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an image of active Atlantic rise sedimentation;

deep-water lateral sediment transport

THE NORTH CAROLINA CONTINENTAL RISE--AN ACTIVELY DISSECTED-SLUMPED AREA

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Abstract

A GLORIA survey of the North Carolina Continental Rise shows a complex pattern of linear northwest-trending streaks and bands that end against the Hatteras Transverse Canyon and Hatteras Outer Ridge. In combination with 3.5 kHz high resolution reflection profiles, the GLORIA mosaic, provides a regional look at present and near present patterns of sedimentation as mass movement, gravity and contour current deposits. The high backscatter pattern of sea floor returns in the GLORIA mosaic are from channels and mass movement deposits that cover much of the North Carolina rise. Two large slide complexes impinge on the Hatteras Cone at the southern edge of the survey area.

INTRODUCTION

Seaward of North Carolina, transport of sediment from the continental shelf to the Hatteras Abyssal Plain follows a circuitous route, partly because of diversion by the Hatteras Outer Ridge (HOR) on the lower continental rise (fig. 1) (Schlee and others, 1992). The Hatteras Outer Ridge is significant because its development during the Miocene created enough of a barrier (Tucholke and Laine, 1982; McMaster and others, 1989) to cause the formation of the Hatteras Transverse Canyon by diversion to the southwest of the normal southeast trend of transport.

My purpose is to show the nature of past and present sedimentary processes on the Carolina rise as revealed by high resolution reflection profiles, combined with an analysis of the GLORIA (Geological LOng Range Inclined Asdic) sidescan image of the same area. The image gives a regional sonic view of the rise off the Carolinas; when the patterns of acoustic backscatter are used in combination with 3.5kHz reflection profiles collected at the same time, some idea can be gained of the different kinds of processes that have shaped the rise and formed its major features.

Through its patterns of streaks and bands, the GLORIA sidescan-sonar image shows the dominant transport pathways to the southeast as tributary canyons and debris flows that span the North Carolina rise. Within the lower rise is the Hatteras Transverse Canyon which shows on the mosaic as a sharp change in the trend of acoustic returns to the southwest. The canyon was charted before the 1987 GLORIA survey, but mainly as part of larger bathymetric compilations (Uchupi, 1965; Belding and Holland, 1970; Newton and others, 1971), or seismic studies of adjacent areas (Tucholke and Laine, 1982; Embley and Jacobi, 1986;

McMaster and others, 1989), or as part of large sonic profile compilations (Pratson and Laine, 1989)

PHYSIOGRAPHY AND GEOLOGIC HISTORY

The major features on the lower continental rise off North Carolina (fig. 1) are three cross-rise, channel-canyon complexes (Pamlico, Hatteras, and Albemarle Canyons), several slide complexes (Cape Fear, Cape Lookout, and Albemarle-Currituck; EEZ SCAN 87, 1991)), the Hatteras Transverse Canyon, the Hatteras Outer Ridge and Lower Rise Hills, and the flat area of the lower rise upslope of the Hatteras Outer Ridge (fig. 1) (Newton and others, 1971). Ambivalence about the channel-canyons arises because the rise channels are labeled canyons in the atlas (EEZ SCAN 87, 1991) but appear in the profiles as channnel-like incisions into the rise. The rise has a declivity of about 0.5°; it separates the slope, which has a declivity of 3° to 12° from the flat- floored Hatteras Abyssal Plain (beyond the survey area), and is between 2000 and 5300 m water depth. To the north of the North Carolina Rise is the middle Atlantic rise, a gradually deepening area that has a gradient of between 1:150 and 1:1400 (Heezen, and others, 1959, table 1) and that has acted as a repository of sediment brought in by turbidity currents from the northwest and north. The lower rise in the study area is bounded to the southeast by the

Hatteras Outer Ridge, a broad elongate swell 400 m high, 40 km wide, and 190 km long that stretches from 33°N latitude off Cape Lookout to 36°N latitude and is between a water depth of 4300-5000 m. Upslope from this feature is the Hatteras Transverse Canyon (HTC) a channel which is incised up to 200 m below the sea floor, that is as much as 8 km wide and can be traced cut over a length of 160 km in water depths of 4500-5000 m. The Hatteras Transverse Canyon is particularly well defined as a channel where the rise channels from the North Carolina Continental Rise feed into it.

The Hatteras Transverse Canyon ends to the southwest in the Hatteras Cone, a fan (fig. 1) that opens out into the Hatteras Abyssal Plain (Cleary and others, 1977) mainly southeast of the study area.

The bathymetry at the head of the Hatteras Cone has been described by Cleary and others (1977, fig. 2) who contoured a limited area of the fan head at a 10 m interval; their map shows an area of diverging, poorly defined channels and isolated low hillocks. Their high-resolution seismic reflection profiles across the fan show small low relief channels that dissect a nearly flat area characterized by a hummocky bottom return (Cleary and others, 1977, Fig. 3A,B,C).

The main reason for the existence of the Hatteras Transverse Canyon is the development of the Hatteras Outer Ridge during the Miocene as a series of northeasterly trending sediment drifts at the seaward ends of rise fans that coalesced to form a ridge (Tucholke and Laine, 1982; McMaster and others, 1989; Locker and Laine, 1992). The lower and the middle parts of the continental rise *north* of the North Carolina rise have been filled by ponded turbidites; sediment from this area flow in ill-defined channels cut through northern part of the Hatteras Outer Ridge and feeds directly into the Hatteras Abyssal Plain (Asquith, 1979; Cleary and others, 1985; Pratson and Laine, 1989). Thus, though the Hatteras Transverse Canyon reaches into the area of ponded turbidites, it lacks a clearly developed "headwater" tributary system in part because debris from the Wilmington and Washington-Norfolk valleys exits to the Hatteras Abyssal Plain across the Hatteras Outer Ridge-Lower Rise Hills area well to the north of the area imaged (Asquith, 1979; Ayers and Cleary, 1980; Cleary and others, 1985).

GLORIA IMAGERY and SONIC PROFILES

The acquisition and processing techniques used to create the GLORIA mosaic have been described in the Atlas (EEZ SCAN 87 Scientific Staff, 1991). The mosaic presents the deep water Atlantic margin images in a series of 21 quadrangles at a scale of 1/500,000.

In this paper, four of the original adjacent quads have been combined to provide an image of the Carolina Rise. Figure 2 shows the main elements of the Carolina Rise as a GLORIA mosaic. The upper left part of the mosaic is a series of northwesterly trending stripes and irregular bands that show differing degrees of backscatter (white to black) over the northwestern two-thirds of the image; also present on the GLORIA mosaic are thin evenly-spaced stripes that are the ship's tracklines. The southeastern one-quarter of the mosaic is part of the Hatteras Outer Ridge (HOR); acoustic backscatter over it is low (dark) to high (white). Also present on the Ridge are many small discontinuous stripes of high backscatter. In the southernmost part of the mosaic, is a conspicuous high backscatter band with irregular borders, the Cape Fear slide complex. Between the HOR and the main part of the Carolina Rise is the Hatteras Transverse Canyon-- a lateral collector canyon that feeds into the Hatteras Cone, and shows on the mosaic as a northeasterly trending irregular high backscatter band. Along with the GLORIA survey, 3.5-kHz reflection profiles were collected along the same survey lines to show the sonic characteristics of different kinds of deposits.

Lower Rise Hills

Covering the southeast flank of the Hatteras Outer Ridge are the Lower Rise Hills, a group of east-trending hills (figs. 2 and 3) that show on the mosaic as fairly evenly spaced discontinuous moderate backscatter bands (fig. 3). These trends differ significantly from those mapped by Rona (1969, fig. 2), who showed the hills in the southeastern most corner of figure 3 at a 25 m interval and trending northwest where he contoured them in a bathymetric map (Rona, 1969, fig. 2).

Asquith (1979) mapped an area of the Lower Rise Hills northeast of the area of the Hatteras Outer Ridge imaged in this study. Because of data from a dense grid of high-resolution profiles and piston cores, he postulated that a complex series of elongate hills has been sculpted by distributary channels that were cut across the Hatteras Outer Ridge by turbidity currents in the Pleistocene. Later geostrophic currents like the Western Boundary Undercurrent modified the hills to deposit mud on the upcurrent sides of the hills. Pratson and Laine (1989, fig. 3) mapped the echo characteristics to be one of either a large wavy echo (their type VC), or terraced echo (their type IV A), indicative of contour current or a combination of processes (possibly listric faulting, contour currents or other processes) (Pratson and Laine, 1989, table 1). They also mapped a swath of distributary channels (their type III C) that cross the HOR northeast of the area in the GLORIA survey but in the same area studied by Asquith (1979)

The 3.5kHz profiles over the lower rise hills show much of the external form of those shown by Rona (1969, figs. 4 and 5) and Asquith (1979, fig. 9) in that the profiles oriented normal to the crests of the hills show their dune-like configuration most clearly. This particular profile (fig. 4) shows the internal structure of the mud waves, their spacing of 3 km here, and a relief of 70-80 m. A faint internal stratification shows a buildup to the north where the southward moving Western Boundary Undercurrent probably deposited mud on the hill flank, much as postulated by Rona (1969, p. 1136-1140). Seismic returns (fig. 4) are most pronounced (darker) on the depositional side of the hill where layers were added. Nine cores collected by Rona of the mud shows them to be yellowish-brown silt and clay. The nineteen cores examined by Asquith across two closely spaced hills and an intervening channel showed textural and compositional changes depending on their location; sandy intercalations, clay, and marl were sampled on the upcurrent sides of the hills.

