U.S. DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY

MISCELLANEOUS FIELD STUDIES
MAP MF–2211

Albers Equal-Area projection
Bathymetry derived from National Ocean Service bathymetric maps
Coastline from World Data Bank 2, Coastline System, North Atlantic region

SCALE 1:2,000,000

0 50 100 150 200 KILOMETERS
0 50 100 NAUTICAL MILES

Introduction

This mosaic is a GLORIA (*G*eological *LO*ng *R*ange *I*nclined *A*sdic) view of the deep sea floor off the East Coast of the United States. It covers a surveyed region (fig. 1) of 195,000 square miles, an area nearly as large as Texas. The survey is part of a program to map the entire Exclusive Economic Zone (EEZ) of the United States and its island territories (also including Puerto Rico and the Northern Mariana Islands) carried out by the U.S. Geological Survey in cooperation with the British Institute of Oceanographic Sciences (IOS). A detailed atlas of the East Coast data has been published (EEZ-SCAN 87 Scientific Staff, 1991), and, along with this report, provides an overall view of the morphology and texture of the sea floor in the EEZ beyond the Continental Shelf.

The image is made by use of a long-range sidescan-sonar imaging system developed by the IOS (Somers and others, 1978). The system produces a picture of the deep sea floor much like high-altitude photographs taken over land, but uses sound rather than light to image the sea floor. Data are collected from a ship that traverses the area, surveying a swath as much as 45 km wide (22.5 km on each side of the ship's track). The ship tows a torpedo-shaped vehicle ("towed fish"), which is 8 m long, 0.7 m in diameter, and weighs 2.25 tons in air. A series of high-frequency sonar pulses (approximately 6.5 kiloHertz [kHz]) emitted by the towed fish are reflected off the sea floor below (fig. 2). The reflected sound is received by a transducer in the towed fish, and the signal is then transmitted through a towing cable to a shipboard computer that processes the signal. The image is further processed ashore to produce the digital mosaic shown here.

The reflected sound presents an image of the sea floor which depends on the type of sediment, on outcrops of underlying rocks, and on the small- and large-scale topography. Light-colored parts of the image represent a strong return from the sea floor, reflected from areas of consolidated sedimentary rocks or areas where the bottom topography is such that the angle between the sea floor and incoming sound pulses is high (fig. 3). Dark areas represent weak returns, from soft, muddy sediment that absorbs much of the incoming sound or from topography that results in an "acoustic" shadow (occurring where the incoming sound intersects the sea floor at a low angle; see figure 3). While the basic pattern of reflected sound from various features is understood, research is still needed to determine what differences exist between reflections from sea-floor features and reflections from features buried under the sea floor.

Sunken ships or other manmade debris are too small to be "seen" by the GLORIA system, which can resolve features a hundred meters or more in size.

This mosaic of the submarine landscape off the Atlantic Coast reveals a vast sediment dispersal system of canyons that carry turbid flows of sediment from the Continental Shelf (the shallow platform 0–200 m deep), down the continental slope (200–2,000 m) and the continental rise (2,000–4,000 m) to the deep abyssal plains seaward of the area of the mosaic. In a curious way, the mosaic reveals the widespread shedding of sediment to the deep sea, a process that is similar to the manner by which sediment is shed in the interior drainage (closed valleys and basins lacking rivers that flow to the ocean) in the western United States. The ocean basins are also closed, so that the abyssal plains (east of the surveyed area) are the final depositional sites for sediment contributed from shallow-water source areas like the Continental Shelf.

New England Continental Rise

Off New England, the mosaic shows a sediment-covered continental rise. Six ancient volcanoes, part of a chain of 42 subsea volcanoes which stretches 1,200 km to the east of Georges Bank over a width of 200 km (Emery and Uchupi, 1972, p. 72) are seen on the mosaic. Formed during the Cretaceous Period approximately 125 million years ago (de Boer and others, 1988; Schlee and others, 1988, p. 370), these volcanoes are now partly buried by a sedimentary wedge that has accumulated seaward of Georges Bank.

The continental rise south of New England is marked by slide complexes that were active during the Pleistocene Epoch (from approximately 2 million to 10,000 years ago). The slides originated by mass movement on the lower slope in water depths greater than 1,000 m; sections of strata as much as 300 m thick were removed by sliding. The Southeast New England slide complex between Block and Veatch Canyons is 175 km wide and extends at least 200 km to the southeast.

