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GEOLOGICAL SURVEY

Physiography of the New England Continental Slope based on GLORIA II long-range sidescan-sonar survey

by

Kathryn M. Scanlon[1]

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1. Woods Hole, MA 02543

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INTRODUCTION

Mapping the bathymetric features of the Atlantic Continental Slope has posed a problem for many years because a clear concept of the submarine physiography has been lacking. Before Veatch and Smith (1939) published their map of the Continental Shelf and Slope off the northeastern United States it was assumed, on the basis of widely spaced soundings, that all changes in depth in the deep ocean were gradual. With the advent of the continuous-profile echo-sounder, Veatch and Smith (1939) were able to demonstrate the existence of steep-sided canyons and gullies on the Continental Slope. Sonar profiles, however, leave much to the physiographer's imagination. Steep slopes deflect the sonar signal, returning little or none of it to the waiting receiver. Rugged terrain in deeply incised areas such as the Continental Slope can produce a plethora of "side-echoes" from nearby cliffs and pinnacles, thus creating a confusing record.

Since Veatch and Smith's (1939) pioneer work other bathymetric maps of the Continental Shelf and Slope off New England have been published (Uchupi, 1968; American Association of Petroleum Geologists (AAPG), 1970; National Ocean Survey (NOS), 1978a,b). In the area between Lydonia and Hydrographer Canyons (fig. 3) these maps are all based on the echo-soundings which Veatch and Smith (1939) used, augmented with various amounts of additional data. Each map is significantly different. Veatch and Smith (1939) show a pinnate canyon and gully pattern (fig. 2a) in which closely spaced downslope-trending canyons are fringed by short secondary canyons or gullies. Uchupi (1968) and AAPG (1970) show fewer large downslope-trending canyons and very few secondary gullies (figs. 2b,c). Contours on the AAPG (1970) map indicate a rounded and relatively smooth surface between canyons whereas Uchupi's (1968) map shows these areas to be incised by numerous small downslope-trending gullies. The canyon pattern on the NOS (1978a,b) maps most closely resembles a dendritic drainage pattern although in places it appears to be parallel or even deranged (fig. 2d). Besides these differences in geomorphic style, the maps also differ in the numbers, locations, and courses of the canyons which they show.

It is important to accurately define the physiography of the Continental Slope in order to understand the processes that have shaped this major transition zone and to determine which of those processes might create hazards for man's mineral exploration and exploitation activities. To this end, the U.S. Geological Survey (USGS) and Great Britain's Institute of Oceanographic Sciences (IOS), with partial support from the U.S. Bureau of Land Management (BLM), undertook a joint survey of the Continental Slope and Rise off the eastern United States between Maine and Florida. This report deals with the data collected seaward of New England (fig. 1).

DATA COLLECTION

GLORIA II, a long-range sidescan-sonar system developed at IOS (Somers and others, 1978) for reconnaissance mapping of the deep ocean floor, was chosen as the primary survey tool. The vehicle which houses the transducers is neutrally bouyant and is approximately 0.70 meter (m) in diameter and 7.75 m in length. It is towed at 50-m water depth, 300 m behind the ship. Each side of the vehicle is equipped with 60 transducers that operate between 6.2 and 6.8 kHz. When operated at its maximum towing speed of 10 knots and its maximum range of 30 kilometers (km) to each side, GLORIA II can scan over 1,000 km^2 in one hour.

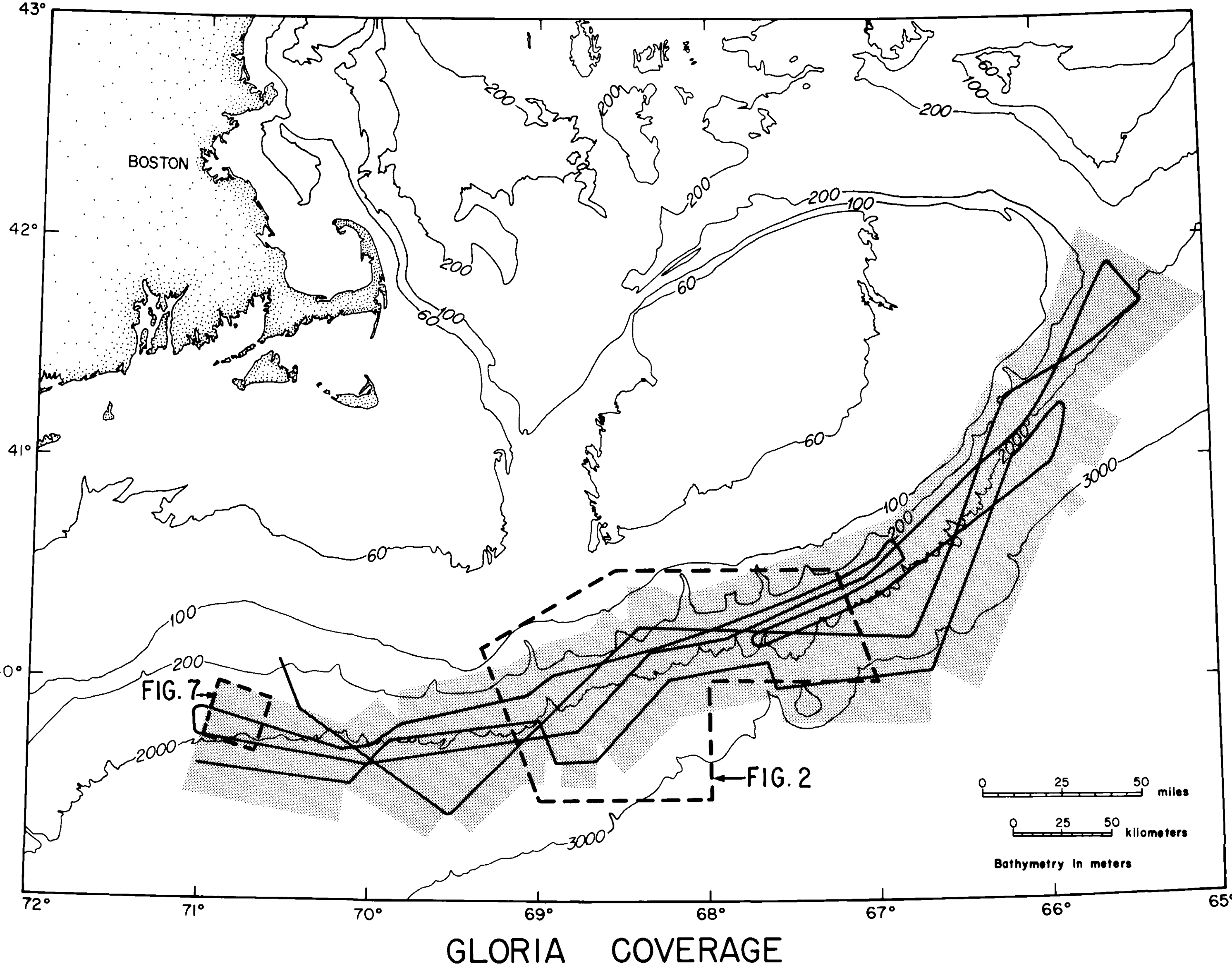

Figure 1. Location map showing DESV STARELLA trackline and the coverage obtained by the GLORIA II sidescan-sonar system.

