "healthy" reef is a resource in itself. Also, because coral reefs are living biological communities, they are sensitive to marine pollution and have the potential of being used as an "early warning" system in the case of widespread or significant pollution problems. Ongoing studies designed to document the effects of major storms on the "health" of coral reefs used the reef complexes around the island Culebra as a model (Schwab and Rodríguez, 1992). In this investigation, divers examined and photographed reefs around the island, drilled deep cores to determine the geologic history of reefs and took cores from individual living corals to study growth rates and evaluate the effect of Hurricane Hugo and previous major storms. Preliminary results show that reefs on the east and southeast (windward) side of Culebra were devastated by Hurricane Hugo, whereas only minor damage to the coral reefs along the west (lee) side of Culebra was found. In spite of the devastation, however, the reefs on the east side of Culebra are showing signs of a healthy regrowth. Future plans are to continue to monitor the recolonization of these reefs and possibly expand the mapping and monitoring program to other reef complexes around Puerto Rico.

Heavy minerals can be concentrated by fluvial, coastal and shelf processes into deposits known as placers. The mapping of fine-grained placer deposits offers potential both for economic recovery and as an indicator of sediment/pollutant transport (Poppe and others, 1992). A pilot program has been initiated to assess the application of this methodology along the northern coast of Puerto Rico. Preliminary results of mineralogic studies of sediment samples from the rivers (Rio de la Plata, rivers of the Rio Cibuco system, and Rio Grande de Manatí) and insular shelf of north-central Puerto Rico (Fig. 2) indicate that the silt fraction is predominantly detrital, but contains a strong authigenic component (Poppe and others, 1993). Elevated concentrations of cerargyrite, chromite, gold, magnetite, manganese oxides and the titanium-bearing minerals have been detected in these sediments.

Lateral variability in silt-fraction mineralogy is considerable. Within the Rio Cibuco system, the variability is related to the differences in composition of the rapidly-eroding source rocks. On the high-energy, wave-dominated shelf, silt-size heavy-mineral abundances are greatest at the river mouths and decrease seaward. Variability in the shelf samples is related primarily to the source river and shelf sorting processes. Important differences are present between the silt heavy-mineral assemblages in the rivers and the insular shelf, and between the heavy-mineral assemblages in the silt and sand-sized fractions from these areas.

TECTONIC AND STRATIGRAPHIC EVOLUTION OF THE INSULAR MARGIN

Puerto Rico and the Virgin Islands are located on a microplate in a plate boundary zone where the microplate is sliding relatively eastward over a downbent slab of oceanic crust (Masson and Scanlon, 1991; Coleman and Dillon, 1993). The structural framework and plate interactions in this zone are poorly understood. In 1984, the USGS, in keeping with its mission to map the federal lands and to determine their resource potential, began a program to provide maps of the deep water areas of the U.S. Exclusive Economic Zone (EEZ). In 1985, the USGS conducted a sidescan-sonar survey of the EEZ of Puerto Rico using the long-range sidescan sonar system GLORIA. Seismic-reflection and magnetic-field data were also collected along all of the ship's tracks during this survey. These data were computer processed and published in 1987 (EEZ-SCAN 85 Scientific Staff, 1987). The GLORIA sidescan-sonar imagery of the Puerto Rico EEZ (Fig. 7) furnishes a new perspective of one of the Earth's dynamic plate boundaries; clarifying the structural framework of the region (Scanlon and Masson, 1988a and Masson and Scanlon, 1991). These data also revealed previously unknown aspects of the insular margin of Puerto Rico. For example, the GLORIA imagery shows numerous channels that cut the insular slope both north and south of Puerto Rico. These submarine channels are thought to act (or have acted) as conduits of sediment transport from the insular shelf to the abyssal sea floor (Scanlon and Mason, 1994). One of the most spectacular findings was a large amphitheater-shaped scarp, representing the removal of more than 1,500 cubic kilometers of sedimentary rock (EEZ Scan Scientific Staff, 1987; Scanlon and others, 1988; Schwab and others, 1991) on the insular slope near longitude 66°45' W (Fig. 8). The head of the scarp is about 3,000 m deep. It is not known if this feature was formed by a single catastrophic event or by slower erosion and dissolution processes. These GLORIA data are presently being analyzed along with existing data in order to better understand the origin of this large scarp and to assess the relation of this feature to regional geologic hazards. The GLORIA data also are being analyzed with information on earthquake distribution to analyze plate interactions and their significance to earthquakes.

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Figure 1. Map of Puerto Rico showing the status of publications of the reconnaissance insular shelf mapping project and the location of sand and gravel deposits with high economic potential.