Seismic profiles collected subparallel to the hill crests do not show the hills as clearly, but instead show an evenly layered return (extreme right of fig. 5) that follows the existing subdued topography, except where the Hatteras Transverse Canyon cuts through . The Lower Rise Hills are low and indistinct over most of the southeastern flank of the Hatteras Outer Ridge; the profiles there indicate faintly stratified sediment.

The rise-"headwater" area of the Hatteras Transverse Canyon

The GLORIA image of the "headwater" area of the Hatteras Transverse Canyon, and lower rise northwest of the HOR is a mottled relatively high to low backscatter pattern of short variably oriented streaks (fig. 6). Toward the west, the backscatter pattern is a more faintly mottled. High-resolution profiles (fig.5) show a return that sharply defines the sea floor, and has extended high amplitude return below the bottom; a faint sinuous subbottom layering is also present along with some low hummocky returns that may be from shallow surficial channels that cross this flat lower rise area. Lacking are a series of well-defined continuous channels that can be matched to the mosaic; figure 5 shows a sharply incised narrow Hatteras Transverse Canyon at 4750 m. Other light-toned sonar returns in this area are from limited areas of slide debris, which show sharp lateral changes from layered returns to hummocky ones with no subbottom layering (fig. 7).

The echo characteristic map of this area (Pratson and Laine, 1989, fig. 3) shows southeasterly trending patterns of deeps sea channels (their type VI B), prolonged echoes (their type II B), irregular semiprolonged echo (their type III C) and several other types inferred to be turbidity current deposits and distributary channels associated with them.

North Carolina Rise Area

The main sediment sources into the Hatteras Transverse Canyon are from the North Carolina Rise (fig. 6) which has canyons, debris flows, and slide complexes all trending downslope from the northwest. The GLORIA image (fig. 6) shows a series of northwest-trending high backscatter streaks that merge on the lower rise to the southeast as Hatteras and Albemarle Canyons. Also present are broad irregular swaths of moderate backscatter that come into the area from the northwest (upper left)--part of the Albemarle-Currituck and Hatteras slide complexes. The lower end of the Hatteras Slide Complex feeds into the Albemarle Canyon (fig. 6). Several of the narrow swaths of moderate backscatter appear to converge and merge (headwater area of the Hatteras Canyon for example) part way across the rise (fig. 6). Splaying or diverging of swaths such as might be expected in a fan is not obvious across the North Carolina Rise in spite of the fact that some areas have been interpreted and labeled as fans (EEZ SCAN 87 Scientific Staff, 1991, Sheets 12 and 13). From the reflection profiles that cross the fan area as shown in the atlas, it is not possible to pick out divergent channels with levee deposits that could be interpreted as part of a submarine fan. The sedimentary cover in this fan area is more of a blanket that has been disturbed in many areas by debris flows (segments of hummocky diffuse returns). The echo character map of Pratson and Laine (1989, fig. 3) show this area as mainly one of sharp echo with parallel continuous subbottom echoes or a semiprolonged echo with intermittent subbottom reflections (their type I E or type II A), or regular wavy echo with migrating subbottom reflector (their type V B); some returns are regular to irregular wavy echoes with parallel subbottom reflections (their types IV A and V A). Most of these types of returns they interpret to be the result of combined processes of turbidity currents and contour currents (Pratson and Laine 1989, table 1).

On the mosaic (fig. 6), the areas of low backscatter that lack obvious patterns (streaks and coarsely speckled patterns) are mainly areas of hemipelagic drape and are characterized on the profiles by fairly continuous parallel reflections that follow existing topography (Sangree and Widmier, 1977, table 1); the textured moderate backscatter patterns of thin, speckled light-gray cross-rise stripes are mainly debris flows adjacent associated with narrow valleys cut into the rise, The cross-rise canyons to the Hatteras Transverse Canyon are small (5 to 7 km wide) and they are 100 to 120 m below the adjacent terrain. The Hatteras Canyon "fan area" (EEZ SCAN 87, 1991, sheet 12)(fig. 8A) shows a broadly incised canyon (~ 5 km) marked by an isolated strong return below the sea floor with limited layered-drape facies on one of the flanks of the valley; it lacks a clearly defined flat-floored channel axis. The upper rise part of this tributary valley is similar to that shown in figure 8A, but the valley is narrower, of similar relief, and in a topography that is more rolling and mantled by layered drape. A view of the same feature on the next seismic profile to the southeast (fig. 8B) shows a wider valley (~7 km) marked by hummocky diffuse returns, but with no clearly defined canyon axis.

The Albemarle Canyon (fig. 6) is really a low relief broad swath that crosses the middle and lower rise and lacks a clearly defined main channel (fig. 9). The return is prolonged and lacks subbottom reflections, similar to what Pratson and Laine (1989, fig, 3; table 1) interpret to be turbidity current deposits. Most of the high-backscattered, southwest-trending swaths so evident on the mosaic (fig. 6) are erosional features as shown on the 3.5kHz profiles. Many of the rise canyons are not delineated by the widely spaced bathymetric contours given in the Atlas.

A few cross-rise canyons like Pamlico Canyon end in fan-like areas (EEZ SCAN 87 Scientific Staff, 1991, sheet 16) interrupted by the Cape Lookout slide or as minor canyons associated with debris flows and a widespread blanket of layered drape.

Slide Complexes

Much in evidence on the southwest quadrant of the mosaic are the Cape Fear and the older Cape Lookout Slide Complexes (fig. 10). They appear as mottled moderate to high backscatter northwest-trending swaths on the mosaic and with finger-like projections along an irregular boundary. On most seismic profiles, the surface of the slide complex is depressed a few tens of meters below the adjacent continental rise (fig. 11A). The seismic return from the slide complexes is a sharply defined sea floor that is gently rolling and marked by closely spaced hyperbolic returns with no subbottom returns. These slide complexes originated on the lower continental slope in areas of failure scars mapped by Embley (1980), Popenoe and others (1982), Cashman and Popenoe (1985), Embley and Jacobi (1986), EEZ SCAN-87 Scientific Staff(1991), and Schmuck and others, 1992.

In its lower reaches, the Cape Lookout Slide Complex is a debris flow that is partly covered by the Cape Fear Slide Complex. The contact between the two (fig. 12) shows a series of block-like displacements with thin sediment wedges filling along the tilted bent edges of the blocks. The Cape Fear Slide Complex is slightly higher than the Cape Lookout slide complex and has a rolling surface with a diffuse structureless return. These slide complexes continue to the edge of the survey, hence the nature of their terminuses are unknown. These slide complexes have resisted attempts to subdivide them into smaller more restricted units mainly because the pattern changes on the mosaic cannot be correlated to changes in reflection characteristics on the 3.5-kHz profiles. Further, though the slide complexes are shown by a moderate backscatter pattern, which is easily seen on the mosaic, the boundary may be more indefinite than indicated by the backscatter intensity. In figure 11B, the drop to the slide is gradual, and the low-angled, beveled, layered return gives way to a faint structureless return. The boundary change is more subtle on the profiles than one might expect from the sharp change in backscatter intensity from the sea bed seen in the GLORIA image.

The slide complexes like the Hatteras and Albemarle-Currituck may extend over a much wider area than the mosaic would indicate. The high strength of backscatter (white) return helps to show to their extent on the mosaic.

However, the hummocky returns on the profiles suggest that the debris flows and other mass movement flows that they spawn are spread over a larger area than the slide complexes alone, yet a clear definitive pattern for the small local flows is hard to see on the mosaic. The estimate by Embley (1980) that debris flows cover 40% of the rise in this area may be a minimum figure.

Hatteras Transverse Canyon.

The main Hatteras Transverse Canyon has a clearly defined non-meandering channel (highlighted by a thin band of high acoustic backscatter on the mosaic) (EEZ SCAN 87 Scientific Staff,1991) and by a gentle scarp for the valley (figures 5 and 13). The image (fig. 6) shows moderate levels of backscatter in the central part of the canyon, but decreasing backscatter toward the area of the Hatteras Cone (lower left of the image in figure 6).