A few continental slope canyons such as Hydrographer and Nygren received enough sediment from Georges Bank to maintain their courses across the rise to the southeastern limit of the GLORIA survey area, but most continue only a short distance onto the rise.

Middle Atlantic and Carolina Continental Rise

The continental slope from Long Island to Virginia is cut by the largest submarine canyons (Hudson, Wilmington, Baltimore, Washington, and Norfolk) along the U.S. Atlantic continental margin. Except for Hudson Canyon, the canyons extend only 10 to 80 km onto the rise. Major canyons like Baltimore and Wilmington, for example, appear on the mosaic as highly reflective stripes that fade out a short distance onto the rise. Hudson Canyon, on the other hand, shows channels on the rise which connect directly to the lower slope. Major rise channelways like Wilmington Valley appear to collect sediment from "gather" areas on the slope and rise that are conduits for sediment flow. Close inspection of the mosaic where Baltimore and Wilmington Canyons disappear on the upper rise reveals indistinct, discontinuous, highly reflective bands that could be fragments of the original dispersal systems. Later sedimentation from mass wasting (landslides) and from hemipelagic deposition (long-term settling of sediment from oceanic waters) has largely obliterated clear sonic expression of the channel systems in the areas labelled "drape" on the map.

Farther southwest, an irregular, tongue-shaped feature that appears as a mottled light-gray area on the mosaic marks the Albemarle-Currituck slide complex. This immense mass movement deposit extends in a broad arc 190 km across the rise off North Carolina and Virginia. The head of the slide extends as several scars having a combined length of over 55 km along the continental slope. The scars delineate the probable source area for the original mass movement flows.

The Hatteras Transverse Canyon off North Carolina is a broad canyon that extends along the rise and collects fine-grained sediment funneled across the upper rise. Sediment from the middle Atlantic and Carolina continental shelves is deposited into the transverse canyon system through feeder canyons like Hatteras and Albemarle. The transverse canyon leads to the Hatteras Cone, a broad, fan-shaped sedimentary body opening out into deeper water on the northwestern side of the Hatteras Abyssal Plain, east of the GLORIA survey limit.

The Lower Rise Hills can be seen on the mosaic as a faintly striped area between the Hatteras Transverse Canyon and the EEZ boundary. The stripes represent abyssal mud dunes (Tucholke and Laine, 1982, p. 297) that extend 3–4 km from crest to crest and show approximately 50 m of relief. They have formed in response to the Western Boundary Undercurrent, a strong bottom current that flows southwestward, subparallel to the depth contours and counter to the northeast-flowing Gulf Stream. The Lower Rise Hills and the Western Boundary Undercurrent act as a partial barrier to the southeastward dispersal of fine-grained sediment, hence the development of the Hatteras Transverse Canyon subparallel to the continental slope.

Off North Carolina the continental slope is steeper than it is farther north, ranging from 7° to 16°. The Cape Fear and Cape Lookout slide complexes, which are very conspicuous on the mosaic, are the most prominent mass movement features here. They are 30–70 km wide and more than 250 km long. Seismic-reflection profiles show that the Cape Fear slide has removed as much as 80 m of sediment from the upper rise. The debris flows emanating from the slump scar are marked on the mosaic by a bright acoustic return that crosses the continental rise.

Blake Plateau and Blake Escarpment

Southward from South Carolina, the mosaic shows the northern part of a vast submerged limestone plateau called the Blake Plateau, and its eroded edge, the Blake Escarpment. The Blake Plateau was at sea level, like the modern Bahama Platform, until the middle part of the Cretaceous Period (about 95 million years ago) when gradual subsidence, scouring by the ancestral Gulf Stream, and low depositional rates resulted in regional submergence. On the mosaic, the conspicuous white band and projecting nose-like feature (the Blake Spur) mark an eroded escarpment nearly 4,000 m high. Only the northern part of the plateau was surveyed during the GLORIA project and the mosaic shows extensive areas of limestone of Cretaceous and Paleogene age (Dillon and Popenoe, 1988) at the sea floor. Elsewhere the sea floor in this area is covered by up to 0.5 m of cemented phosphatic gravel (EEZ-SCAN 87 Scientific Staff, 1991). Tonal variations in the mosaic depend mainly on the hardness and topography of the bottom. Brightest returns are from areas of cemented phosphatic gravel, from outcrops of hard Paleogene limestone, and from steep slopes faced by the incoming signal during the survey. Darker returns indicate the rock is less well cemented. Areas of darkest return are from unconsolidated sand or from a mud-covered bottom.