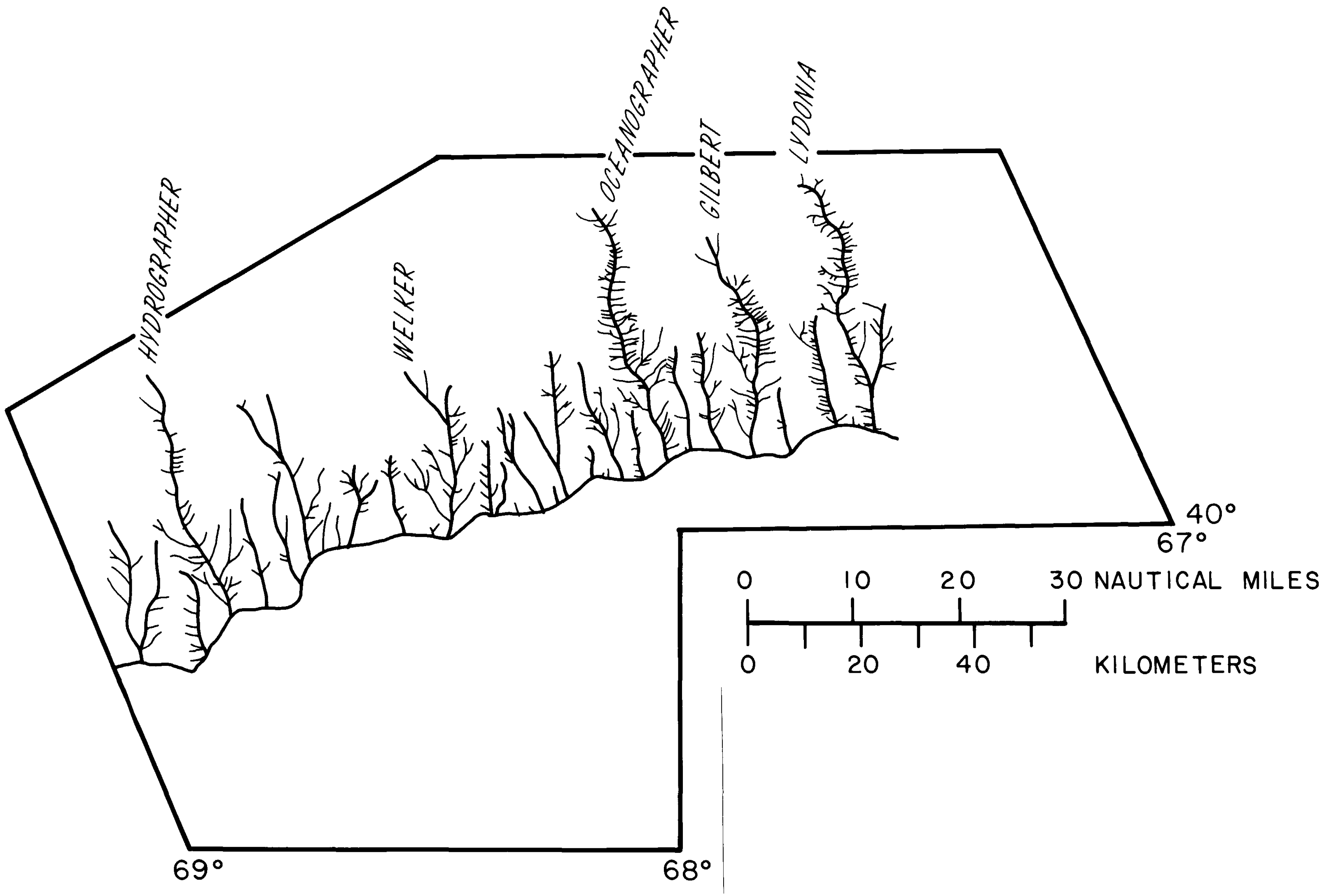

Figure 2a. Canyon axis pattern taken from Veatch and Smith (1939). Location shown in figure 1.

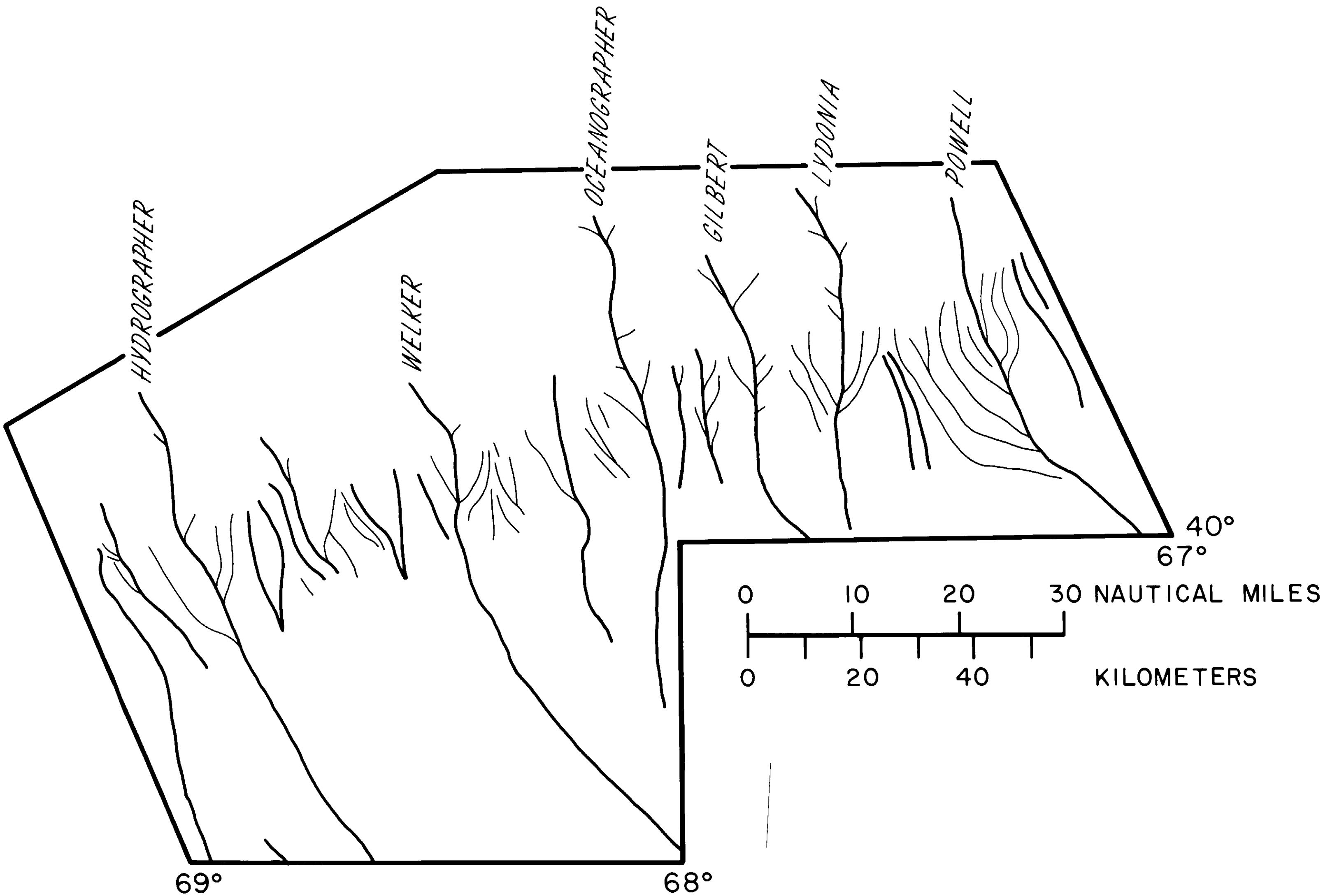

Figure 2b. Canyon axis pattern taken from Uchupi (1968). Location shown in figure 1.