Profiles across the northern part of the Hatteras Transverse Canyon (fig. 5) show an incised narrow feature with one central valley approximately 75 m deep (below the adjacent rise) and ~1 km wide. Further southwest (fig. 13), the canyon is wider; layered drape gives way to a slumped hummocky return on the canyon sides, then to a sharp flat return from the channel floor. Still farther down the valley, the main channel is 200 m deep and approximately 3 km wide; it appears more on figure 13 because of the transverse crossing of the valley.

Hatteras Cone

The Hatteras Cone (fig. 6) south of where the Hatteras Rise Canyon joins the Hatteras Transverse Canyon, is a broad low marked by hummocky returns (fig. 14A) with a relief of a few meters over a distance of 20 km. The remanent of a probable channel is shown by several hyperbolic returns that are lower than the rest of the profile (fig. 14A). Farther out on the cone, the relief is lower and parts of two channels are evident (fig. 14B). The channels are 30 m or less deep and are as much as 3 km wide; hyperbolae are smaller, and the interfluve area is lower (deeper) than the bordering Hatteras Outer Ridge and returns are a sharp, and structureless. Divergent channels are not evident on the GLORIA image (figs. 6 and 10) of this area. The cone is encroached on from the northwest by the Cape Lookout and Cape Fear Slide Complexes (fig. 10).

DISCUSSION

The Hatteras Transverse Canyon

A unique feature of the Carolina Rise is a lateral conduit-collector of sediment along the rise -- the Hatteras Transverse Canyon. Other "along-rise" channels have been described by Hesse and others (1987), Hesse (1989), and Hesse and Rakofsky (1992) for the Labrador Sea as an alternative to deep-sea fan systems, but their setting and origin are different from those seen in the North Carolina Rise; they described in detail a deep sea channel/submarine yazoo system in the deep-water area between western Greenland and Labrador.

The Labrador Sea Channel is much like the alluvial valley of the MIssissippi River, where tributary channels paralleled the main channel for many tens of kilometers before entering it. Besides the yazoo-type tributaries, they also described braided-plain systems southwest of Greenland that also parallel the mid-ocean channel. The parallel arrangement of sediment dispersal systems is fostered in the Labrador Sea by the development of broad levees on the mid-ocean channel that are high enough to block direct contribution of sediment by rise tributaries.

The studies by Hesse and others are significant because they emphasize the dominance of braided *convergent* channels in dispersing sediment to the deep sea from glacial sources. They note the presence of multiple sources of a broad range of sediment types; also the lack of sharp changes of sea floor gradient (slope-rise) has led to long continuity of dispersal channels. The formation of the channel/submarine yazoo system has created distinctive turbidite facies (Hesse and others, 1987) in the channel-levee areas.

The GLORIA mosaic (fig. 2) shows that the Hatteras Transverse Canyon has *some* elements of the model described by Hesse and others but does differ significantly in other ways. On the rise is a converging deep water channel system both off the Carolinas and farther north (Schlee and Robb, 1991). The channelways leading to the deep sea, however, lack the major levee-buildup needed to promote the development of long parallel yazoo and braided systems. Canyons like Albemarle and Hatteras enter directly the Hatteras Transverse Canyon (fig. 3). The Hatteras Transverse Canyon system lacks sustained input from glacial sources and bathymetric profiles reveal substantial gradient changes across the slope and rise (Heezen and others, 1959). The rise has had fan construction in the past (Poag, 1992) and selected areas are interpreted as fans on the present sea floor (EEZ SCAN 87 Scientific Staff, 1991, sheets 13 and 16), but a clear indication of divergent channels is lacking both on the mosaic and in the parallel adjacent seismic reflection profiles of the same area. What is clear from the mosaic is that despite a gradient change at the base of the slope, numerous channels continue as erosional features across the upper rise and that some merge on the middle rise so that only a few large channels enter the Hatteras Transverse Canyon (fig. 3). Another important factor that has affected the growth of the Hatteras Transverse Canyon, is growth of the Hatteras Outer Ridge, which has acted as a barrier to the direct dispersal of sediment to the Hatteras Abyssal Plain and has deflected the downslope flow southward. As shown by the stratigraphic studies of Tucholke and Laine (1982, fig. 4) the ancestral rise had a broad northeast-trending depression behind the Hatteras Outer Ridge that was later filled by turbidites spread into the area by channelways off the middle part of the U.S. Atlantic margin.

Rise channels and processes

The topographic extension of the rise channels is a second characteristic of the North Carolina rise and one not well developed farther north on the rise (Schlee and Robb, 1991). Canyons like Albemarle and Hatteras on the North Carolina margin (fig. 2) continue across the rise. Why the change from the mid-Atlantic rise where only a few widely spaced channels cross the rise? Is it that the multiple slope-shelf sediment sources are nearby to maintain them better? Certainly, the disruption of military communication cables on the North Carolina rise a few years ago would seem to suggest the periodic influx of sediment through the area (Silva, A., Univ. Rhode Island, oral communication, January 1993). Like the GLORIA mosaic, the atlas of the North Carolina slope and rise (Newton and others, 1971, fig. 8; pl. 1) show the slope to be eroded by numerous canyons that extend across the rise. Interestingly, topography (slope to upper rise) is most gullied in the area where the adjacent continental shelf is the narrowest and hence, where the supply of shallow-water sediment should be closest for periodic influx to the slope.

The development of a many branched convergent channel system of the Carolina rise appears to be more closely tied to the presence of multiple sediment sources from estuaries draining the southeastern United States than along other sectors of the Atlantic margin. Transport of suspended fine-grained sediment from Albemarle and Pamlico Sounds to the shelf has been clearly shown on Apollo IX photographs (Mairs, 1970). The area is one of convergent transport systems that merge on and adjacent to, the North Carolina Shelf. Dominant transport along the shelf is to the south, whereas Gulf Stream movement over the slope, is to the northeast. The currents interact to focus transport of sand across the narrow shelf as the southeasterly trending Diamond Shoals (Hunt and others, 1977). Further, the rivers draining the southeastern United States have been shown by Meade (1969, fig. 2A) to be large carriers of suspended sediment, though much of it ends up being trapped in the dredged estuaries under average "day to day" conditions. We lack studies that summarize the delivery of sediment to the shelf and slope in this area under peak river flow conditions.

The main factors affecting the backscatter patterns seen in the GLORIA mosaic are the present and late Pleistocene processes that operated across the Carolina Rise (fig. 15). Most previous studies in the area (Embley, 1980; Tucholke, 1987; Booth and others, 1988; EEZ SCAN 87 Scientific Staff, 1991) have emphasized mass flow of sediment across the continental rise from slope sources, bottom current transport on the Hatteras Outer Ridge to build mud waves (dotted pattern - fig. 15) and hemipelagic drape on part of the slope. Indeed, a drape of silty clay tends to be a blanket covering some of the rise, but it is only a meter or less thick, and too thin to show up as a clearly defined layer on the high-resolution reflection profiles, yet thin enough to be "seen" through by the GLORIA system (Schlee and Robb, 1991, p. 1090).

The mosaic (fig. 2), in combination with high resolution profiles, confirms that the mass movement and geostrophic processes are the main processes, through the patterns seen on the mosaic--particularly, the slide complexes (dashed lines - fig. 15) and the Lower Rise Hills abyssal dunes (fig. 15). The northwest half of the mosaic is a complex pattern of northwest-trending swaths, bands, and streaks which are the mosaic's expression of numerous debris flows from the slope that incise and spread across the rise.

CONCLUSIONS

The GLORIA mosaic of the Carolina Rise shows a wide range of patterns and degrees of backscatter, many of which trend southeast down the regional slope. Several of the streaks converge into a few rise channels that feed into the Hatteras Transverse Canyon The sonic returns from the rise show the convergent linear nature of mass-wastage deposits there. An exception to this pattern is the large slide complexes (Cape Fear and Cape Lookout) which spread across the southwest part of the mosaic and widen in deeper water.

The Hatteras Transverse Canyon is a smaller example of a convergent lateral transport system. Unlike the one off Labrador, it lacks the glacial input and levee development, but the tributaries are basically convergent, and the Hatteras Transverse Canyon does act as a collector of turbidity and debris flows for the Hatteras Cone. Creation of the Hatteras Outer Ridge appears to have been essential as a barrier-diverter for the growth of the Hatteras Transverse Canyon adjacent to a limited part of the ridge.

Additional mapping of the slide complexes is needed to identify the different kinds of slump deposits that make up a slide complex. Also needed are higher resolution, more detailed sidescan sonar surveys coupled with selective sampling. We need a clearer idea of just how much of the rise has moved by different kinds of mass movement, and when.