The Blake Escarpment is an immense undersea cliff. Most of its surface consists of giant steps caused by the erosion of flat-lying limestone strata by southward-flowing deep-sea currents (EEZ-SCAN 87 Scientific Staff, 1991). At the northern end of the escarpment, the Blake Spur projects seaward, interrupting the current flow, so that a series of canyons is preserved in the lee just to its south. Dives in the research submersible *Alvin* at the spur show that the cliff is nearly vertical and has been caused by erosion of its face. The strong, southward-flowing bottom currents have scoured a depression at the bottom of the escarpment off the end of the spur. The depression shows on the mosaic as a streaky zone of moderately high reflectivity.

Summary and Considerations for Future Studies

The Atlantic Coast GLORIA mosaic provides for the first time an overall view of the morphology and texture of the sea floor in the EEZ beyond the Continental Shelf. It shows that the continental rise morphology is fully as complex as any subaerial landscape, and is a product of volcanism, mass movement of sediment as huge submarine landslides, flows of turbid water confined to river-like channels, and sediment movement by bottom currents to create large dune-like features. The mosaicked area actually resembles the western United States where characterized by "interior drainage."

The GLORIA survey has raised many questions that need further study through more detailed surveys of selected areas of the EEZ. The GLORIA image provides a reconnaissance view of the deep sea floor, and one that is limited in resolution. Using different acoustic frequencies and sound sources towed close to the sea floor will provide more detailed, higher resolution sidescan surveys. For example, a high-resolution survey of the outer part of the Mississippi Fan in the deep Gulf of Mexico (Twichell and O'Connell, 1990) revealed the intricate nature of the depositional lobes that make up the outer fringes of the fan.

Future studies will focus on understanding the processes that have shaped the features observed in the mosaic and on understanding what the images reveal of the sea floor. We need to know much more about the mass movement deposits in the deep sea (debris flows, turbidity flows, and slide and slump complexes) because they make up such a large part of the continental rise. Questions to ask include the following: Are these deposits recent or relict? What caused them? Are they potential hazards to future activity on the sea floor? We need to distinguish modern processes from those that operated during Pleistocene time, when sediment was more actively delivered to the continental rise. Similar surveys of selected areas of the Continental Shelf are also needed.

Surveys like GLORIA give us a new way to view the areal patterns of deep-sea sedimentation, and when combined with other types of geologic and physical oceanographic data they allow us to comment on competing uses of the sea floor which relate to national or regional needs. Through mapping of mass movement complexes we can characterize areas of the sea floor that are unstable for the placement of hazardous waste, submarine cables, and pipelines. For waste disposal we need to map pathways of active sediment dispersal and active sediment accumulation, depending on whether we wish to disperse or bury the waste substance. Through interpretation of geophysical profiles combined with GLORIA surveys, we can pinpoint potential deep-sea resources like phosphatic pavements, frozen gas horizons (clathrates), and manganese nodules.