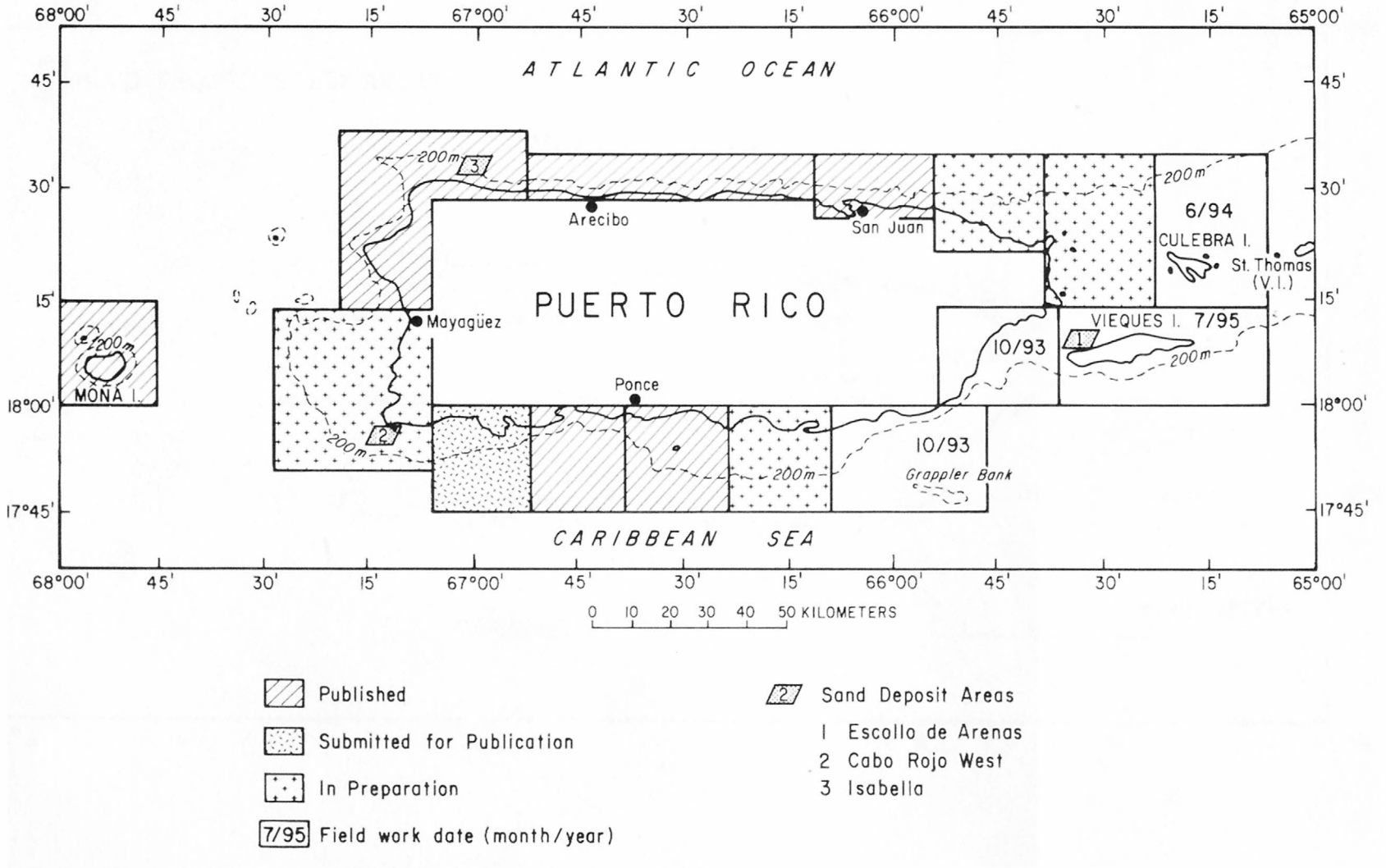


Figure 2. Map of Puerto Rico showing the location of study areas used to asses the impact of Hurricane Hugo on coastal resources and the location of rivers used in the heavy mineral study.

