SHALLOW FAULTS

Shallow faults are potential geologic hazards to drilling operations and related petroleum development for these reasons:

1. Extensive shallow faulting may indicate a history of geologic instability. Pipelines or drill rigs could be subject to rupture or differential settling if instability such as an earthquake should occur.
2. Normal or gravity faults and slump faults indicate slope instability and a resultant danger of mass movement, which could cause rig or platform loss or shearing of pipelines and drill stems.
3. Shallow faults could act as conduits for high pressure gas to escape from deep accumulations to the surface. This could result in blowouts or fire.

On acoustic records, faults are recognized by dip changes of reflecting horizons, offsets or terminations of reflections, and upward convex hyperbolas known as diffractions. A diffraction is caused by any sharp corner that strongly reflects seismic signals before and after the seismic source on the ship passes it. The apex of the diffraction marks the fault zone. The vertical displacement of the fault can be estimated by correlating terminated reflections across the disrupted zone.

Three types of faults are illustrated on this sheet. Figure 6 shows many very small disruptions in buried shelf sediments just offshore of Savannah, Ga. These are interpreted as small compactional faults. Typical displacements of these faults are about 1 m, making their interpretation somewhat conjectural because on seismic records faults may look similar to disruptions produced by small velocity differences in near-surface layers. The faults do not appear to extend to the surface and have too small a displacement to be recognized in deeper seismic-reflection records. In the area of figure 6, the faults displace Eocene-, Oligocene-, and Miocene-age rocks consisting of sandy clay, clayey sand, and sandy limestone (McCollum and Herrick, 1964). Throughout this report, geologic ages are assigned to seismic-reflection units on the basis of two independent stratigraphic studies (Edsall, 1979; Paull and Dillon, 1979).

Figures 7 and 8 show larger displacement faults (10-20 m) offsetting Late Cretaceous-age rocks on the inner Blake Plateau. Figure 7 is a high-resolution seismic-reflection profile of a section of line 24A. Figure 8 shows the same type of faulting observed on an air-gun reflection record on line 19. These faults dip nearly vertically, appear to diminish with depth, and do not appear to offset beds younger than Late Cretaceous. They occur in a unit that corresponds to a thick sequence of chalk at the COST GE-1 well (Scholle, 1979) and are believed to have been caused by postdepositional compaction (Paull and Dillon, 1979). They are observed most commonly in the southern half of the study area, near the shelf break and east of it, but they also may be present beneath the shelf.

Figure 9 shows two well-developed gravity faults where line 29 crosses the Florida-Hatteras Slope. The faults dip at about 58° and have a displacement downslope of about 10 m. Faults such as these are common to slope areas and are a sign of slope instability. Gravity faults are not common on the Florida-Hatteras Slope, perhaps because the angle of declivity of the slope averages only about 3.5° (Ball and others, 1980) and because much of the fine-grained component of the sediments has been winnowed away by the Gulf Stream and other currents.

Figure 10 illustrates a slump sheet, a further sign of slope instability. The slump sheet shown in figure 10 occurs on line 19 in 400 m of water at the base of the Florida-Hatteras Slope. It is recognized by the contorted bedding. Here it is about 20 m thick and 5 km long. Slump sheets, like gravity faults, are not common on the slope, indicating that the slope is relatively stable.

Figure 11 illustrates a gravity fault where line 11 crosses the slope. The gravity fault is a relatively young feature as it displaces the surface sediments. Also illustrated are several water-column anomalies at the top of the slope. Although these anomalies can reflect gas seeps, schools of fish, or reef features, the position, shape, and apparent attachment of these anomalies to the bottom strongly suggest that they reflect modern patch reefs.

BURIED CHANNELS

Buried channels and erosional unconformities are potential geologic hazards to petroleum exploration and development. These zones typically contain highly porous materials such as coarse-grained sands or conglomerates. The character of such sediments can change rapidly over short distances. As the character of sediments changes, properties such as the bearing capacity of the sediments change. Therefore, rigs or platforms straddling channels could be subject to differential settling or tilting. Permeable zones can also trap high-pressure gas, cause loss of drilling fluids, or permit the escape of high-pressure gas from a deeper source. Gas accumulations can sometimes be recognized on seismic records as reflection whiteouts, wipeouts, translucent zones, strong reflections, or velocity inversions.

Buried channels and unconformities are recognized on seismic-reflection records by their shape and internal structure. Figure 12 shows a buried river channel on the shelf along line 2. The channel is near the northern end of lease block area D. The top of the channel is 12 m below the ocean bottom and its relief is about 20 m, making the base of the channel about 70 m below present sea level. The channel is over 1/2 km wide. This channel and many others on the shelf were cut during Pleistocene time when sea level dropped to over 100 m below its present level (Curray, 1965; Milliman and Emery, 1968; Ayers and others, 1980). The distribution of the channels within lease block area D and the channels' discontinuous nature suggest that they are of tidal zone origin, formed in back of a barrier sequence during a stillstand of sea level at the mid-shelf.