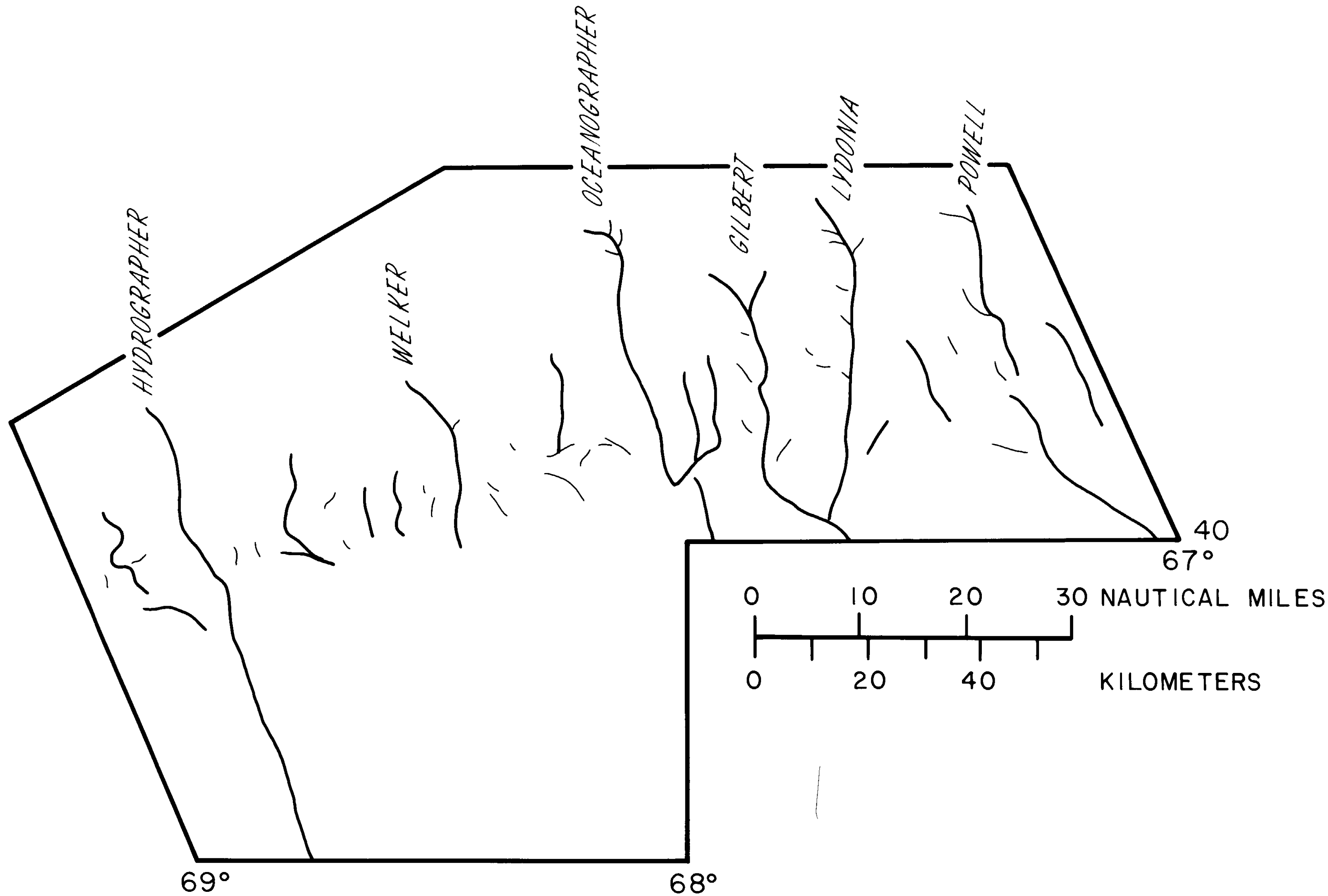

Figure 2c. Canyon axis pattern taken from AAPG (1970). Location shown in figure 1.

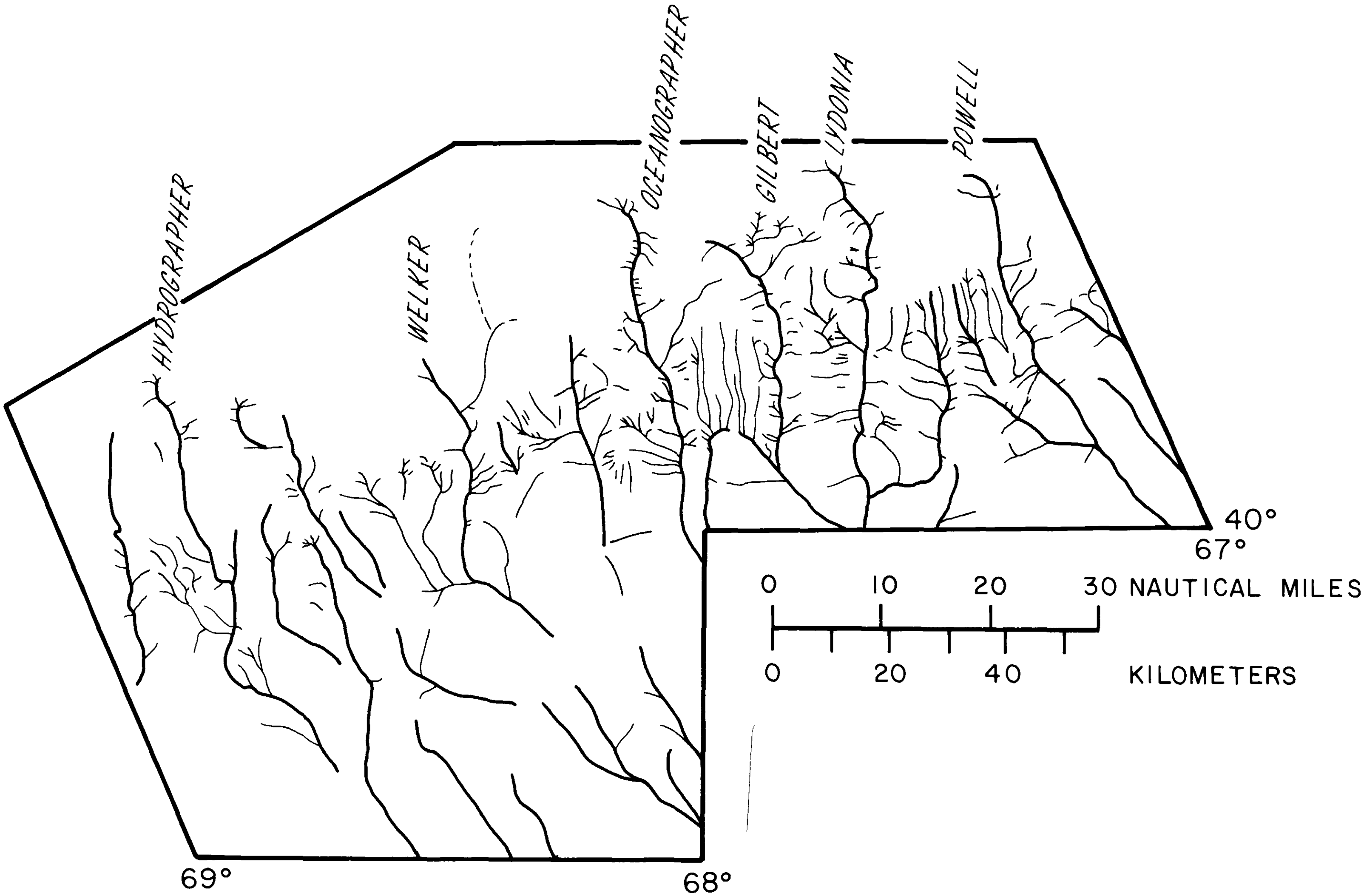

Figure 2d. Canyon axis pattern taken from NOS (1978). Location shown in figure 1.