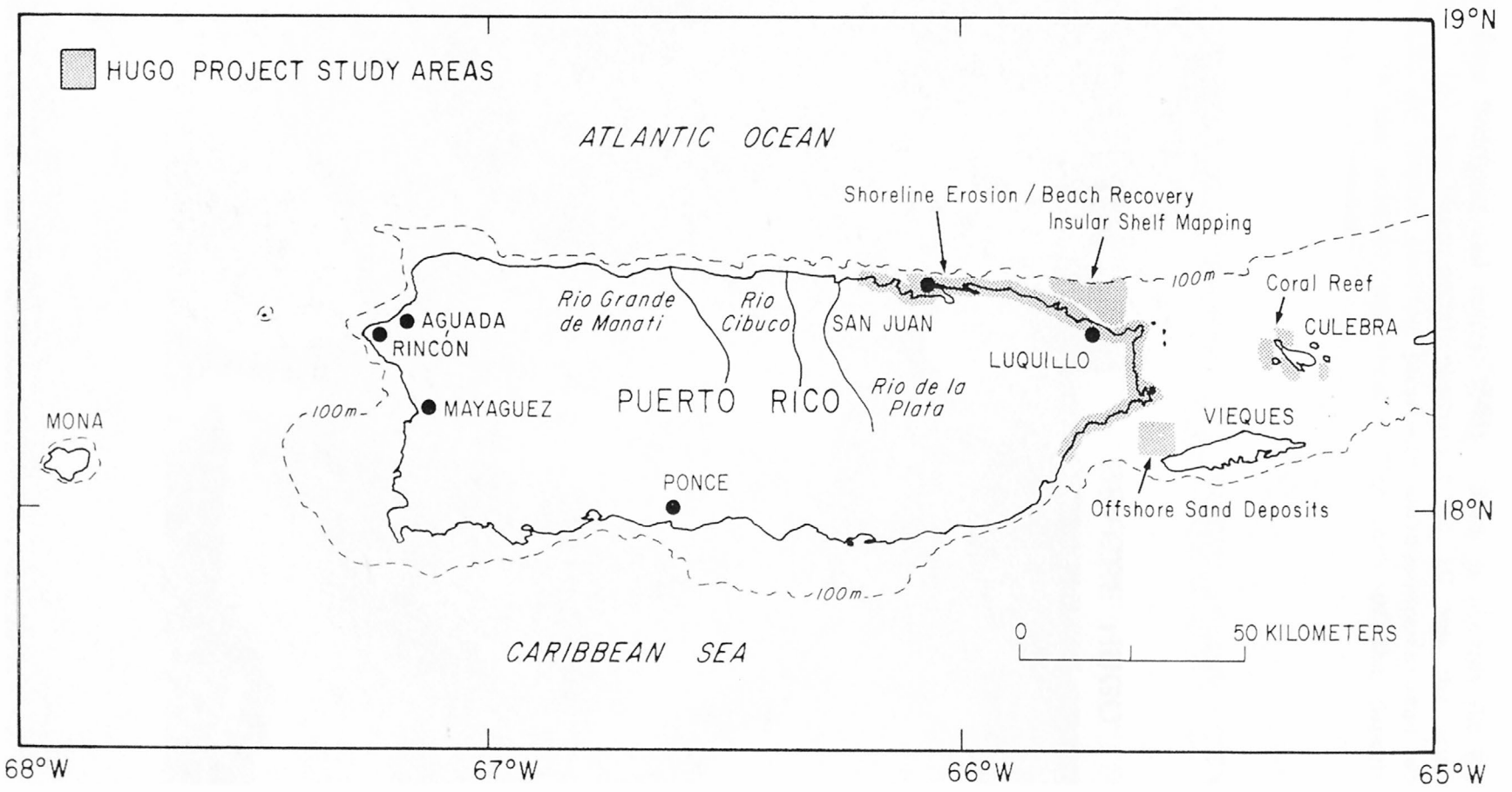
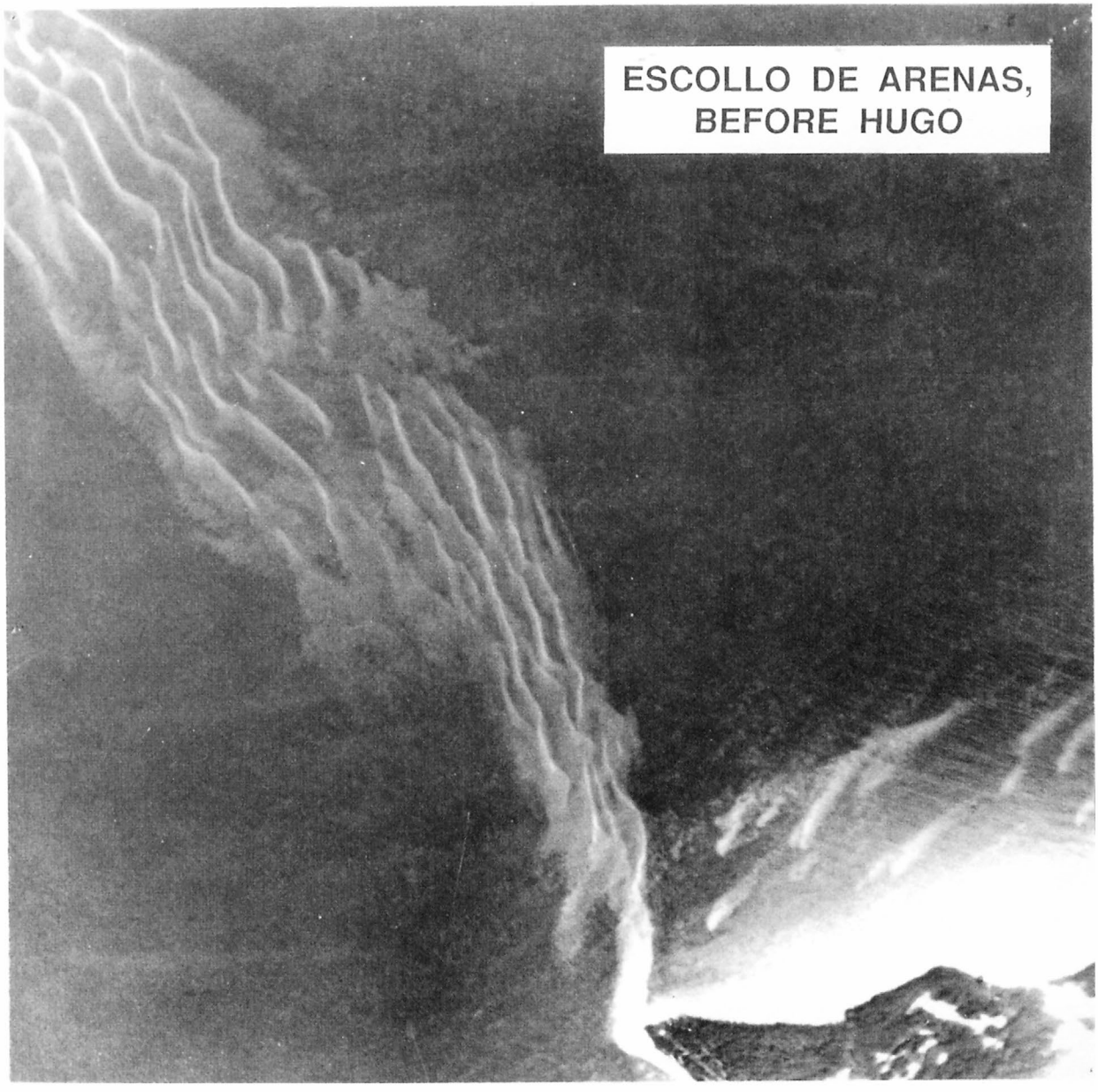