Figure 13 shows multiple channeling and unconformities in lease block area A. The deepest unconformity is cut into Paleocene- and Eocene-age rocks, and the general character of the unconformity is similar to scour features and submarine topography as seen on the Blake Plateau beneath the Gulf Stream today (fig. 24, sheet 3). The extensive cut-and-fill seen on this record probably reflects a long history of submarine current erosion from the ancestral Gulf Stream during incursions onto the shelf at high-stands of sea level.[1]

[1] The use of trade names in this publication is for descriptive purposes only and does not constitute endorsement by the U.S. Geological Survey.

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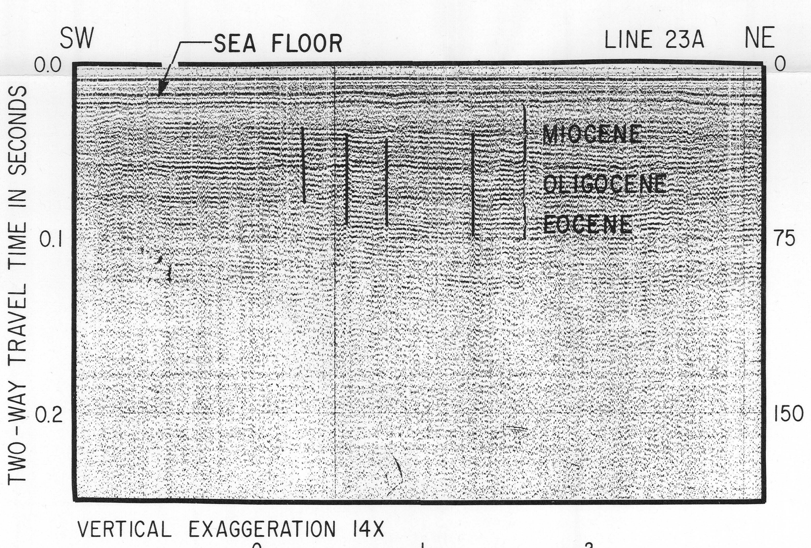

Figure 6.--Seismic-reflection record showing shallow faults on the Florida-Hatteras Shelf. Faults are highlighted by solid lines.

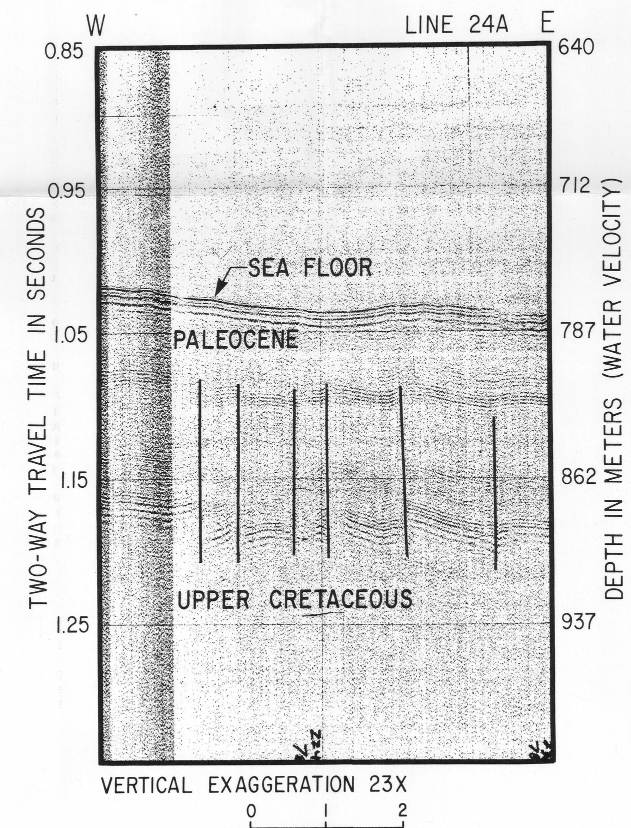

Figure 7.--Sparker[1] seismic-reflection record showing buried faults on the Blake Plateau. Faults are highlighted by solid lines.

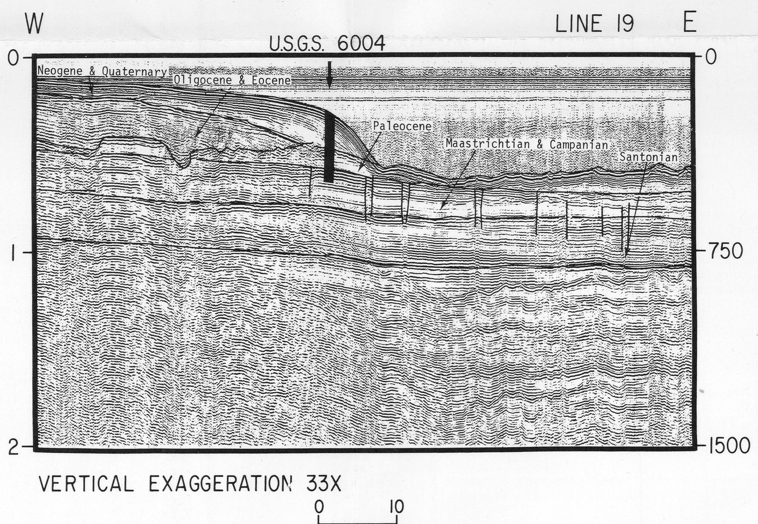

Figure 8.--Interpreted air-gun seismic-reflection record showing buried faults in Upper Cretaceous rocks. Faults are highlighted by solid lines.