Acknowledgments

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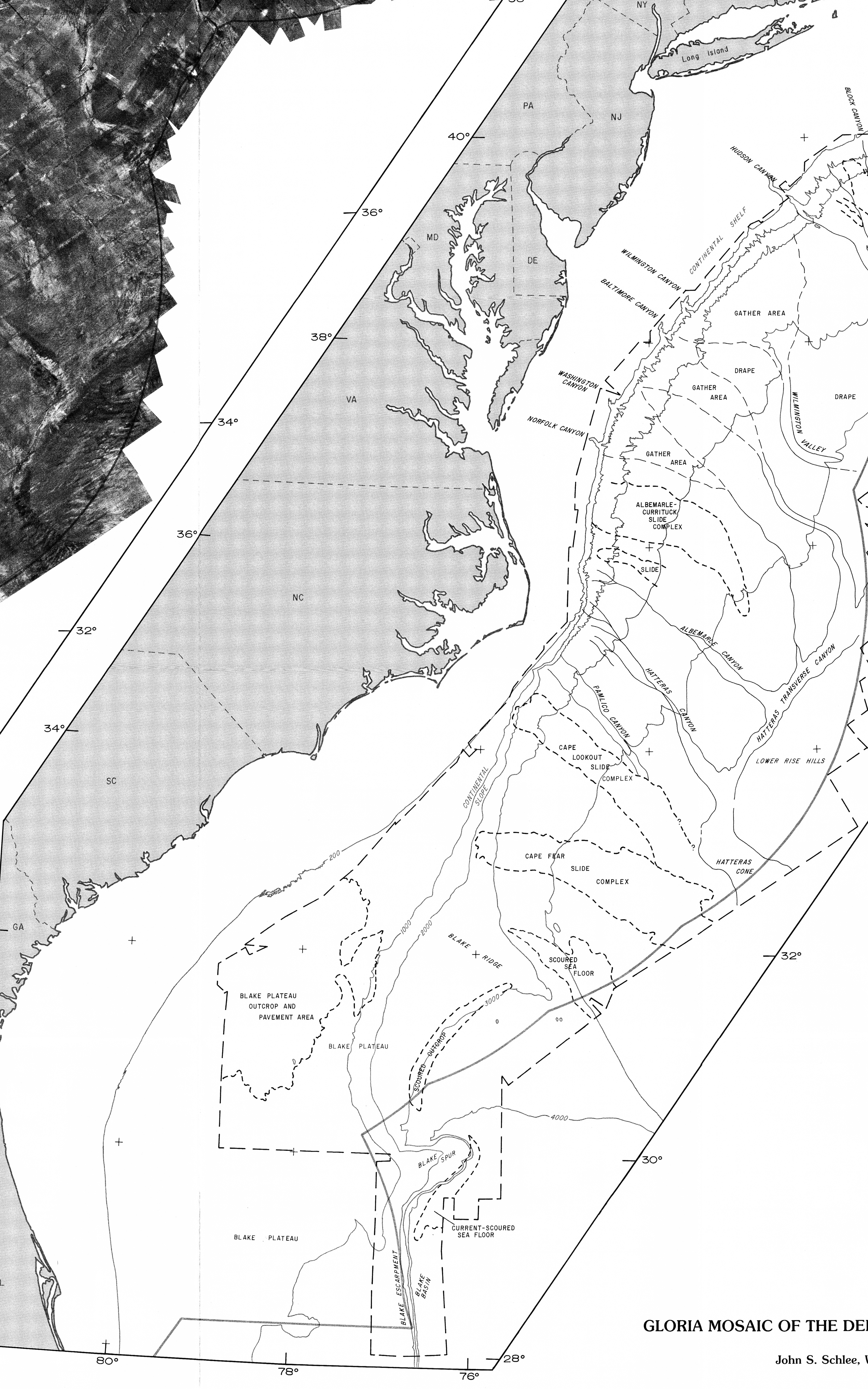

EXPLANATION OF SUBMARINE FEATURES

Canyon, channel, or valley

Broad

Narrow

Limit of sediment "gather" area or of sediment "drape" area

Limit of slide or slide complex, or of scoured sea floor, or of Blake Plateau outcrop and pavement area--Queried where uncertain

BUELL Volcanic seamount

2000 Bathymetric contour--Edge of Continental Shelf (depth 200 meters) is shown; in deeper water contours are shown every thousand meters