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List of Figures

upper part of the Hatteras Transverse Canyon in the center. Location of profile shown in figure 1.

Figure 6 -- An enlargement of the part of the GLORIA mosaic that shows the Carolina Rise and in more detail channel-canyons that cross it as linear streaks and bands. The outline of the area enlarged is shown in Figure 1.

Figure 7 -- A segment of a 3.5-kHz profile across the lower rise to show the lateral change from a debris flow in the left to more evenly layered hemipelagic drape on the right. Location of profile shown on figure 1.

Figure 8

A.A segment of 3.5-kHz profile in the area of the Hatteras Canyon with some layered drape to the northeast, an irregular valley about 1 km wide, and with possibly two auxiliary channels to the southwest. Location of profile shown on figure 1.

B. A segment of a 3.5-kHz profile in the area of the Hatteras Canyon fan to show a channel as a broad hummocky low and with layered drape off to the northeast. Location of profile shown on figure 1.

Figure 9 -- A segment of a 3.5-kHz profile across the lower part of the

Albemarle Canyon to show the broad low-relief swath it occupies with no well defined channel. Location of profile shown on figure 1.

Figure 10 -- An enlargement of the GLORIA mosaic over the Cape Fear and Cape Lookout slide complexes and lower Carolina rise. The slide complexes appear as irregular bands that trend northwest. The outine of the area covered is shown in figure 1.

Figure 11

A. A segment of a 3.5-kHz-profile across the northeast side of the Cape Fear Slide Complex to show the sharp drop from the rise to the hummocky double return of the slide complex. Location of profile shown on figure 1.

B. A segment of a 3.5-kHz profile across the southwest side of the Cape Fear Slide Complex that shows the change from a faintly layered return on the left through a beveled transitional area in the center and the slide on the right. Location of profile shown on figure 1.

Figure 12 -- A segment of a 3.5-kHz profile that crosses the boundary between the Cape Fear and Cape Lookout Slide Complexes. The Cape Fear is to the left and their Cape Lookout complex is on the right . Location of profile shown on figure 1.

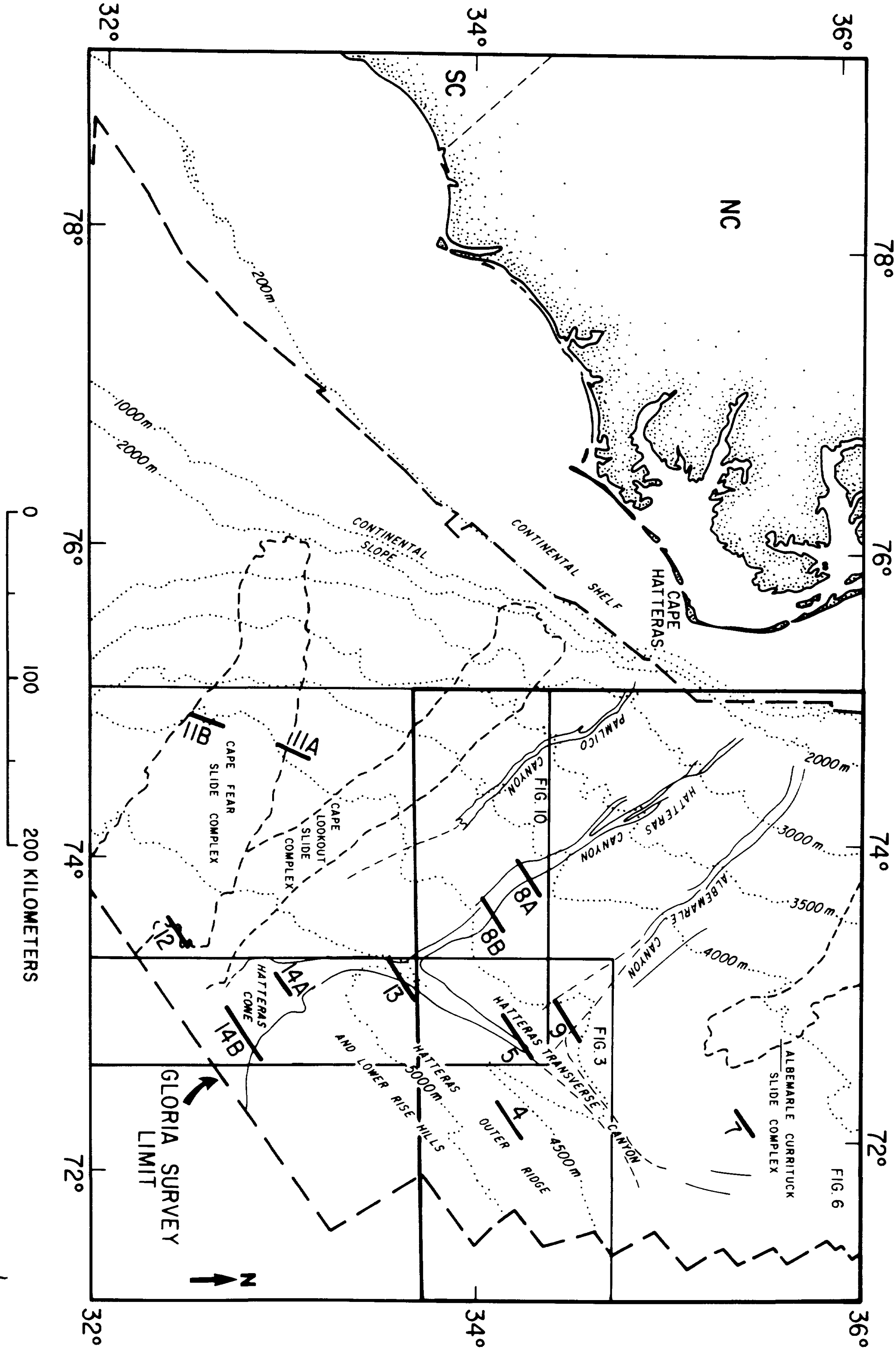
Figure 13 -- A segment of a 3.5-kHz profile across the main valley of the Hatteras Transverse Canyon showing the flat floor and slumped sides marked by hummocky returns along the sides. Location of profile shown on figure 1.

Figure 14

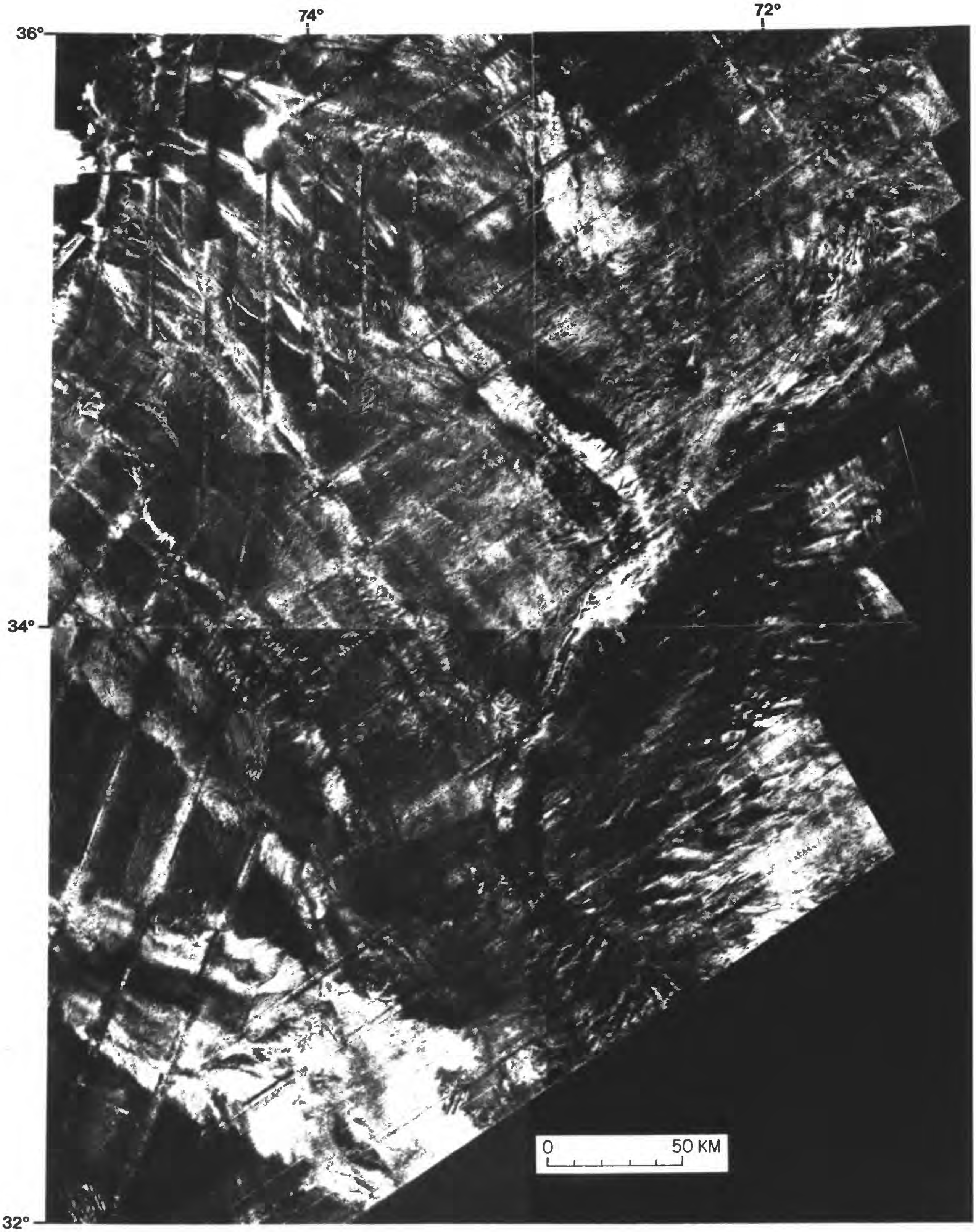
A. A segment of a 3.5kHz profile across the Hatteras Cone to show the low relief, the 35 small channels marked by lows, and the "bow tie" returns. Location of profile shown on figure 1.