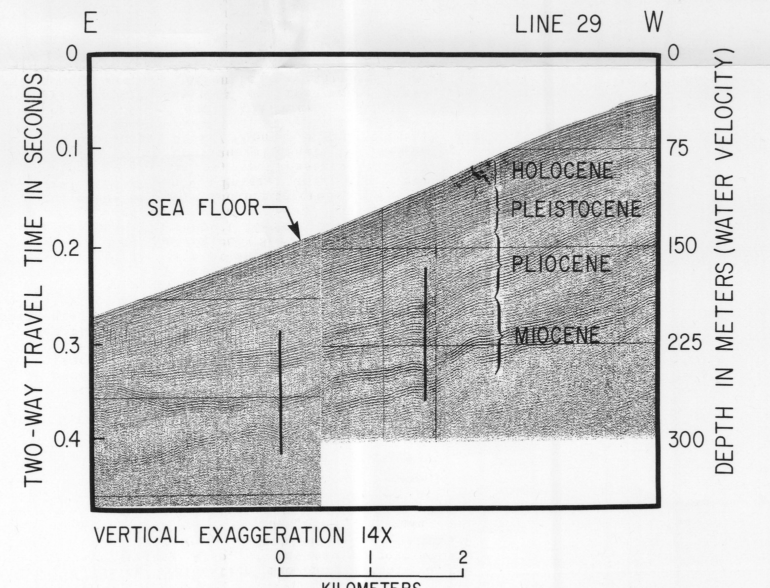

Figure 9.--Seismic-reflection record showing gravity faults on the Florida-Hatteras Slope. Faults are highlighted by solid lines.

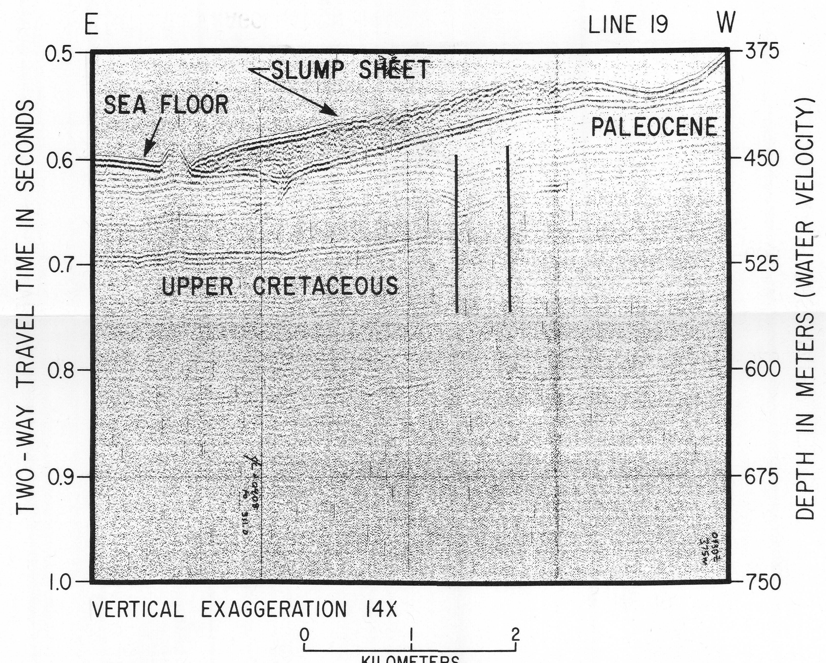

Figure 10.--Seismic-reflection record showing a slump sheet at the base of the Florida-Hatteras Slope.

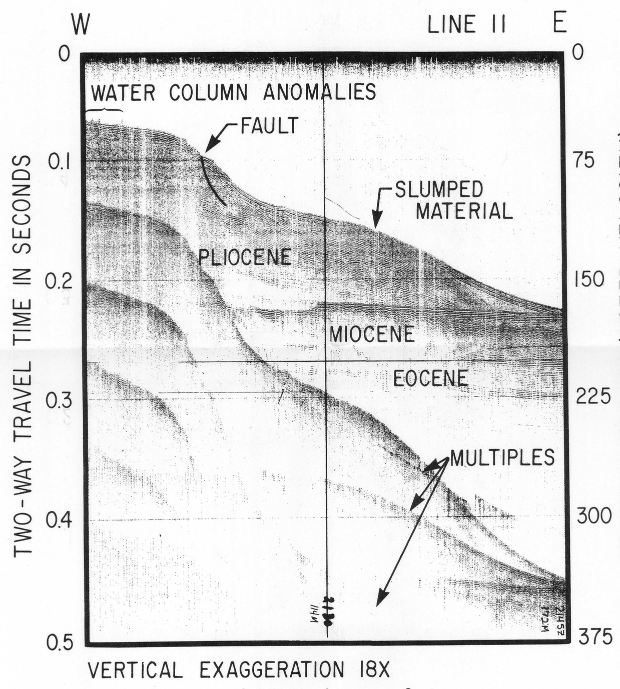

Figure 11.--Seismic-reflection profile across the Florida-Hatteras Slope showing a gravity fault and slumped sediments. The gravity fault is highlighted by a solid line.