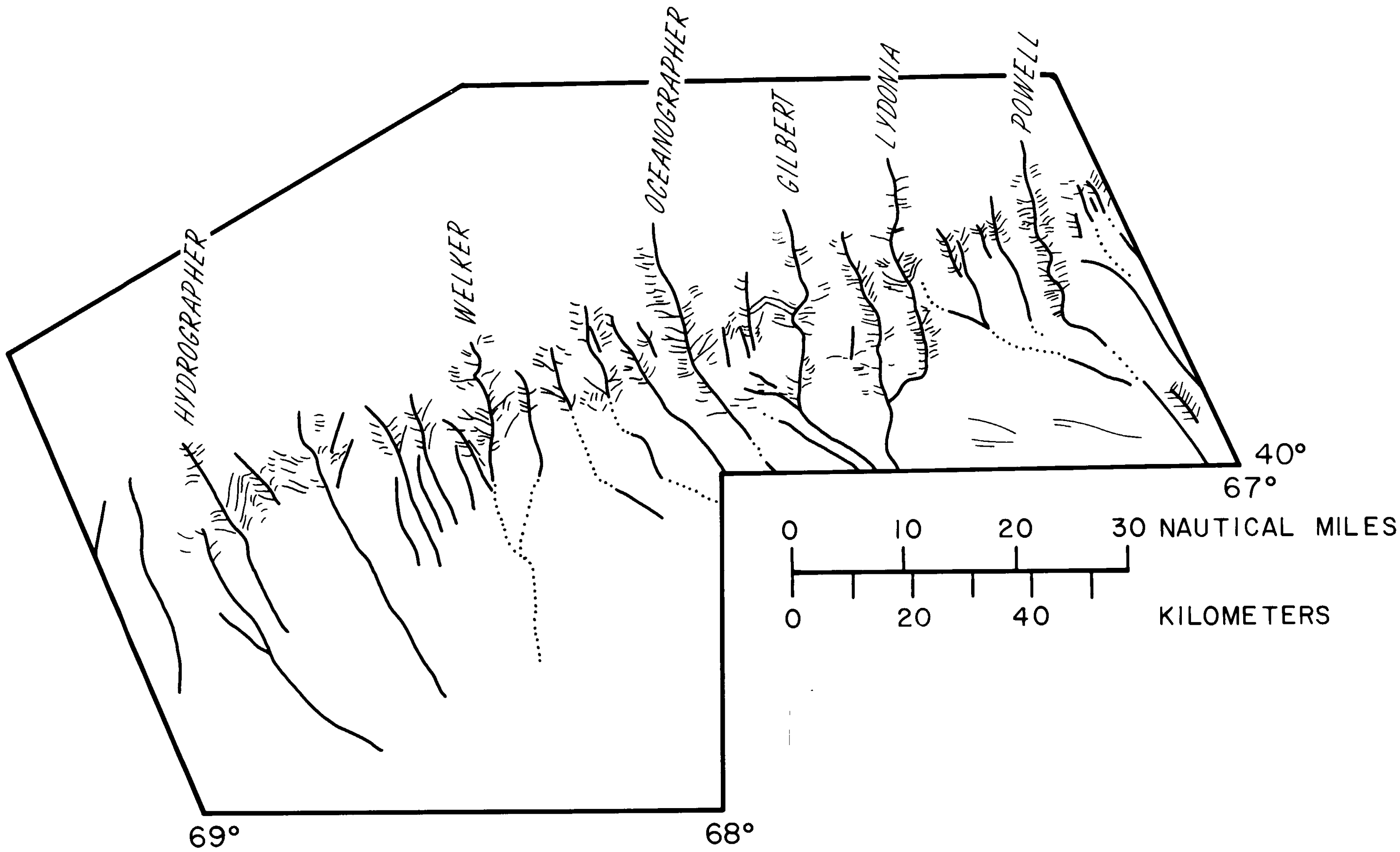

Figure 2e. Canyon axis pattern taken from Scanlon (in press). Location shown in figure 1.

Sonar signals received by GLORIA's transducer arrays are simultaneously recorded on magnetic tape and displayed on a flat-bed recorder. The display is used to monitor the sonar data for problems whereas the taped data are played through a photographic system which produces sonographs that have been corrected for variations in the ship's speed. The scales along the trackline and those perpendicular to the trackline are thus made nearly the same (1:250,000), although the images are not corrected for slant-range distortions. High-resolution single-channel seismic profiles, made using a 10-kHz echo-sounder and a 40-in^3 airgun, were collected simultaneously with the sidescan sonographs along all the tracklines.

Most of the GLORIA data for this study were collected with the range set at 15 km to each side for maximum resolution. Some were collected at the 30-km range setting but, because of the water depth and thermal structure of the water column, a range greater than 10-12 km to each side was rarely achieved.

Tracklines were planned to provide overlapping coverage and more than one insonification direction for most areas. Insonification direction is important because an elongate feature (such as a scarp) may show up clearly when its broad side is facing the transducer array but may be invisible when insonified along its strike.

DATA HANDLING

The GLORIA system provided continuous, near-map-view coverage of the Continental Slope and upper Continental Rise off New England. The advantages of this type of data over conventional seismic-reflection profiles are obvious. It allows linear features, such as canyons and scarps, to be traced continuously across adjacent images, and the areal extents of various types of terrain to be readily defined. Seismic-reflection profiles, on the other hand, provide subsurface information and water-depth information which are not found in sidescan sonographs. Bathymetric information is important in interpreting sidescan data because it provides the means to correlate reflectivity contrasts with changes in the inclination of the sea floor. By using seismic profiles and sidescan sonographs together the morphologic or textural nature of image brightness features seen in sonographs can be determined. Likewise, with the aid of the sonographs, features can be more confidently extrapolated between widely spaced seismic profiles.

For this study the anamorphosed, approximately isometric images were arranged along their tracklines at a scale of 1:250,000 in an overlapping mosaic. Overlays which showed the locations of seismic-reflection profiles from the present study and from several previous cruises (figs. 1, 3) were annotated with morphologic information and used with the sidescan sonographs to arrive at the interpretations shown in plates 1 and 2. When overlapping images did not agree because of uncorrected slant-range distortions, a visual average was made.

DISCUSSION

The GLORIA II images of the study area show a distinct herringbone pattern of strong and weak reflections on the upper Slope (fig. 4) in water depths shallower than ~1,500 m. This pattern represents networks of gullies