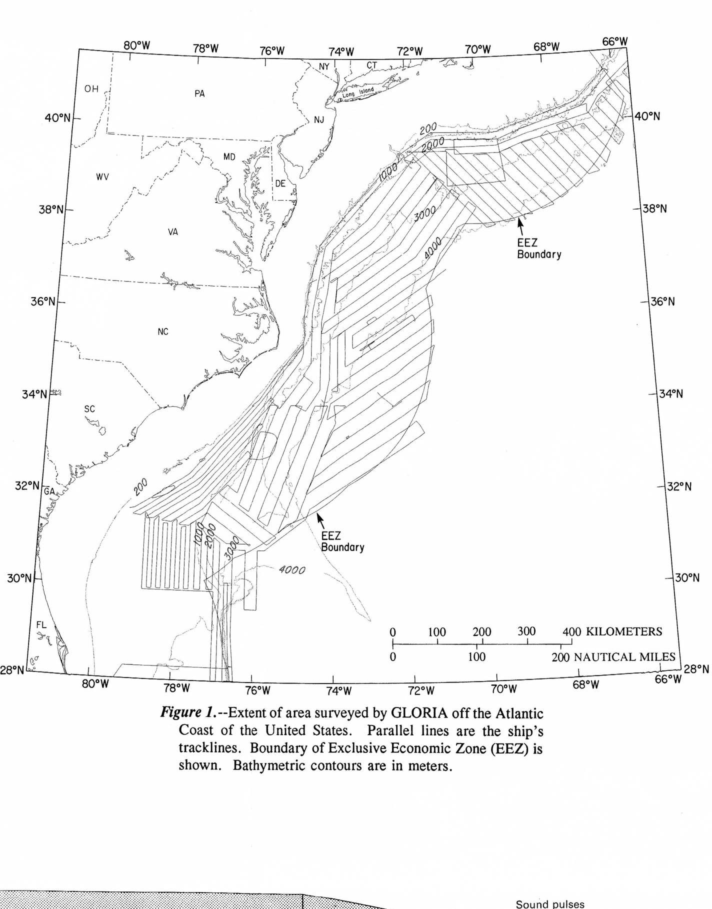

Figure 1.--Extent of area surveyed by GLORIA off the Atlantic Coast of the United States. Parallel lines are the ship's tracklines. Boundary of Exclusive Economic Zone (EEZ) is shown. Bathymetric contours are in meters.

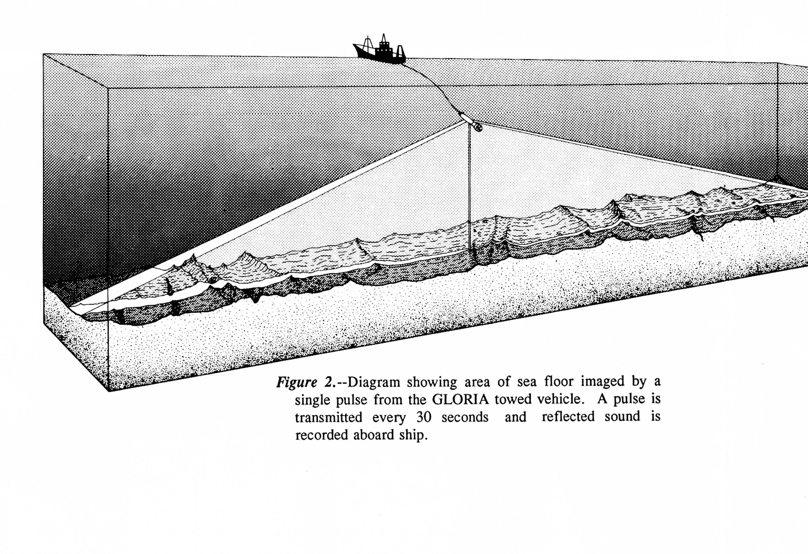

Figure 2.--Diagram showing area of sea floor imaged by a single pulse from the GLORIA towed vehicle. A pulse is transmitted every 30 seconds and reflected sound is recorded aboard ship.

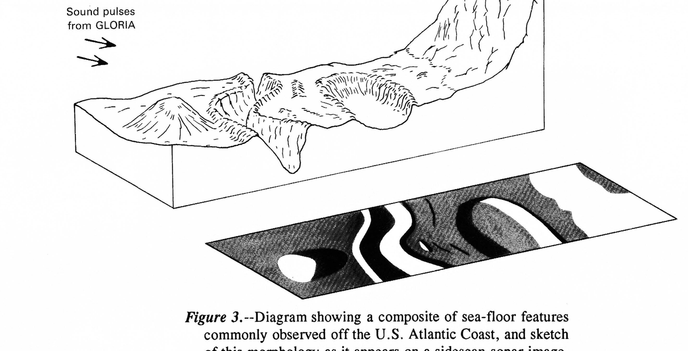

Figure 3.--Diagram showing a composite of sea-floor features commonly observed off the U.S. Atlantic Coast, and sketch of this morphology as it appears on a sidescan-sonar image.

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GLORIA MOSAIC OF THE DEEP SEA FLOOR OFF THE ATLANTIC COAST OF THE UNITED STATES

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