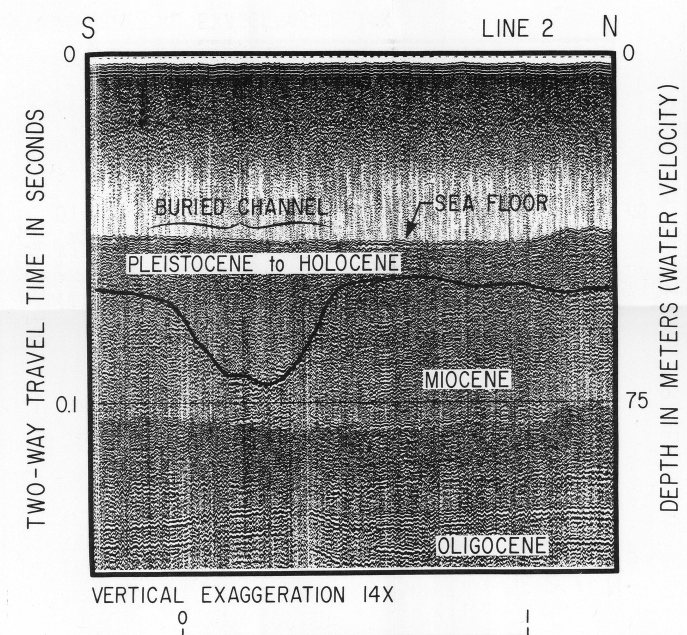

Figure 12.--Seismic-reflection record showing a buried channel on the mid-shelf.

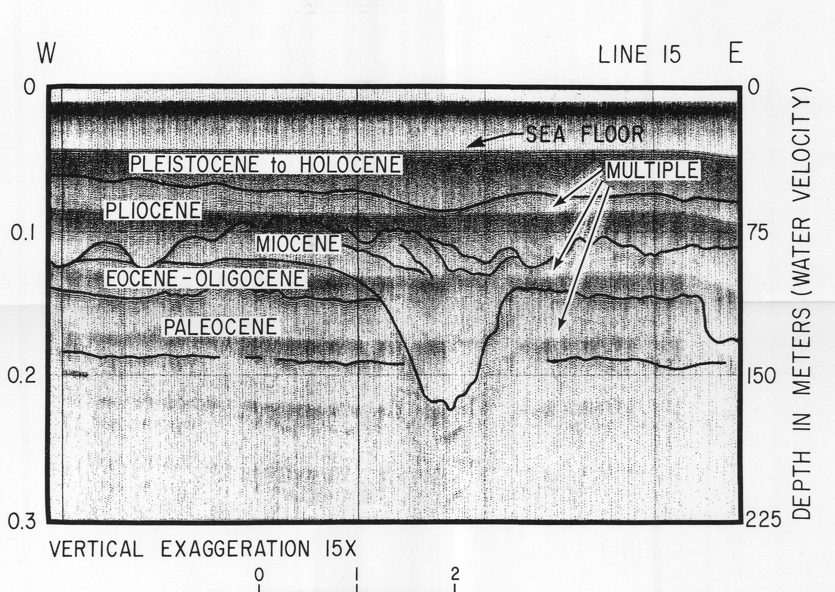

Figure 13.--Seismic-reflection record showing multiple channeling and unconformities on the mid-shelf.

REEFS AND HARDGROUNDS

In scattered areas, the sand bottom is cemented or hard substrate projects through the thin sand cover of the shelf. These areas, known as hard-bottom, hardgrounds, or live-bottoms, vary from relatively smooth outcrops periodically covered and uncovered by a veneer of sand to areas where bottom relief may be as much as 10 m or more (Henry and Giles, 1980). The greatest relief areas are generally found along the shelf edge between Jacksonville, Fla., and Cape Hatteras, N.C., where a discontinuous series of cemented ridges parallels the slope. These ridges are known as shelf-edge reefs (Macintyre and Milliman, 1970).

When hard substrate is exposed, it becomes encrusted by sessile-attaching invertebrates such as fan corals, sponges, sea whips, sea pens, hydroids, barnacles, colonial tube worms, and algae. These fauna and flora and the local bottom relief provide food and shelter for many reef-type fish, including black bass, snapper, grouper, amberjack, baracuda, and other reef-type animals. This abundance of animal life in hard-bottom areas makes them valuable both recreationally and commercially as fishing banks, which should then be protected during petroleum exploration and development.