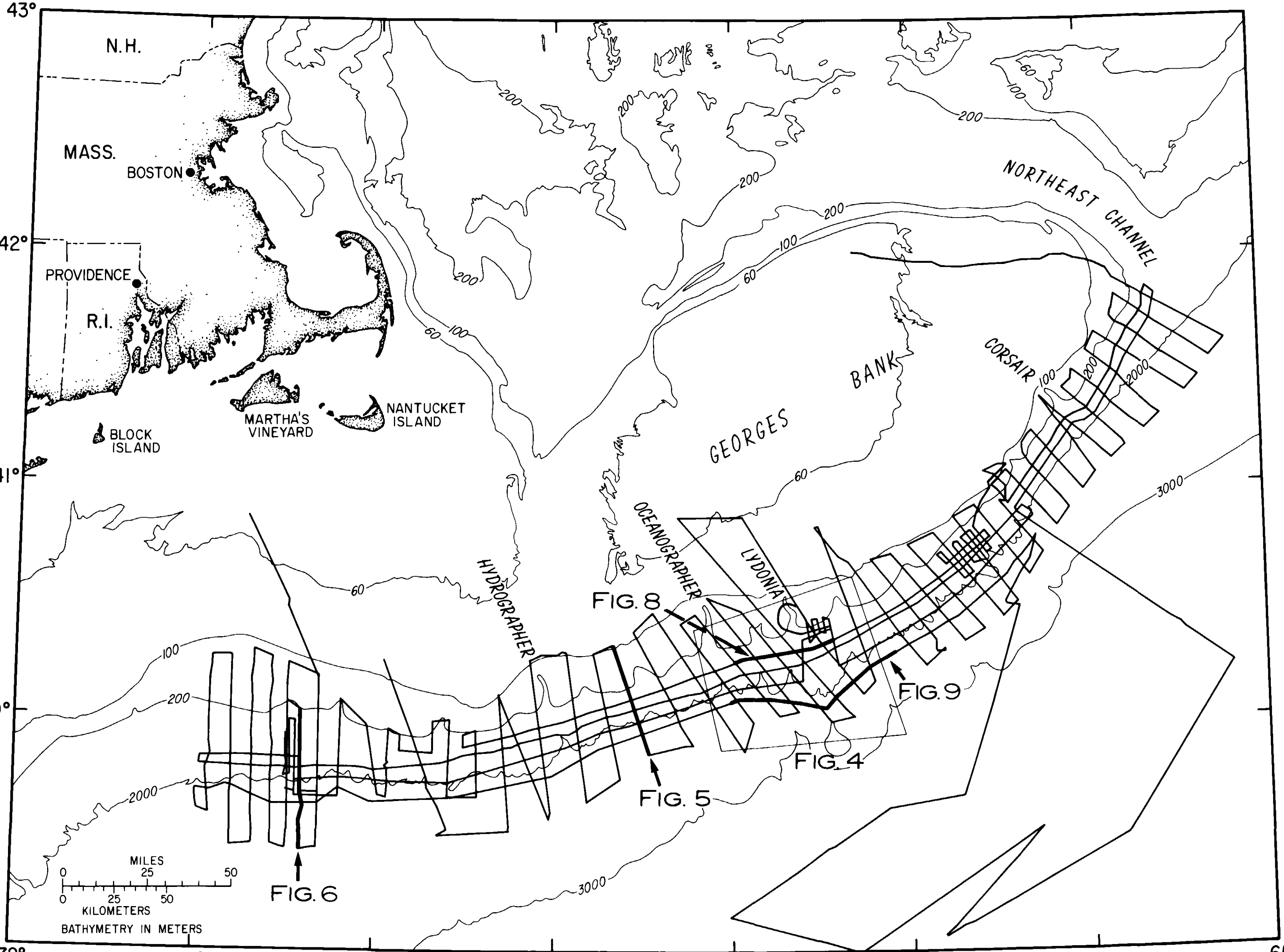

Figure 3. Locations of seismic lines used in this study.

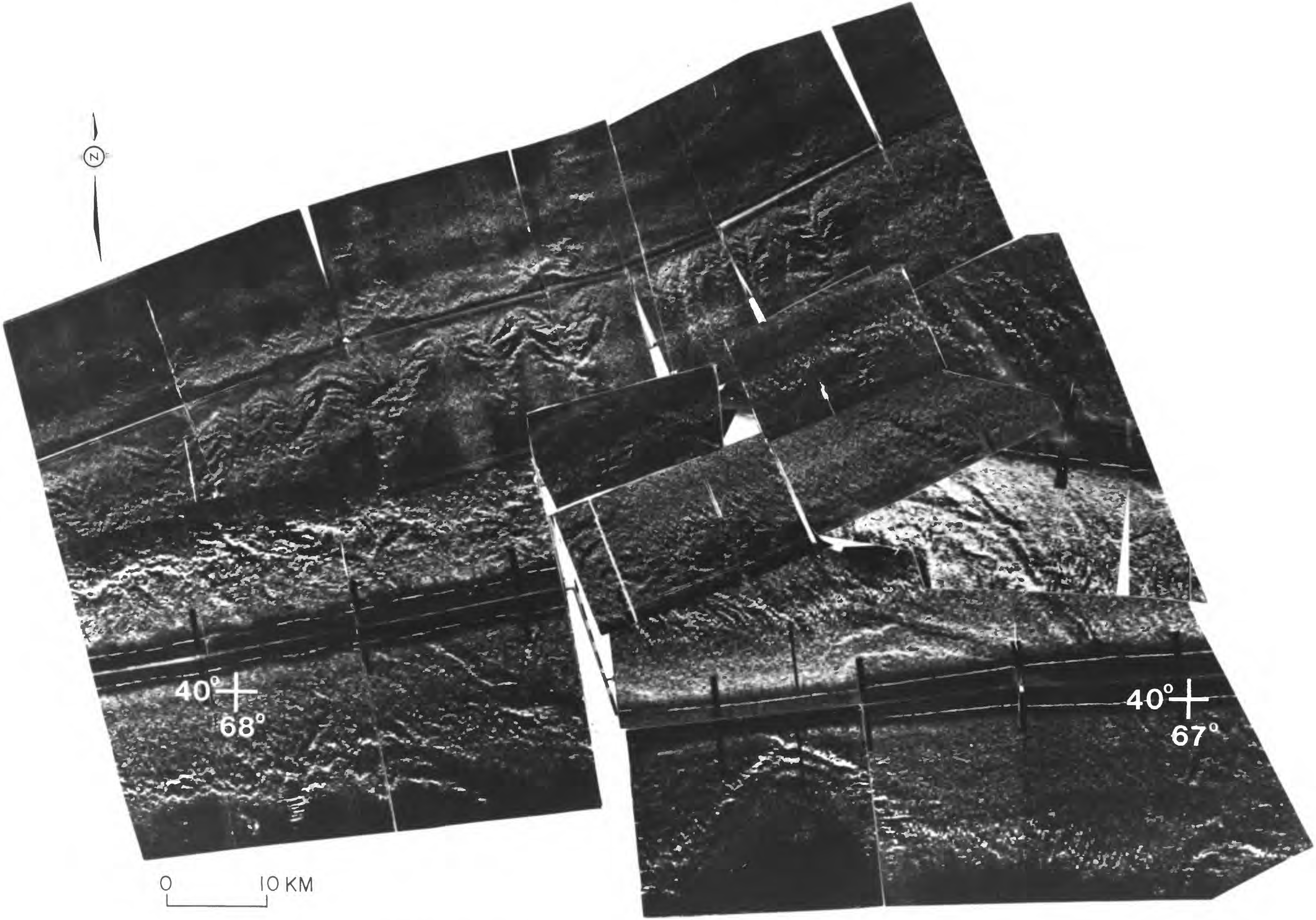

Figure 4. GLORIA II sidescan mosaic. Location shown in figure 3.

incised along the flanks of submarine canyons; it has been seen in sonographs from other parts of the eastern U.S. Continental Slope (Teleki and others, 1981; McGregor and others, 1982; Twichell and Roberts, 1982) and from the Continental Slope off western Europe (Belderson and Stride 1969; Belderson and Kenyon, 1976; Kenyon and others, 1978; Laughton, 1981). Veatch and Smith (1939) correctly anticipated the existence of gully systems which are seen in the GLORIA images to be fringing the canyons in a pinnate pattern (pl. 1, figs. 2a, 2e).

The GLORIA images also reveal variations in the density of gullies along the Continental Slope. An abrupt change takes place in the vicinity of Hydrographer Canyon. West of Hydrographer Canyon the canyons are more widely spaced and the gullies are fewer than they are east of that canyon (pl. 1). West of Veatch Canyon the GLORIA coverage is incomplete, but the sonographs taken suggest that the density of incision by canyons and gullies along the upper Slope may be less than it is east of Hydrographer Canyon. This decrease in canyon and gully occurrence is accompanied by a change in the profile of the Slope. East of Hydrographer Canyon, where canyons and gullies are numerous, the Slope exhibits a distinct shelf break and a concave profile (fig. 5). Strata as shallow as 300 m below sea level are truncated by the upper Slope surface. West of Hydrographer Canyon the shelf break is less distinct, the Slope is broader and has a convex profile, and the surface is conformable with underlying strata to depths as great as 750 m (fig. 6). The change in Slope profile is related to a regional change in structure and to stratigraphy of the Pleistocene section (D. O'Leary, oral commun., 1984) but it is not yet clear whether the character and spacing of upper-Slope incision is also related to regional stratigraphy and structure.