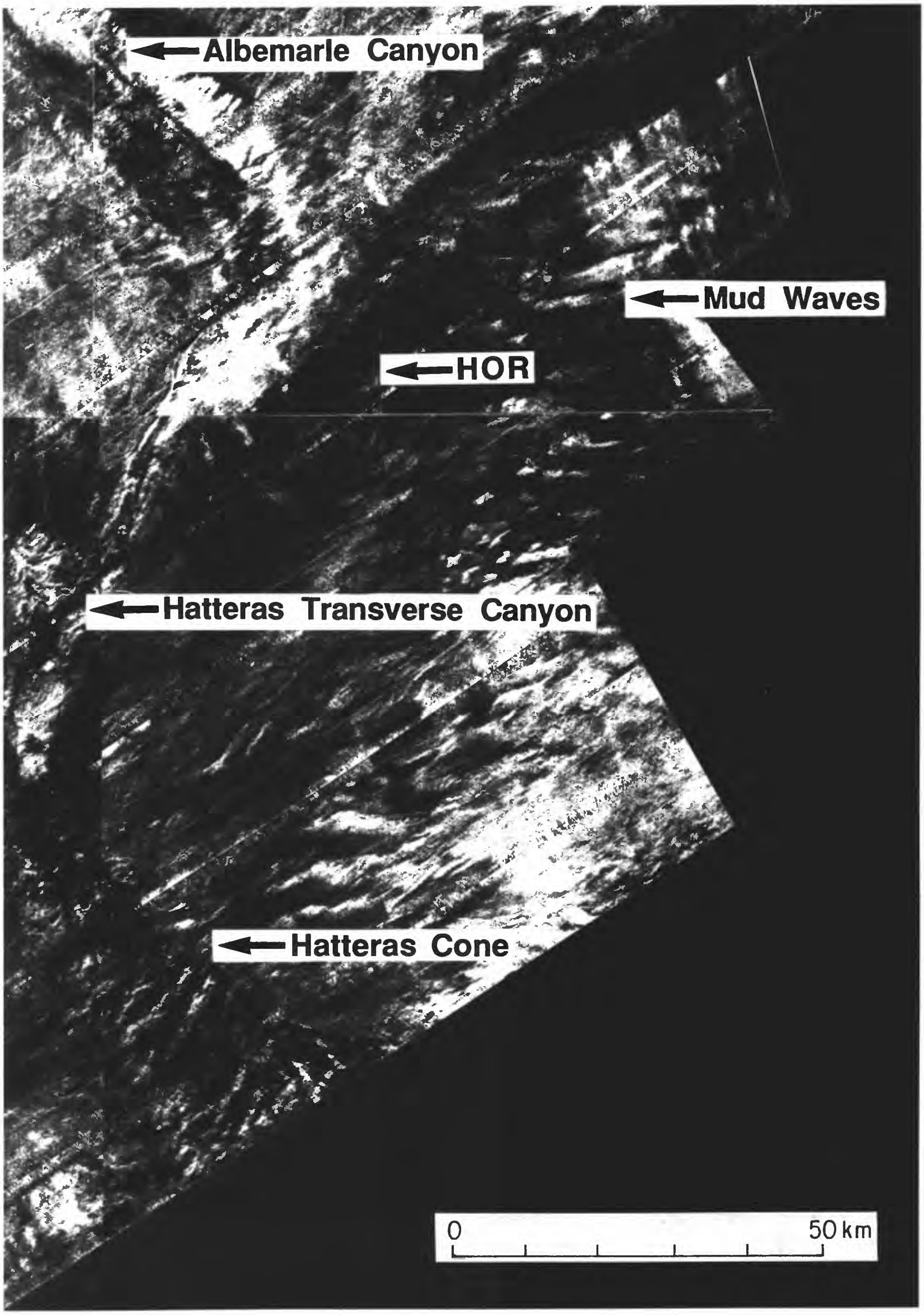
B. A segment of 3.5-kHz profile that shows two low-relief channels on the Hatteras Cone. The channels are marked by hummocky returns. Location of profile shown on figure 1.

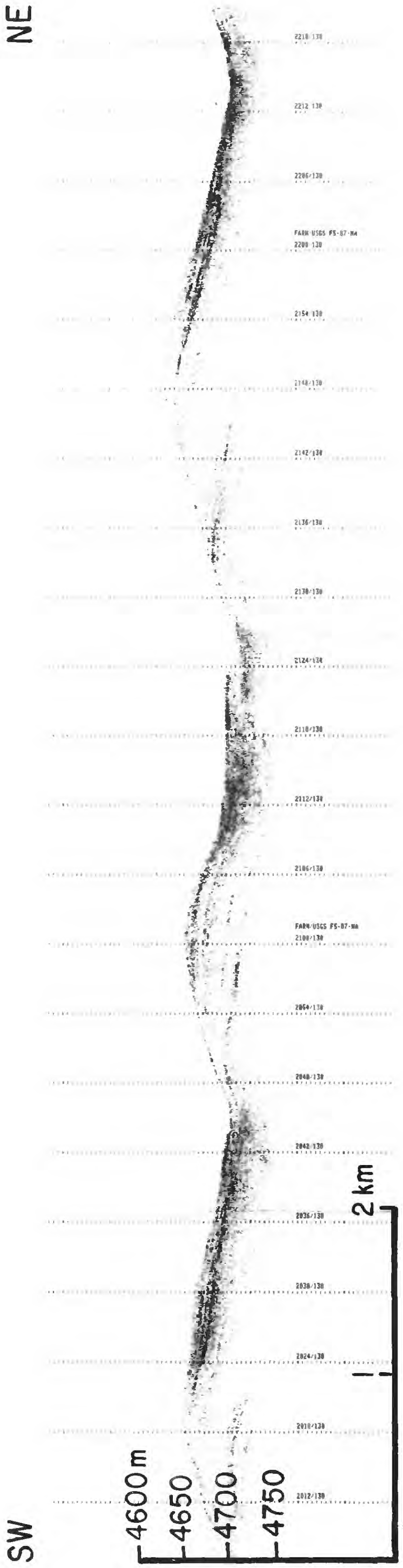
Figure 15 -- Interpretative diagram of figure 2 that shows the main features discussed in the text and interpreted from 3-kHz seismic-reflection profiles. Outlines of slump-slide complexes are dashed; clearly defined crests of Lower Rise Hills deposited by geostrophic current on the Hatteras Outer Ridge are dotted, and topographically define channels are shown with solid lines.