On seismic-reflection records, low-relief hardground areas can sometimes be recognized indirectly by water column anomalies, which indicate schools of fish, or by reflections stronger than those from a sand covered bottom. These reflection differences are best seen in high-frequency reflection records (such as 3.5 kilohertz). However, other techniques that map reflection irregularities of the seafloor, such as side-scan sonar and underwater-towed television, are usually used in conjunction with reflection records to verify the presence of low-relief hardgrounds. Because they are not easily identified from high-resolution seismic-reflection records alone, low-relief hardgrounds are not shown on the map of potential geologic hazards.

Moderate-relief hardgrounds, patch reefs, and the shelf-edge reef can usually be identified from high-resolution seismic records because they project above the bottom or appear as rough bottom. Where they have been identified in the survey area, they are shown on the map of potential hazards as submarine habitats. Figures 14 and 15 are seismic-reflection records showing examples of what has been called a submarine habitat on the hazards map.

Figure 14 shows a moderate-relief hardground on the mid-shelf in about 35 m of water. The hardground projects about 2.5 m above the bottom and is 250 m long. Associated with the hardground is a water column anomaly that is probably caused by a large school of fish. The feature is located on line 4 about 12 km west of the shelf break.

Figure 15 shows the expression of a shelf-edge reef along line 29. Here the reef is in about 50 m of water, although these reefs may occur in water depths up to 150 m (Macintyre and Milliman, 1970). The reef projects slightly above the shelf bottom and about 12 m above what appears to be erosional terrace at the base of the reef. Studies of reef and hardground areas of the shelf (Continental Shelf Associates, Inc., 1979) indicate that many reefs may be forming today from algal cementation of bottom sands and the debris of calcareous sedentary organisms.

Figure 16 is a photograph taken in 80 m of water from a two-man submersible vessel in the area of the shelf-edge reef near line 26. The reef is made up of both nodular and tabular blocks of cemented quartz sand, oolites, and bioclastic calcareous material, and intervening sand bottom. Blocks are encrusted by algaes, soft corals, sponges, bryozoans, anthozoans, and anemones. Note the bottom relief which offers shelter for the small fish seen in the picture.

DEEP REEFS

Extensive areas beneath the Gulf Stream on the Blake Plateau are characterized on seismic records by convex upward hyperbolas (fig. 17) that appear to be both attached and unattached to the seafloor. These features occur in water depths of about 260-800 m. Bottom sampling and photographs have demonstrated that these hyperbolas are reflections from thickets and mounds made up of living and dead deep-water branching corals and pelagic ooze that has been rained down from biologic production in the overlying water and trapped in the reef structure (Stetson and others, 1962; Ayers and others, 1980). Similar to shallower coral reefs, the deep reefs have their own ecological systems. Unlike shelf reefs, however, the populations are sparse as the reefs occur in cold water and in depths where no surface light penetrates. Although deep-water reefs are relatively abundant beneath the Gulf Stream, they represent a fragile ecosystem that should be considered in developmental activity.

Figure 17 shows the appearance of these reefs on a seismic record from line 8 on the northern Blake Plateau. On this record, the largest mound is about 25 m high and 300 m wide. Other records have shown these features to be over 100 m high. The hyperbolas that appear to be beneath the seafloor are reflections from coral thickets and mounds that are off to the side of the traverse.

Figure 18 is a bottom photograph of a deep-water coral thicket on the Blake Plateau (Stetson and others, 1962) showing the sparse nature of deep-water reef development. The white corals seen in the picture are living, whereas the black corals are dead and covered by a manganese coating precipitated from seawater. The intervening material is pelagic ooze, which is chiefly responsible for building the mounds.

SCOUR AND SAND WAVES

Scour and sand waves are evidence of strong currents which present the potential hazard of excavating and abrading structural supports (platform legs, pipelines, anchors, etc.) placed on the bottom, causing them to weaken or settle. In addition to indicating strong currents, sand waves are mobile or migratory bed forms, thus they can move from beneath a structure placed on them or bury a structure such as a pipeline, thereby causing changes in the stresses acting on these structures, perhaps leading to rupture. In most cases, those conditions can be controlled by readily available technology and proper engineering precautions.

Currents that sweep the shelf produce both scour channels and sand waves. The best developed sand waves occur near the outer shelf and offshore of the Capes. Figure 19 shows large, slightly asymmetric sand waves from line 5A about 8 km west of the shelf edge. The sand waves are about 4 m high, 300 m from crest to crest, and occur in 35 m of water. Other sand-wave fields are shown on the map of potential geologic hazards on the inner, middle, and outer shelf.

Very strong currents are associated with the Gulf Stream, which has been the major force to shape the Florida-Hatteras Shelf and Slope and inner Blake Plateau since Paleocene time (Paull and Dillon, 1979). These currents flow northward at maximum speeds of at least 180 centimeters per second (cm/s), which is equivalent to 3.5 knots/hour or 6.5 km/hour, and skirt the Continental Slope from the Straits of Florida to Cape Hatteras. They are responsible for the difference in depth between the Florida-Hatteras Shelf and the Blake Plateau as they have been a barrier to sediment transport beyond the shelf, sweeping sediments north to be deposited on the Continental Rise.