Figure 3. Aerial photographs of the Escollo de Arenas before and after Hurricane Hugo (from Rodríguez and others, 1993). North is towards the top of the photographs. (A) Pre-Hugo aerial photograph of all but the northern limit of the Escollo de Arenas showing prominent sinuous-crested sand waves extending parallel to the axis of the shoal. The area of the deposit is approximately 3 square kilometers.



(B) Post-Hugo aerial photograph of Escollo de Arenas.

Note that sand waves on the sand deposit are suppressed in comparison to the pre-Hugo photograph. Currents generated during Hurricane Hugo flattened the characteristic sand waves and dispersed sand over the adjacent sea floor.

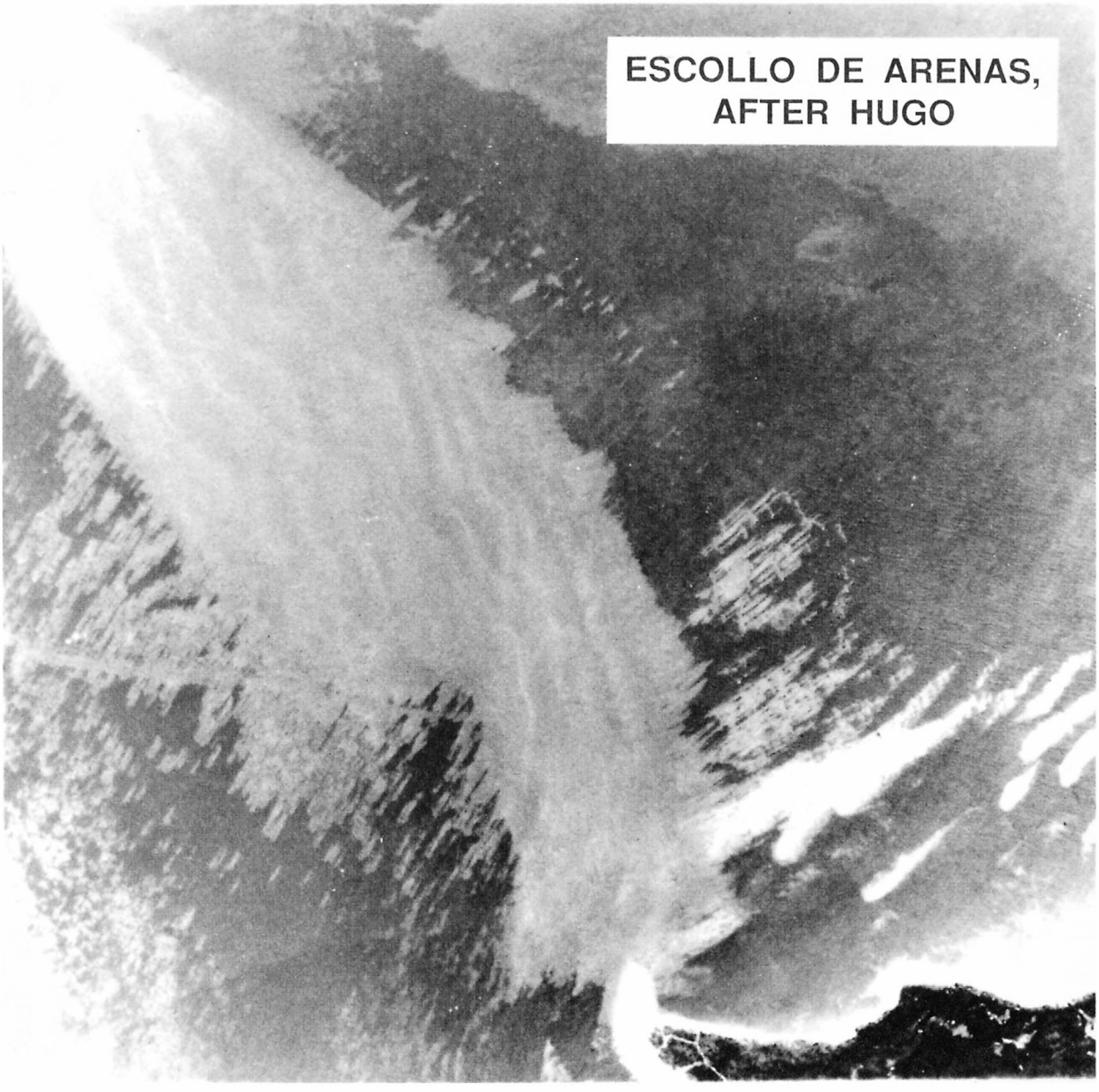


Figure 4. Reduction of the historical shoreline change map for the San Juan area from Punta Las Marias to Alambique (from Schwab and Rodríguez, 1992). There is an apparent long-term trend of shoreline straightening through headland erosion and embayment infilling. The numbers seaward of the shoreline (station locations) refer to beach profile monitoring sights. Transect locations are the measurement points for the historical shoreline change analyses.