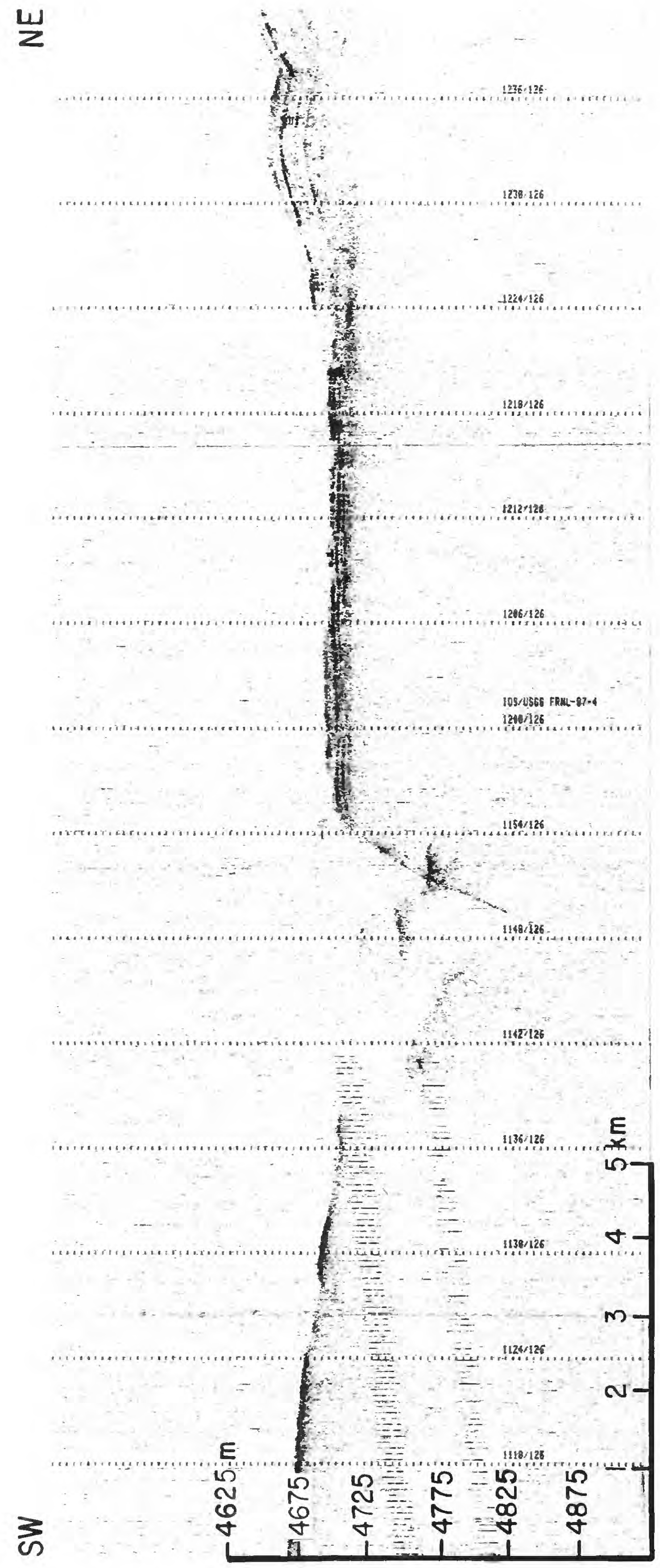


NC
SC
CAPE HATTERAS
CONTINENTAL SHELF
CONTINENTAL SLOPE
200m
1000m
2000m
3000m
3500m
4000m
4500m
5000m
PAMLICO CANYON
HATTERAS CANYON
ALBEMARLE CANYON
HATTERAS TRANSVERSE CANYON
CAPE FEAR SLIDE COMPLEX
CAPE LOOKOUT SLIDE COMPLEX
ALBEMARLE CURRITUCK SLIDE COMPLEX
HATTERAS CONE
HATTERAS AND LOWER RISE HILLS
OUTER RIDGE
FIG. 10
FIG. 3
FIG. 6
11A
11B
12
13
14A
14B
8A
8B
9
5
4
7
GLORIA SURVEY LIMIT
0
100
200 KILOMETERS
N
32°
34°
36°
78°
76°
74°
72°