Although the strength of the current near the bottom is generally less than its surface strength, the Gulf Stream has eroded the bottom beneath it into a series of buttes, mesas, and erosional channels. These bedforms are spectacularly developed off Charleston, S.C., where Oligocene-, Paleocene-, and Late Cretaceous-age sediments are exposed in an erosional window on a structural and bathymetric high known as the Charleston Bump. The seismic records in figures 19-23 show evidence of scour and erosional bedforms, which indicate that strong currents existed in this area in the past. The steep slopes of the buttes are now protected from further erosion and maintained by a pavement of lag gravels and manganese nodules (Ayers and others, 1980).

The Gulf Stream may present a formidable problem in drilling, setting of risers, and emplacing other structures during exploration and development on the inner Blake Plateau. Also, it may cause scour around bottom-mounted structures. Problems of drilling in these currents have been documented by Hathaway and Weed (1976) during operation of the drill ship *Glomar Conception* where severe chatter and bending of the drill string by currents prevented successful operations.

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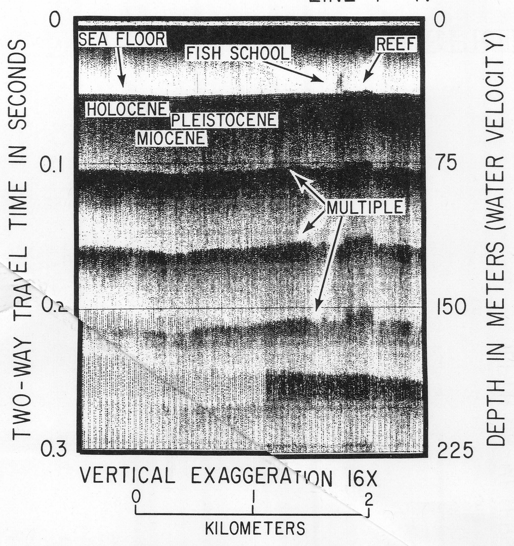

Figure 14.--Seismic-reflection record showing a moderate-relief reef or hardground on the mid-shelf.

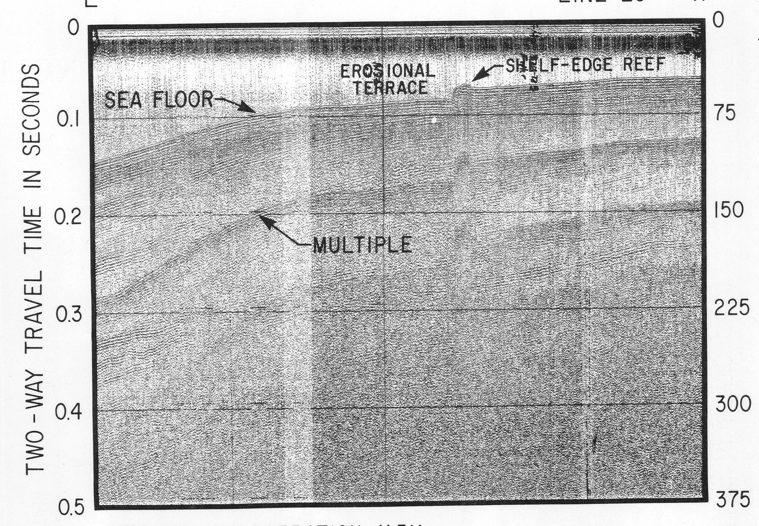

Figure 15.--Seismic-reflection record showing the shelf-edge reef.

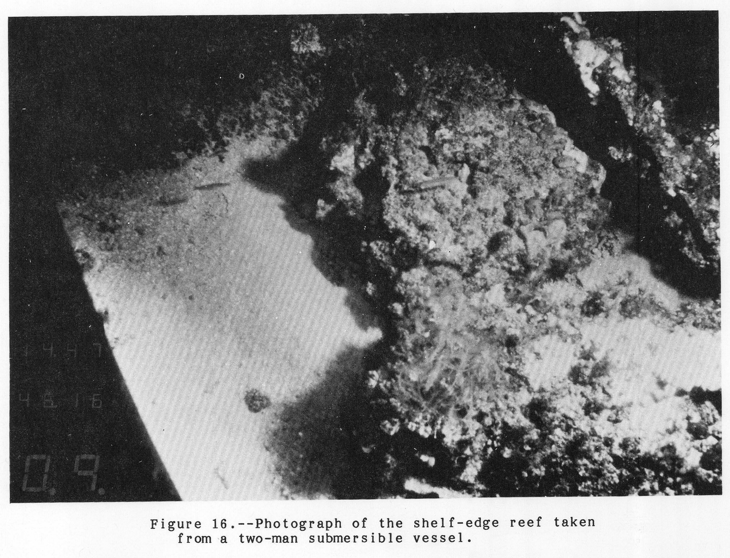

Figure 16.--Photograph of the shelf-edge reef taken from a two-man submersible vessel.