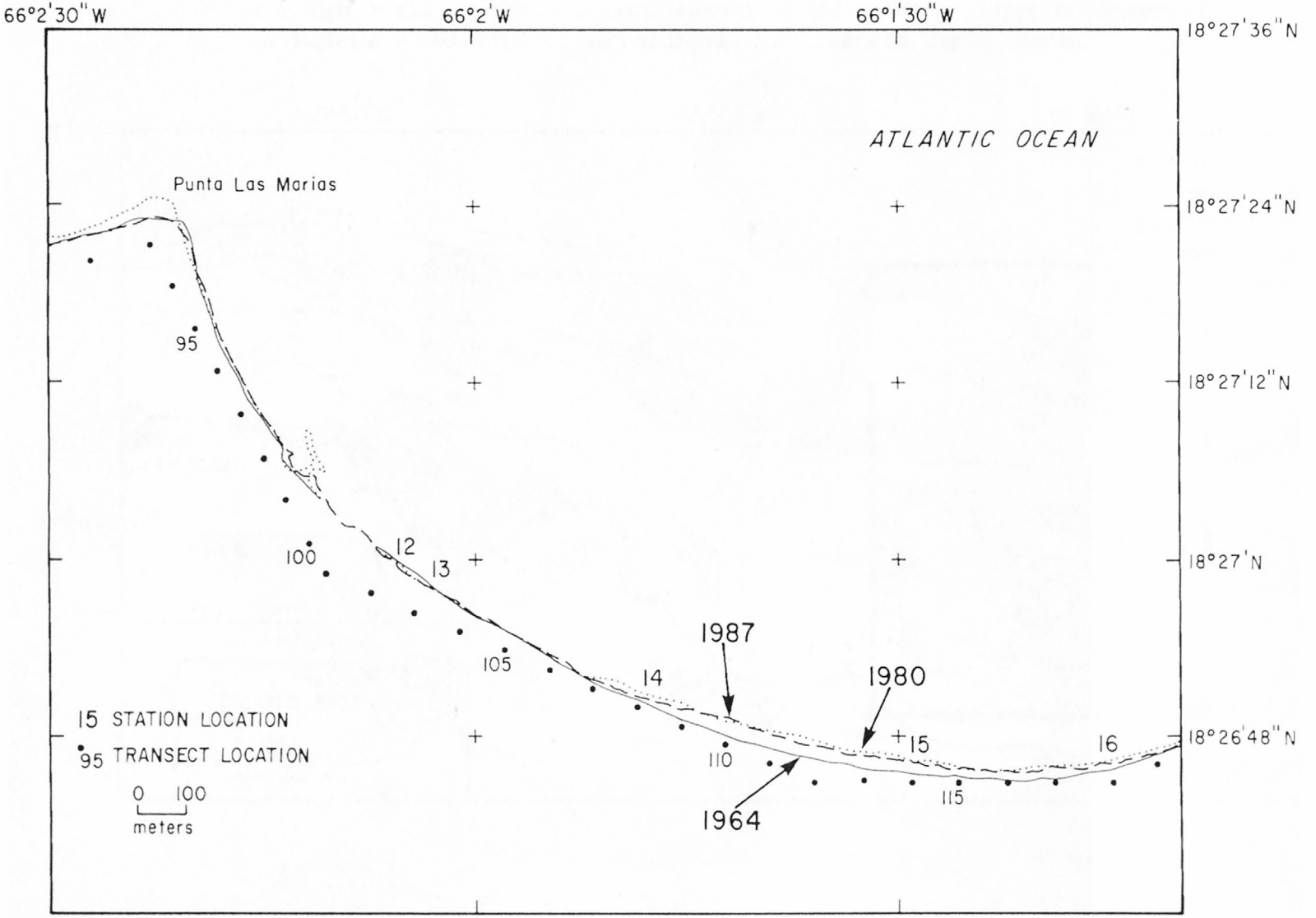


Figure 5. Generalized interpretive map of the Luquillo shelf study area based on analyses of high-resolution seismic-reflection profiles, sidescan-sonar imagery (see Fig. 6), and sediment samples (from Schwab and Rodríguez, 1992). Also shown is the location of Figure 6. The sea floor is dominated by outcropping eolianite. Sand lost from the beach front moves offshore during storms forming, in part, the low backscatter sand deposit. The orientation of the high backscatter sand deposit seaward of the eolianite ridges is interpreted to indicate a net offshore sediment transport direction during storms.