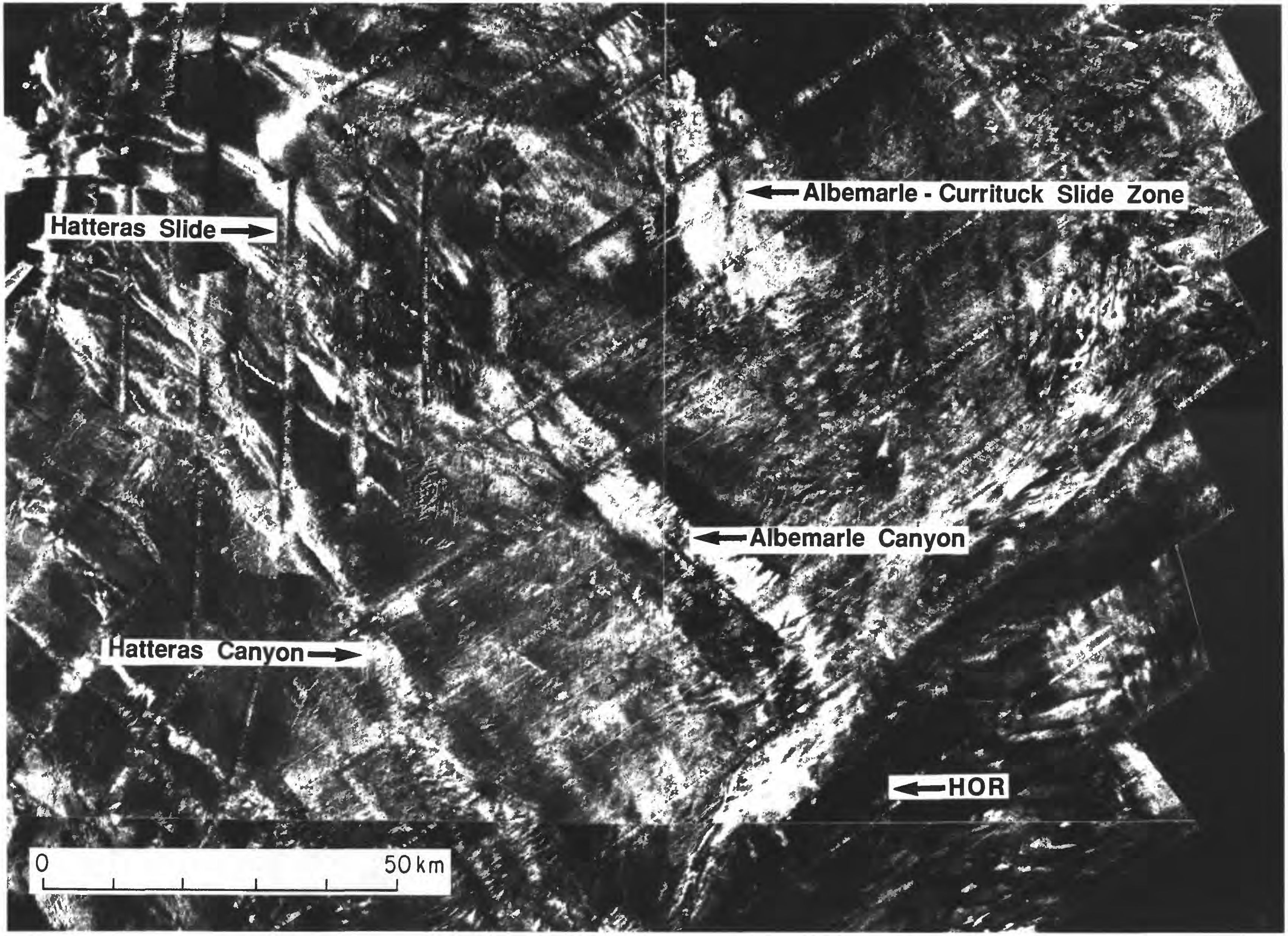

74°
72°
36°
34°
32°
0
50 KM


Albemarle Canyon
Mud Waves
HOR
Hatteras Transverse Canyon
Hatteras Cone
0
50 km

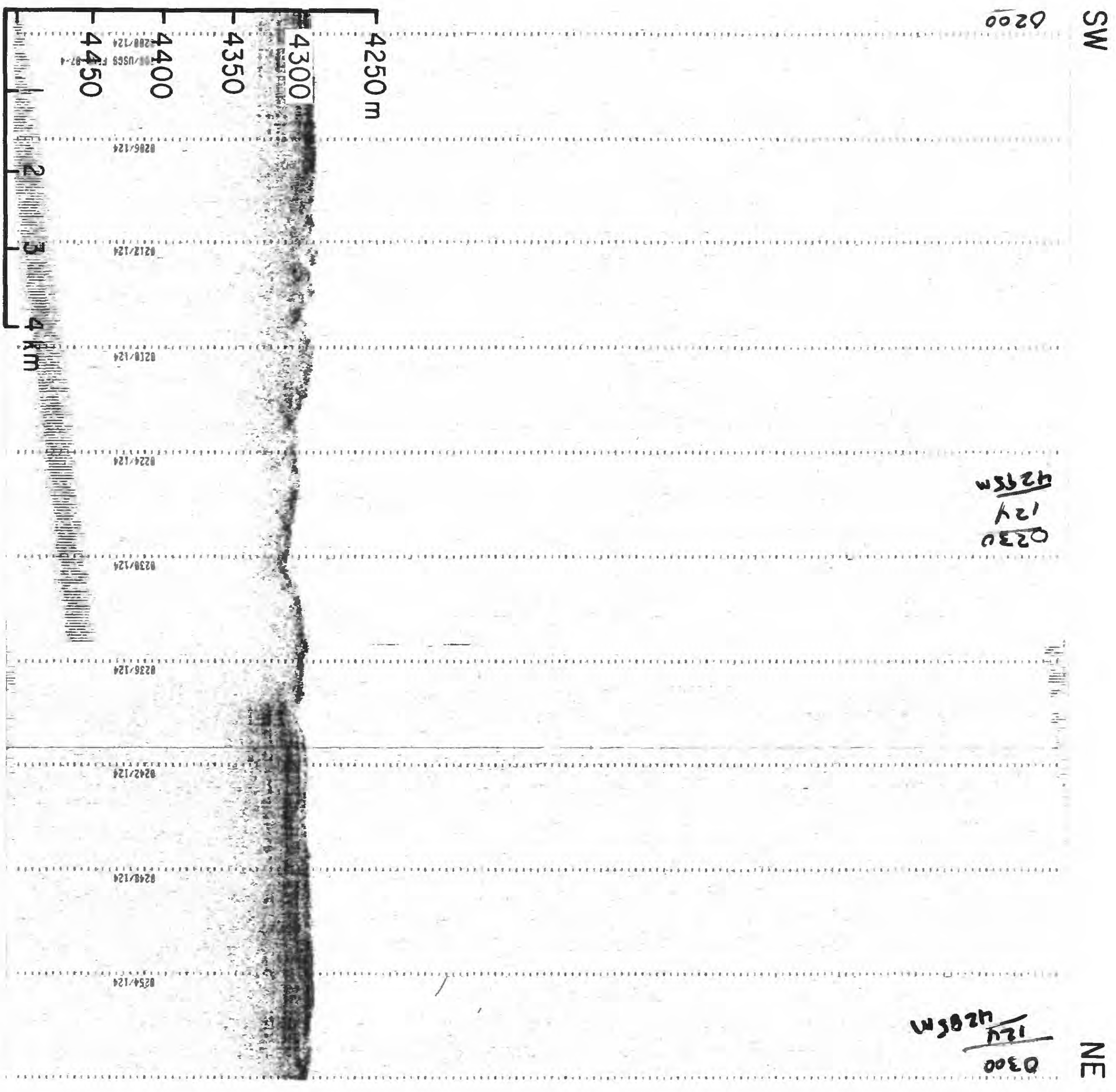

NE
SW
4600 m
4650
4700
4750
2 km

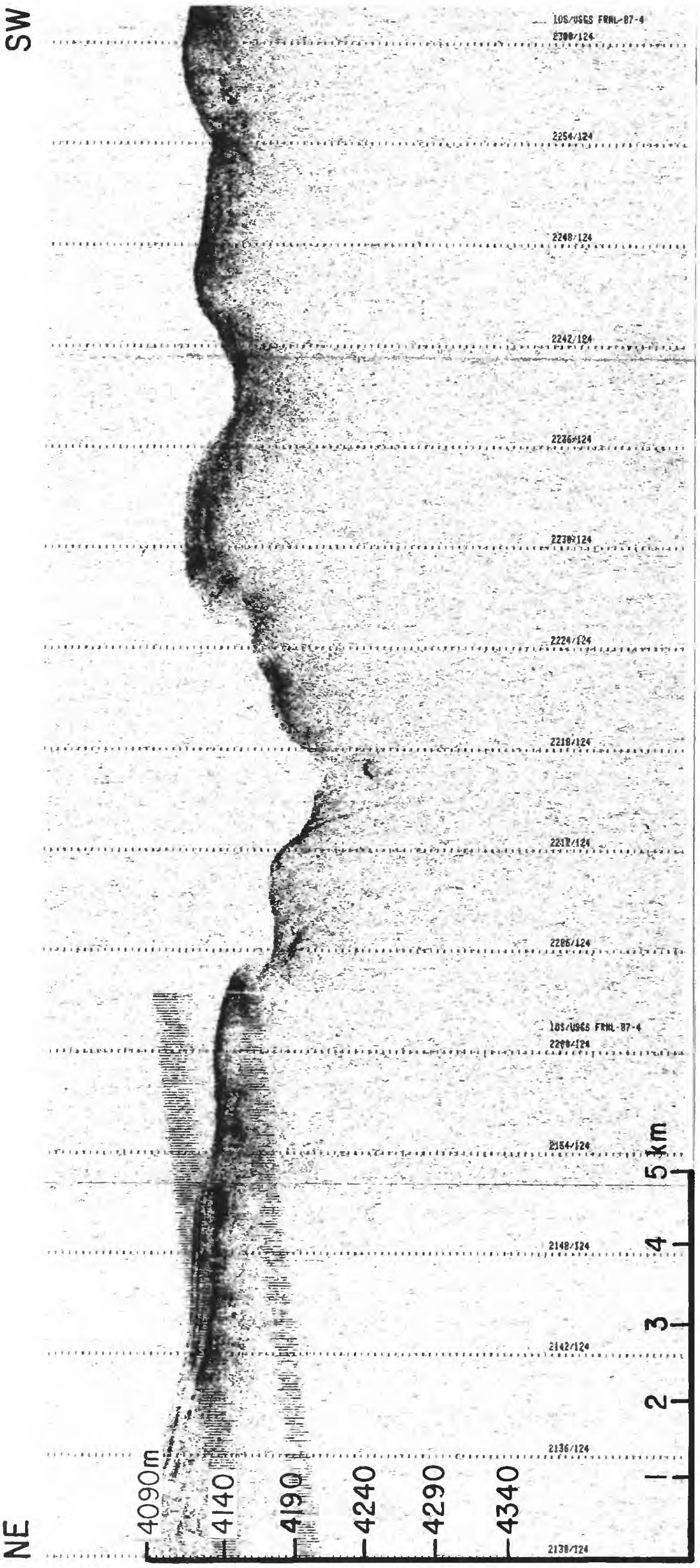


SW
NE
4625 m
4675
4725
4775
4825
4875
1
2
3
4
5 km
1118/126
1124/126
1130/126
1136/126
1142/126
1148/126
1154/126
IOS/USGS FRNL-87-4
1200/126
1206/126
1212/126
1218/126
1224/126
1230/126
1236/126