The gullies intersect the canyon axes at angles between 45^{o}-90^{o} (fig. 4, pl. 1). Small angles are dominant on the steep upper part of the Slope, whereas large angles are more common on the lower part. Most gullies are 1-5 km long, and some large ones have tributaries. The gullies are numerous. As many as two or three dozen gullies mark the sides of a 30-km segment near the heads of some of the large canyons (e.g., Lydonia, Oceanographer, and Powell). Individual gullies are generally less than a kilometer apart and, on deeply incised parts of the upper Continental Slope, the gullies are separated by narrow steep-sided divides.

On the upper Slope in much of the study area the canyons are so closely spaced that the heads of the gullies associated with adjacent canyons meet at the crests of ridgelike intercanyon divides. Approximately 80 percent of the upper Slope is dissected by canyon and gully systems (pl. 2). The lower Slope and upper Rise are much less extensively dissected. There, canyon axes can be as much as 30 km apart, as opposed to the 5-km spacing which is typical on the upper Slope.

In general, the canyons in the study area run directly downslope. However, several exceptions were found. Oceanographer and Gilbert Canyons turn as they reach the base of the Slope and run obliquely across the upper Rise. Lydonia, Gilbert, and Heezen Canyons make sharp turns as they traverse the Slope. Some of the channels on the lower Slope and upper Rise do not appear to be continuous with canyons seen on the upper Slope. Many canyons end before they reach the Rise, and others merge with adjacent canyons. These sharp turns and midslope endings may reflect local structural control.

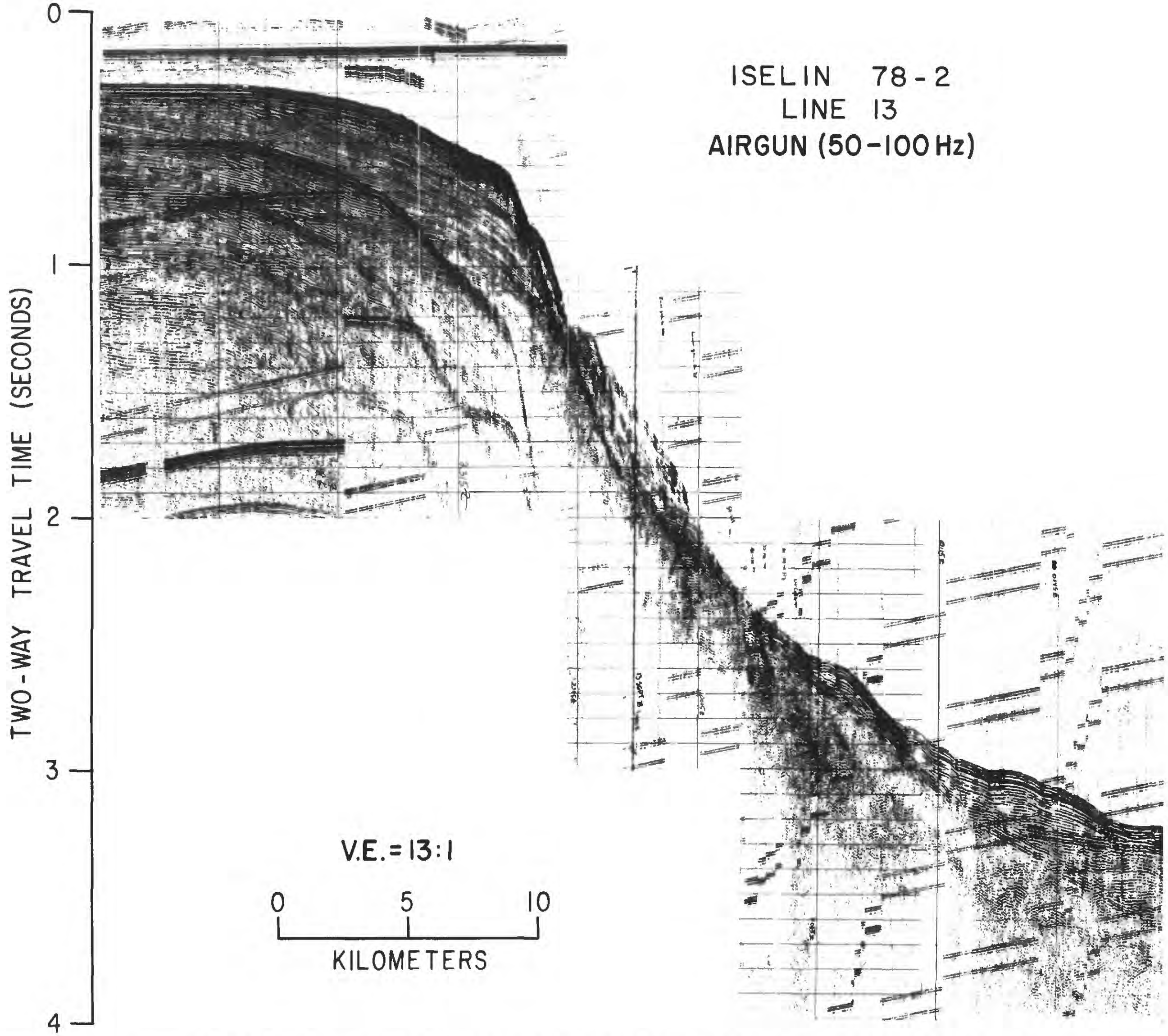

Figure 5. Seismic profile of the Continental Slope east of Hydrographer Canyon. Compare the concave profile seen here with the convex form in figure 6. Location shown in figure 3.