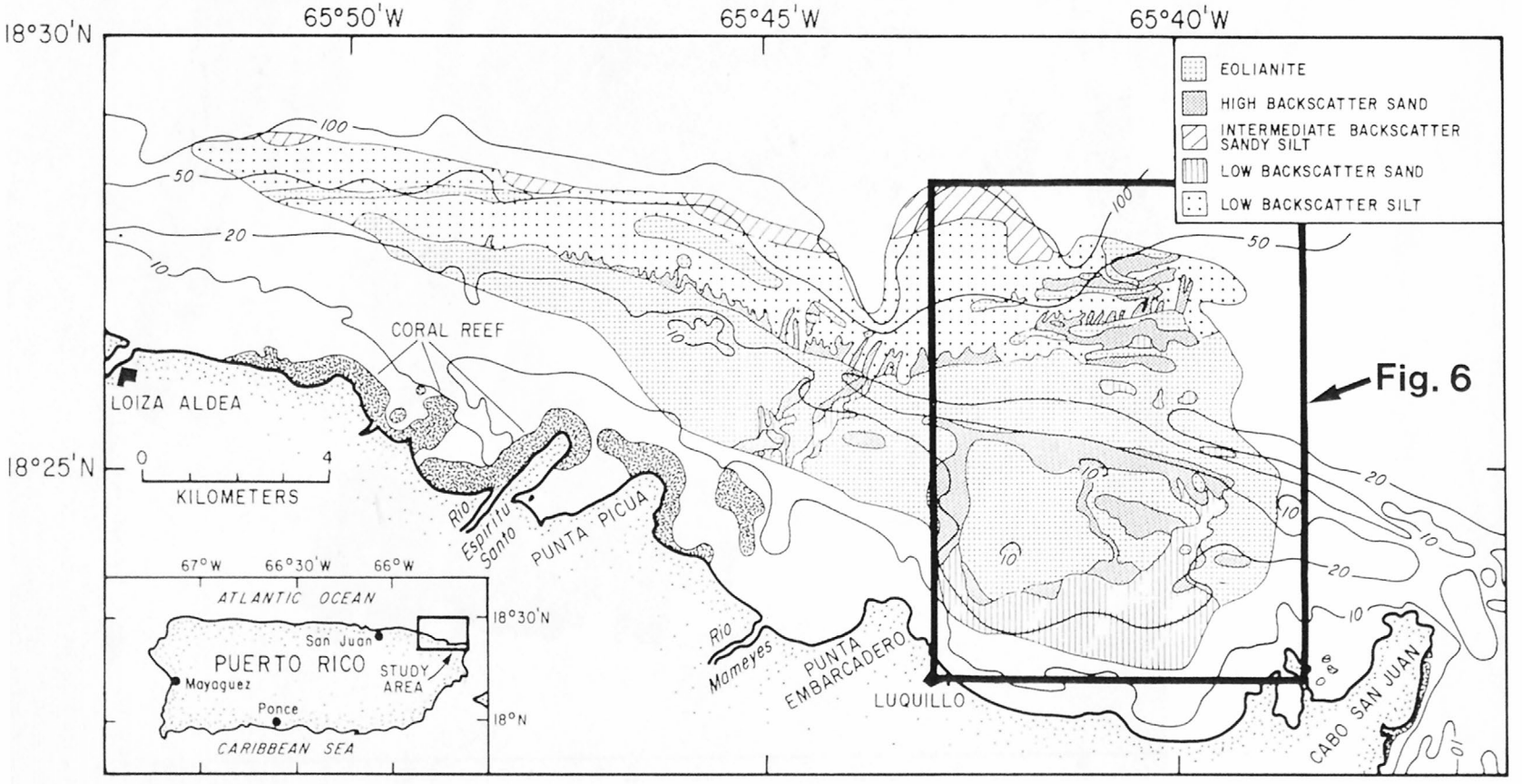


Figure 6. Map showing the sidescan-sonar imagery of the eastern segment of the insular shelf off Luquillo (from Schwab and Rodríguez, 1992). See Figure 5 for location.

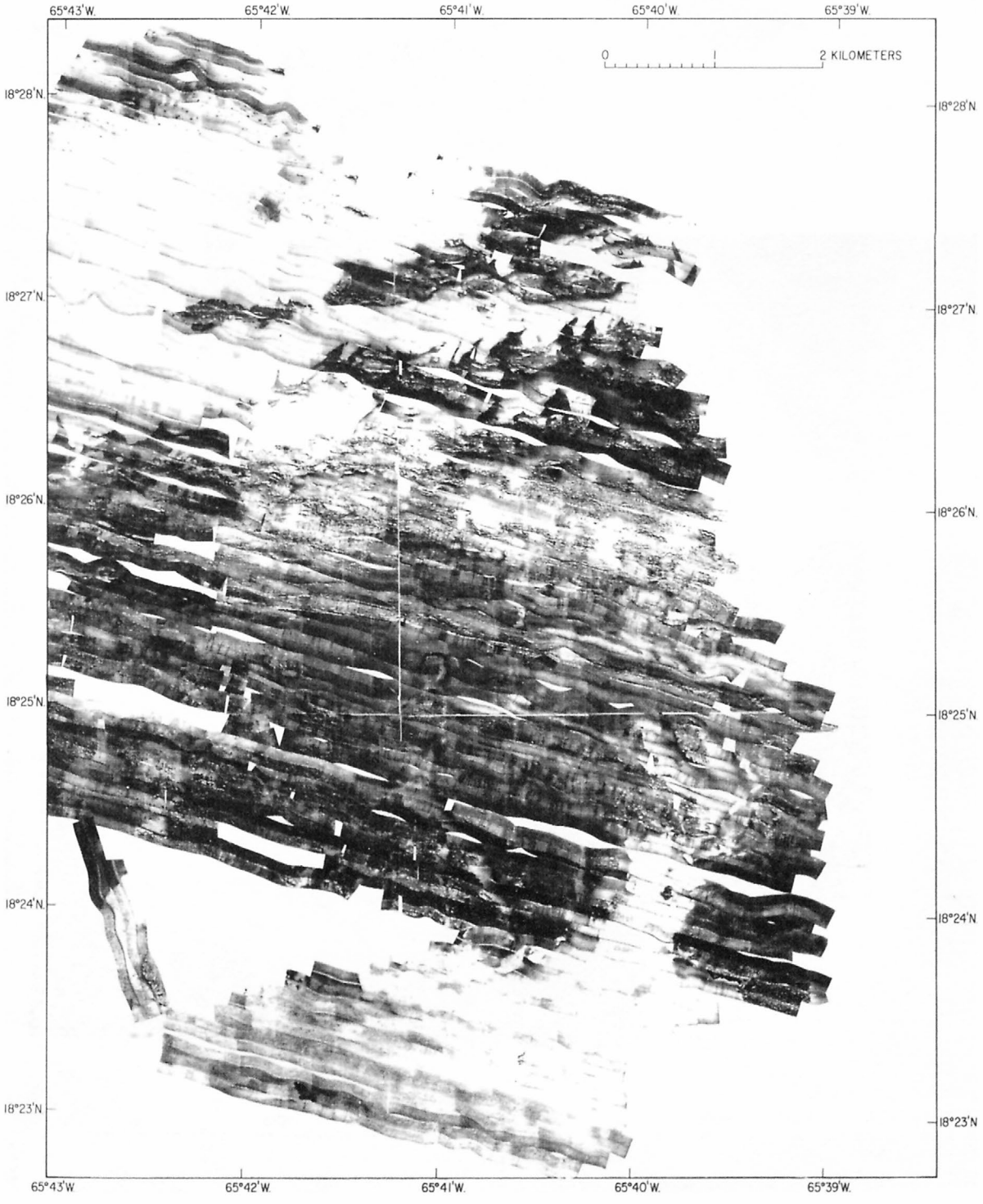


Figure 7. GLORIA reconnaissance sidescan-sonar imagery of the U.S. Exclusive Economic Zone around Puerto Rico and the U.S. Virgin Islands (from EEZ-85 Scientific Staff, 1987). The large numbers represent individual map sheets available in EEZ-85 Scientific Staff (1987).