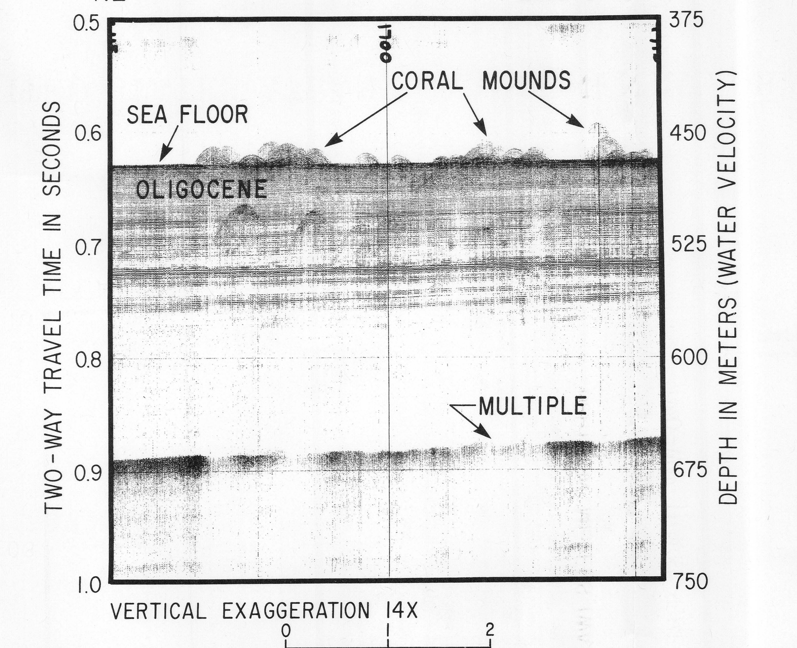

Figure 17.--Hyperbolas on a seismic-reflection record indicating deep-water coral mounds on the Blake Plateau.

Figure 18.--Bottom photograph of the top of a deep-water coral mound taken with a lowered camera.

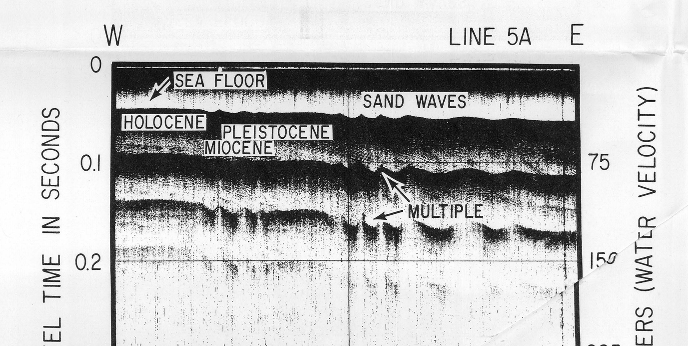

Figure 19.--Seismic-reflection record showing sand waves near the shelf break.

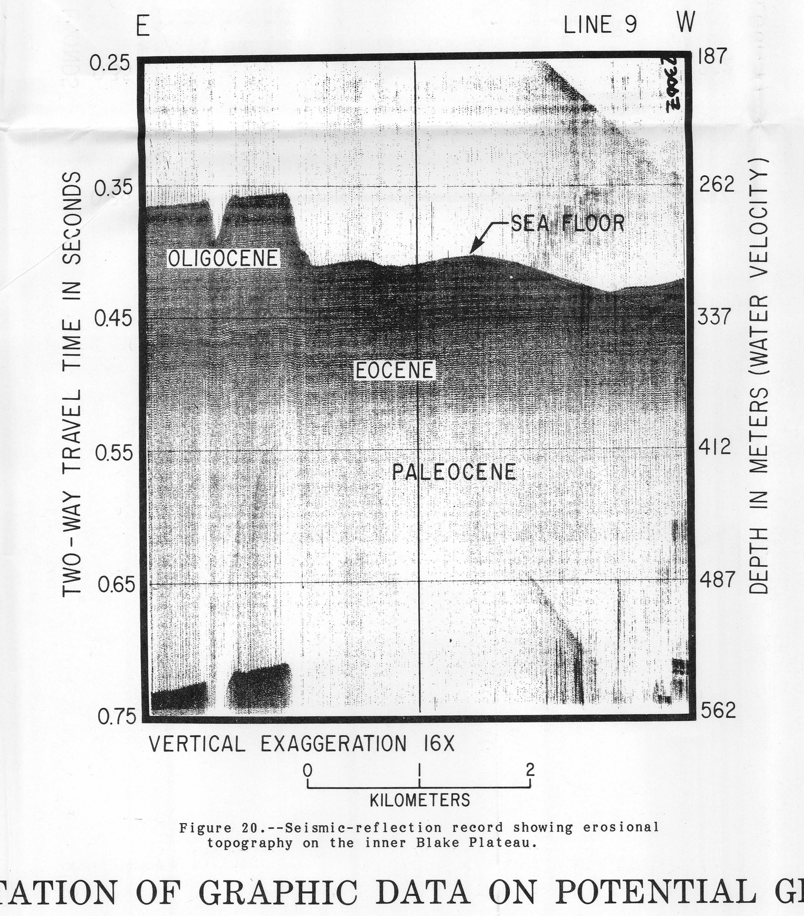

Figure 20.--Seismic-reflection record showing erosional topography on the inner Blake Plateau.