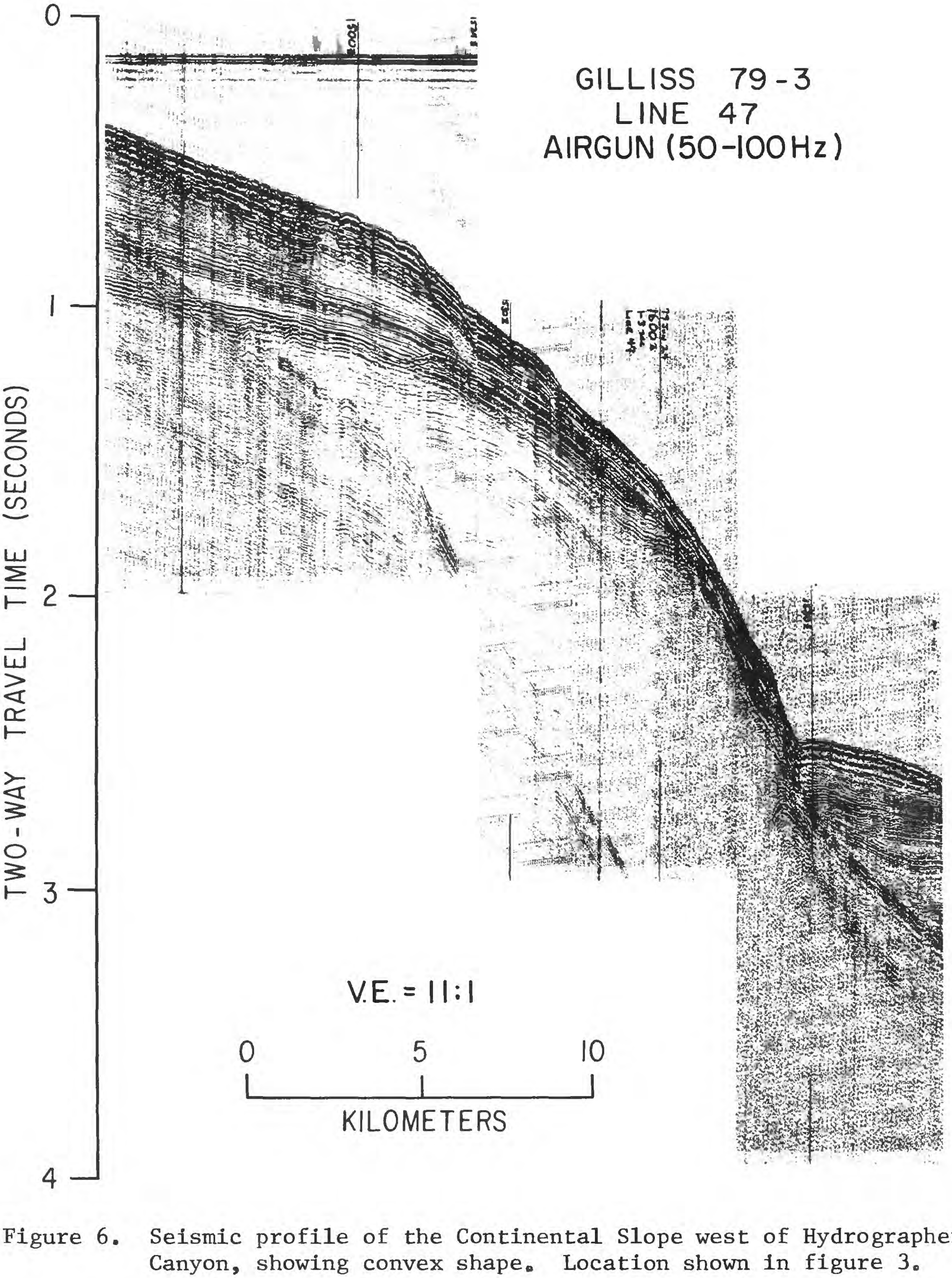

Figure 6. Seismic profile of the Continental Slope west of Hydrographer Canyon, showing convex shape. Location shown in figure 3.

Most of the scarps shown in plate 1 are parallel to and face canyon axes. Exceptions were found on the Continental Slope and upper Rise west of Alvin Canyon and on the Slope and upper Rise between Nygren and Munson Canyons. In the area west of Alvin Canyon, the presence of several downslope-facing scarps (fig. 7) suggests that large amounts of material may have moved downslope. MacIlvaine and Ross (1979) reported numerous slump scars in this area, which they detected on seismic profiles, in bottom photographs, and by direct observations from a submersible. Arcuate scarps have also been seen in this area on midrange sidescan-sonar records (D. W. O'Leary, pers. commun., 1984). Between Nygren and Munson Canyons, a broad, steep-sided trough extends downslope from downslope-facing scarps (pl. 1). This feature, which was also noted on seismic profiles, probably represents a large complex slide scar (D. W. O'Leary, pers. commun., 1984).

On the basis of the GLORIA sonographs and seismic profiles, it is possible to define three major types of terrain found in the study area (pl. 2). A fourth type, local areas of downslope-facing scarps, can be found within any of the three major terrain types. Type 1 terrain includes all areas which contain canyons with secondary gully systems. Type 2 includes canyons which do not have associated gullies. Type 3 encompasses the rest of the surveyed area and contains topography which varies from smooth to hummocky. This third type may be subdivided into the areas seaward of the Shelf edge and those landward of the Shelf edge. For this report, the Shelf edge is assumed to be at 200 m (NOS, 1978a,b), because the GLORIA coverage is not sufficient to map the entire Shelf edge. The northern flank of Bear Seamount, rising over 1,000 m above the surrounding sea floor, can be seen in the GLORIA images of the Continental Rise between Lydonia and Powell canyons (pls. 1 and 2). With its steep sides (10^{o}-90^{o}) and volcanic origin (Emery and Uchupi, 1972) it is an anomaly in the study area and is not included in any of the terrain types shown in plate 2.

The ridge-and-gully terrain (Type 1) is highly dissected (fig. 8) and lies mostly on the steep, upper part of the Slope. The regional inclination of the upper Slope within Type 1 ranges from 3^{o}-10^{o} (NOS, 1978a,b), but locally much steeper slopes and vertical walls (Ryan and others, 1978) are common. The pinnate gully pattern which typifies Type 1 terrain implies that some process akin to subaerial rill erosion, as described by Carson and Kirkby (1972), has formed the steep upper Slope. Mudflows or debris flows are related to rill incision (Carson and Kirkby, 1972), and this type of mass movement may have been an important agent of Slope formation in Type 1 terrain. The sediment on the floors of the canyons in Type 1 terrain varies from mud to sand and includes ice-rafted rock debris and talus blocks derived from the adjacent canyon walls (Ryan and others, 1978). Twichell (1983a) reports that sand from the Continental Shelf in this area may migrate into the heads of some of the canyons.

Type 2 areas include all of the canyons that do not have associated gully systems. These areas are mostly on the lower Slope and on the Rise. The Type 2 terrain is not as deeply incised as in Type 1 nor is the regional slope as steep. Short, steep walls commonly separate the channels here from the surrounding terrain (fig. 9). The canyon floors here, as in Type 1, range from muddy to sandy and contain some erratic blocks. There is evidence that this sediment is mobile (Ryan and others, 1978). Perhaps mass movement in this terrain is restricted to the floors of canyons.

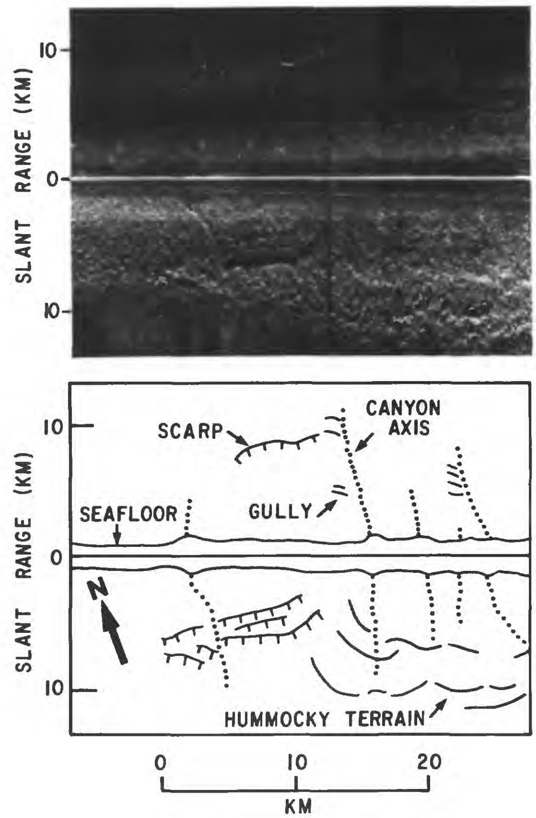

Figure 7. GLORIA II sidescan sonograph showing downslope-facing scarps near Alvin Canyon. Location shown in figure 1.