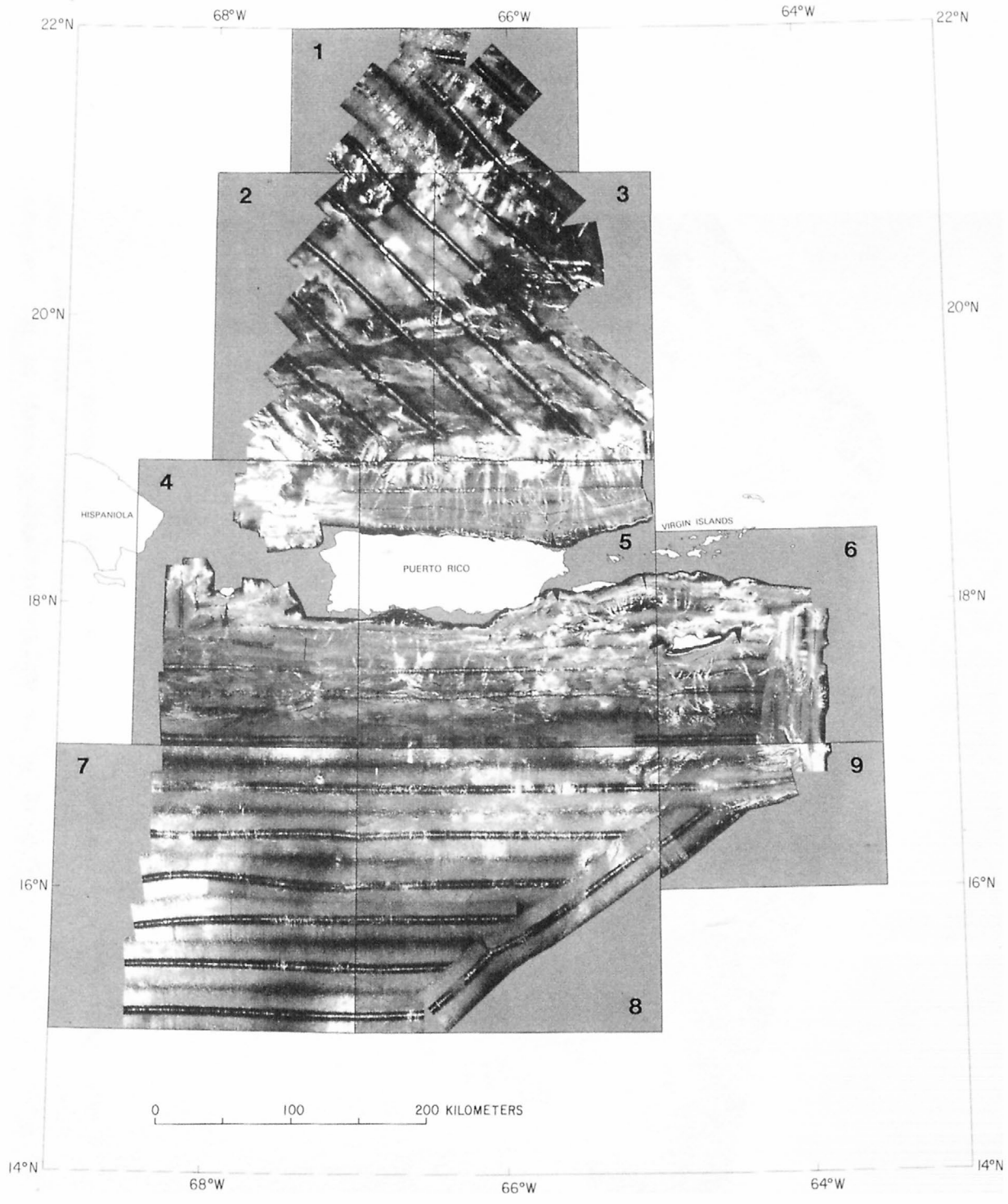


Figure 8. GLORIA imagery of an amphitheater-shaped scarp on the northern insular slope of Puerto Rico, representing the removal of more than 1,500 cubic kilometers of sedimentary rock (from Schwab and others, 1991).