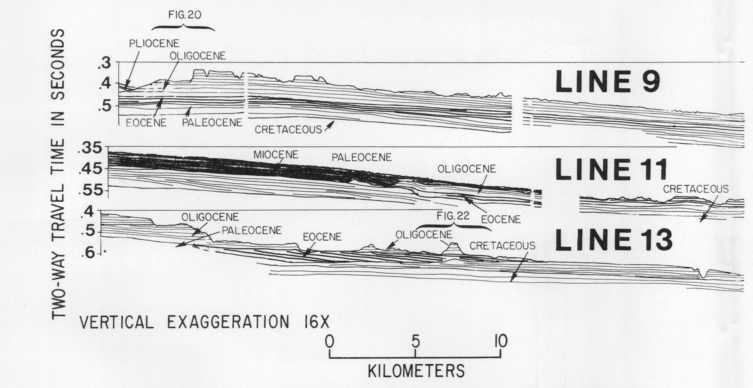

Figure 21.--Line drawings from seismic profiles showing the effect of Gulf Stream erosion on the surface of the Blake Plateau.

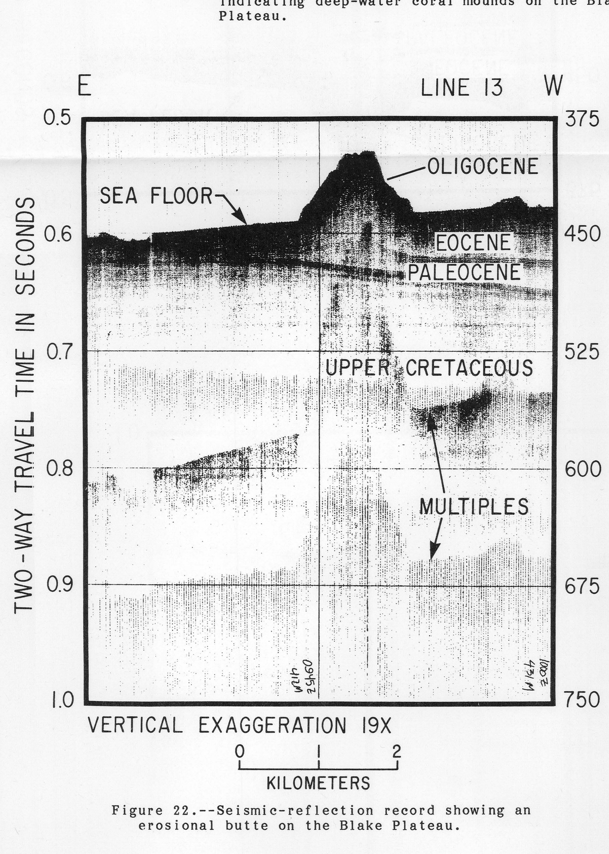

Figure 22.--Seismic-reflection record showing an erosional butte on the Blake Plateau.

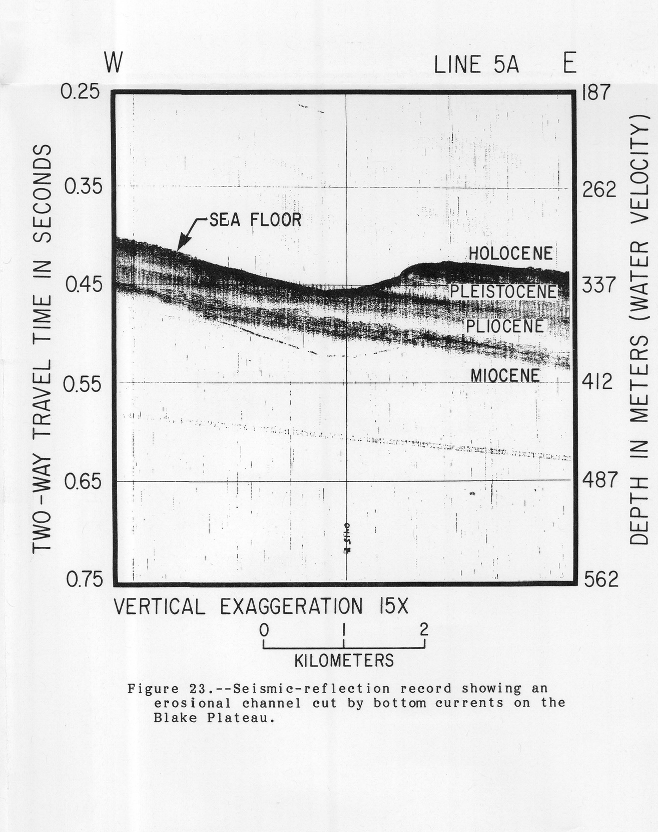

Figure 23.--Seismic-reflection record showing an erosional channel cut by bottom currents on the Blake Plateau.

INTERPRETATION OF GRAPHIC DATA ON POTENTIAL GEOLOGIC HAZARDS ON THE SOUTHEASTERN UNITED STATES ATLANTIC CONTINENTAL SHELF

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1981