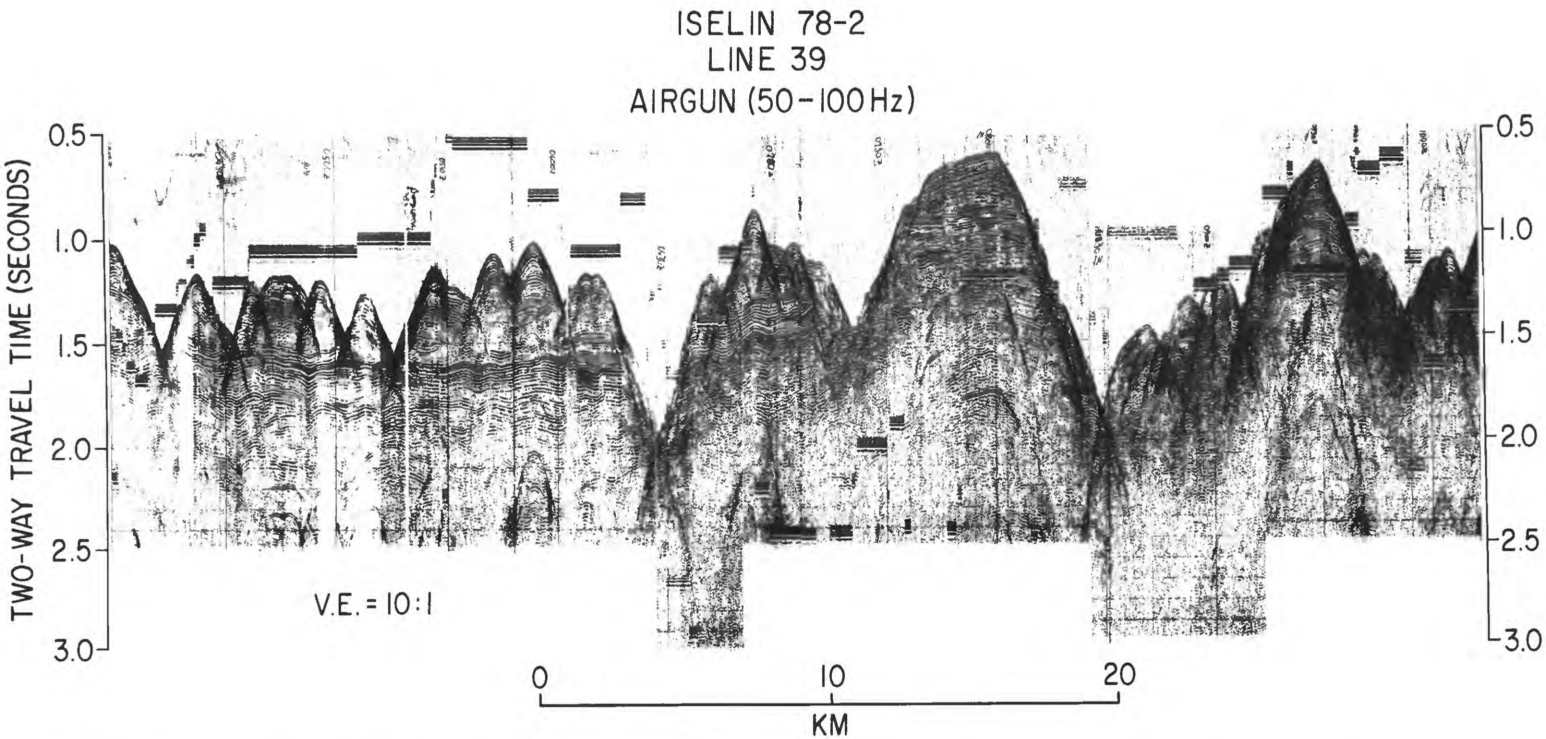

Figure 8. Seismic profile taken along the Continental Slope near the 1,000-m isobath. The steep-sided canyons and gullies are typical of Type 1 terrain. See figure 3 for location.

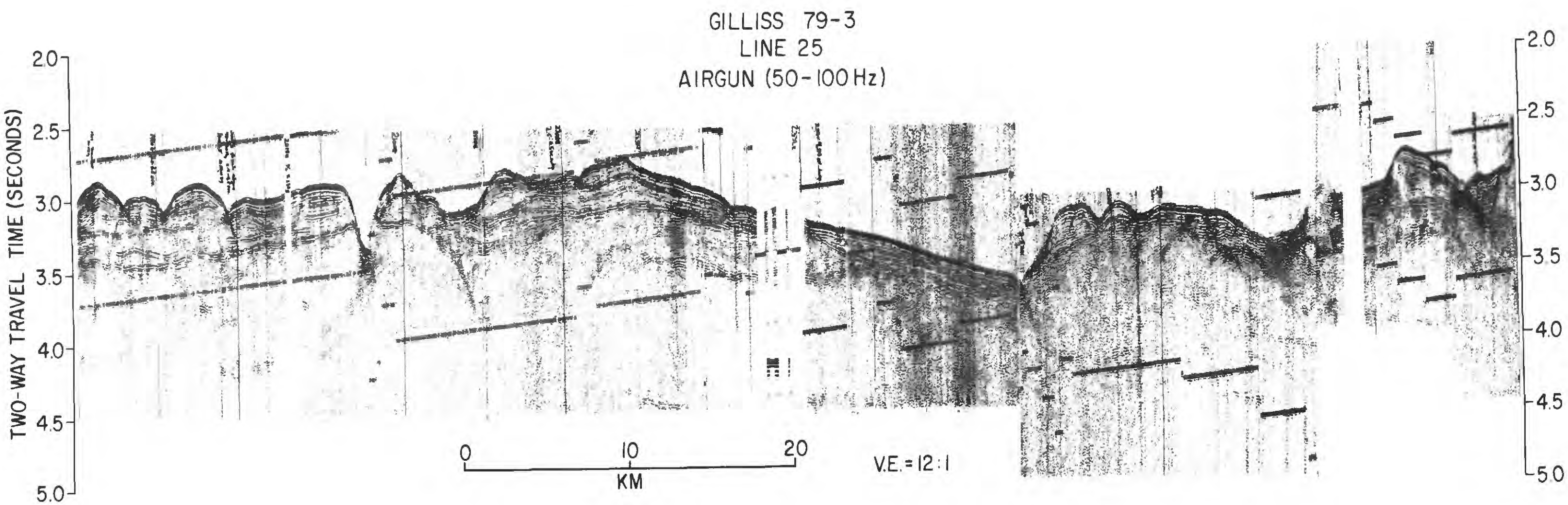

Figure 9. Seismic profile taken along the Continental Slope near the 2,200-m isobath. Compare the more subdued relief of the Types 2 and 3 terrain shown here with the rugged Type 1 terrain shown in figure 8. See figure 3 for location.

Most of the remainder of the study area is mapped as Type 3. Landward of the 200-m isobath, which approximately marks the Shelf edge, the surface is flat or very gently sloping (<2^{o}). Sand waves, common on the Shelf to depths of 60 m (Twichell, 1983b), have also been reported near the Shelf edge (Carpenter and others, 1982); they may provide local relief on an otherwise flat surface. Seaward of 200 m, Type 3 encompasses narrow intercanyon areas on the upper Slope and large expanses on the lower Slope and Rise. Relief here is subdued, the topography varying from smooth to hummocky.

The downslope-facing scarps in Type 4 terrain (pl. 2) may mark areas where large amounts of material have been removed by large-scale sliding at some time or times in the past (MacIlvaine and Ross, 1979).

CONCLUSIONS

The main object of this study was to determine the geomorphic character of the Continental Slope and Rise. The result is summarized in plate 1. This map and the companion map (pl. 2) which shows the distribution of several distinct types of terrain provide a useful data base for studies of structure, stratigraphy, and processes affecting the form of the North Atlantic Continental Slope.

The steep upper Slope east of Hydrographer Canyon is deeply incised by numerous gullies which are apparently tributary to axial canyons. This supports the hypothesis Veatch and Smith (1939) used to translate their depth soundings into the first accurate bathymetric map of the upper Slope and contradicts the rationale used by subsequent cartographers. The ridge and gully terrain implies that the canyons are fed mainly by processes concentrated along the upper Slope and that debris flow is perhaps the most common and effective of these processes. If mass movement occurs or is capable of occurring on the Continental Slope today, debris flows may constitute the chief geologic hazard there.

Abrupt bends seen in the courses of many canyons suggest the possibility that erosion along canyon axes is locally controlled by bedrock fractures. The presence of pronounced, laterally extensive scarps along the lower Slope supports the conclusion of MacIlvaine and Ross (1979) that here slab sliding has occurred. The GLORIA data suggest that slab sliding may have been more widespread along the lower Slope than previously thought.

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