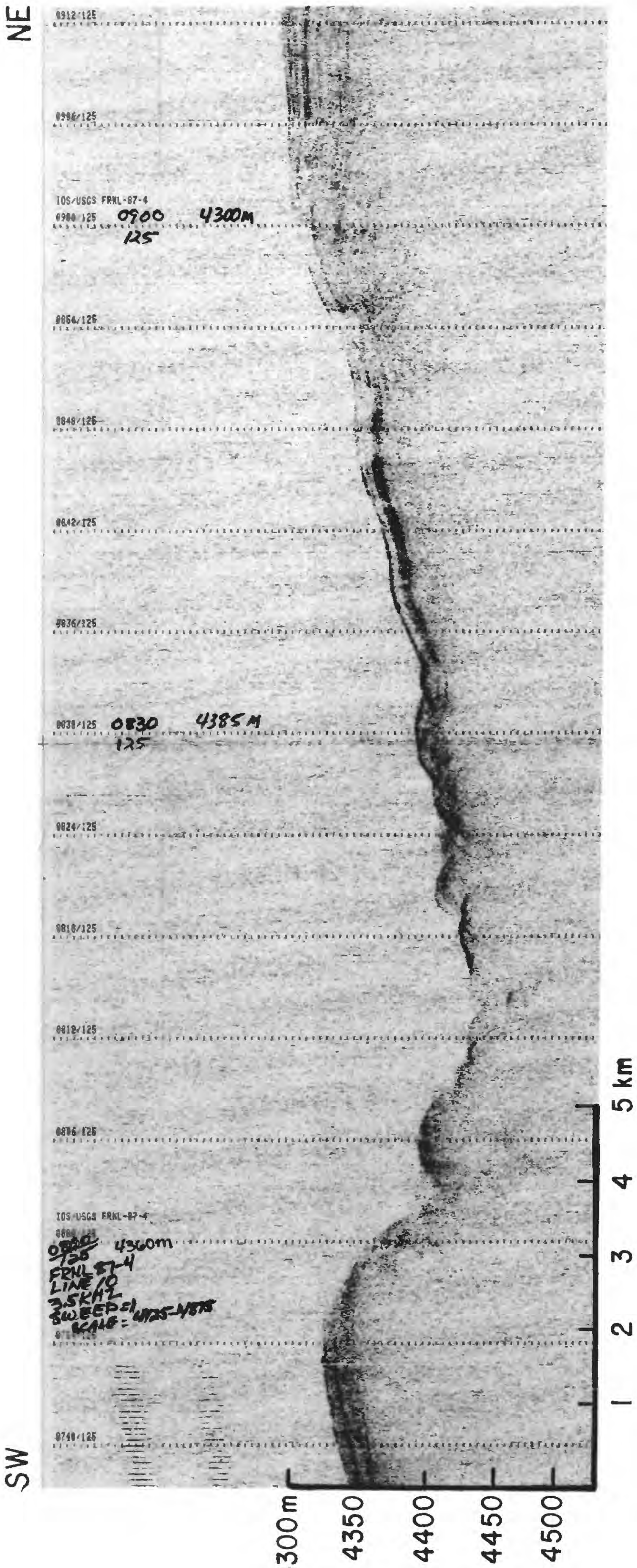


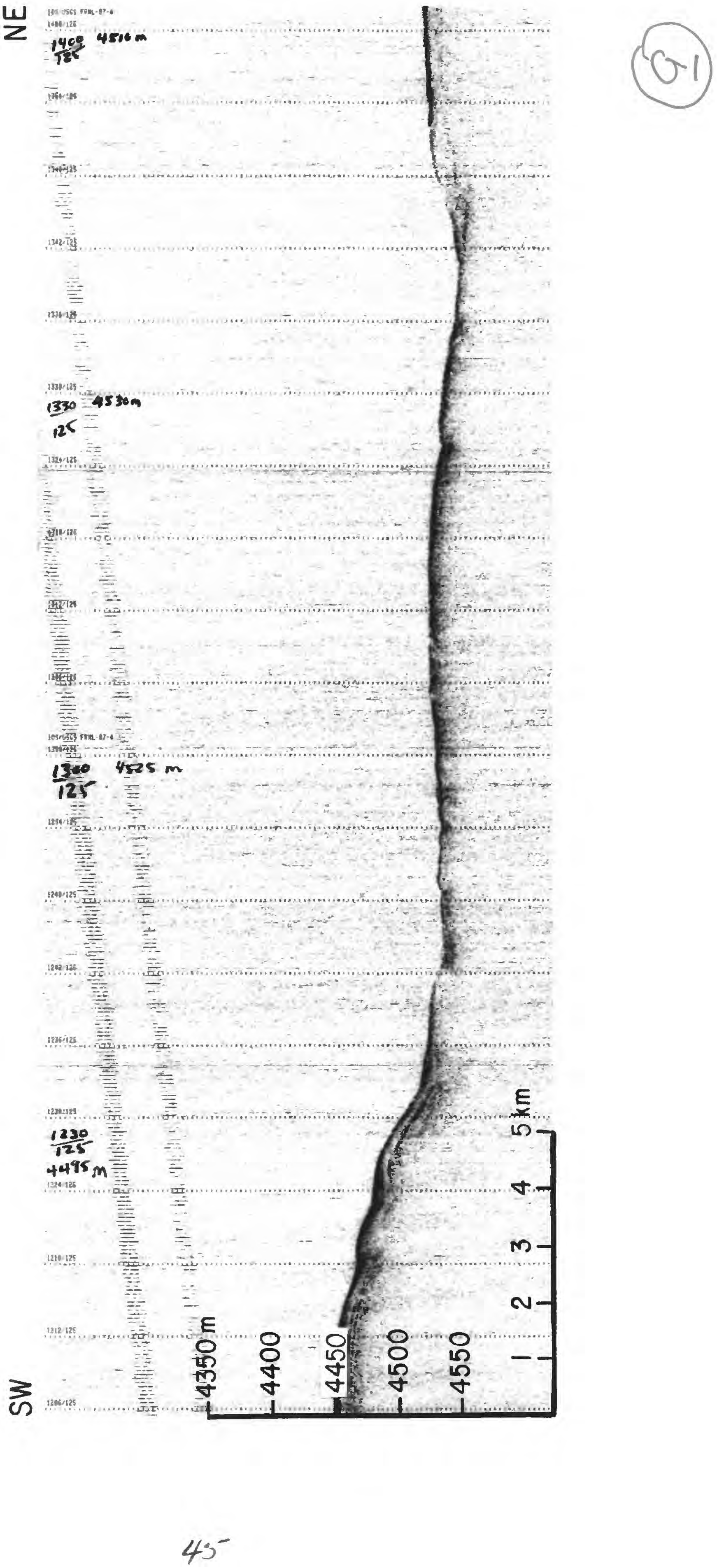
Albemarle - Currituck Slide Zone
Hatteras Slide
Albemarle Canyon
Hatteras Canyon
HOR
0
50 km

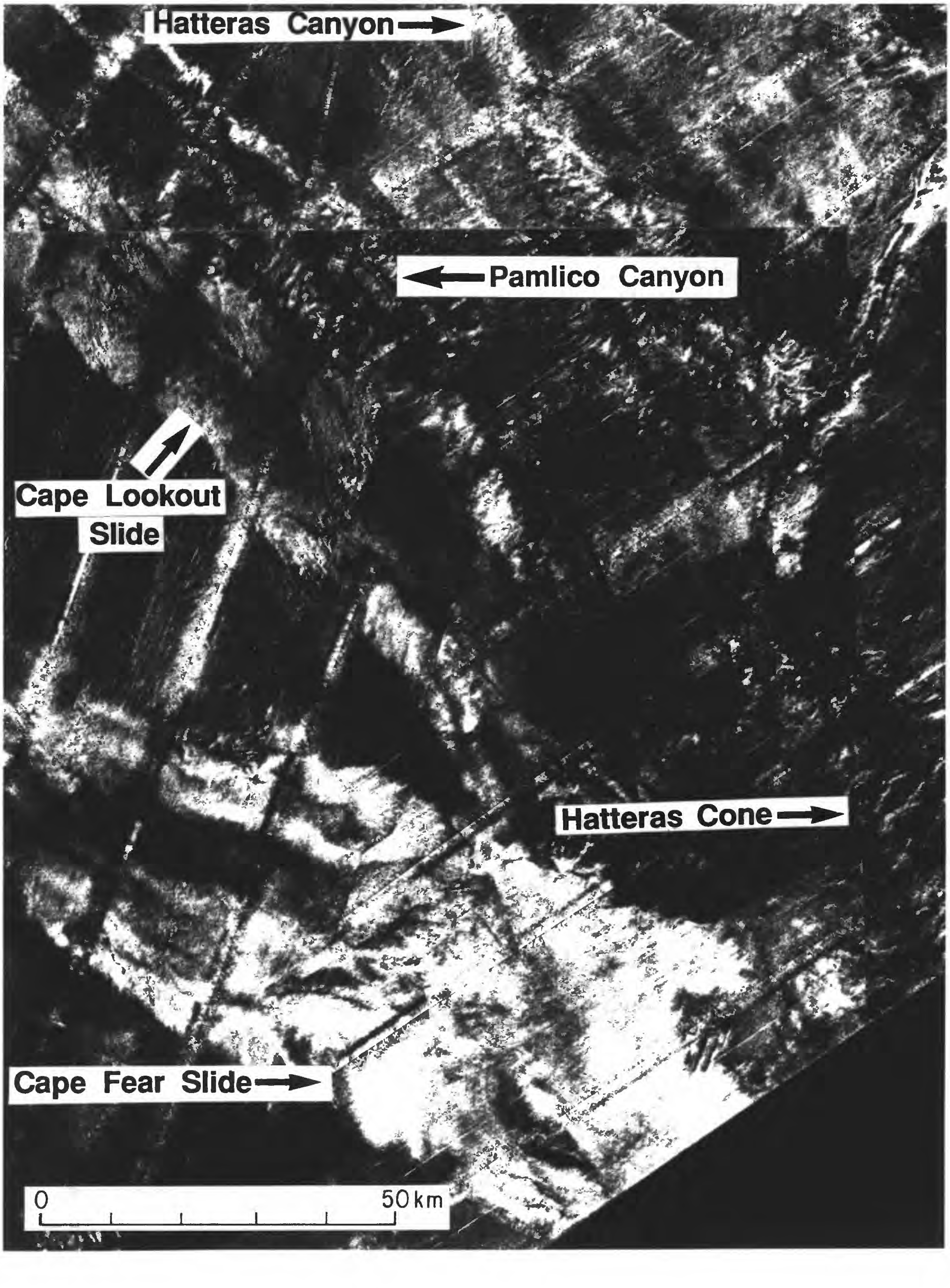

SW
NE
4250 m
4300
4350
4400
4450
1
2
3
4 km
0200
0230
124
4275m
0300
124
4283m


SW
NE
4090m
4140
4190
4240
4290
4340
1
2
3
4
5 km
IOS/USGS FRML-87-4

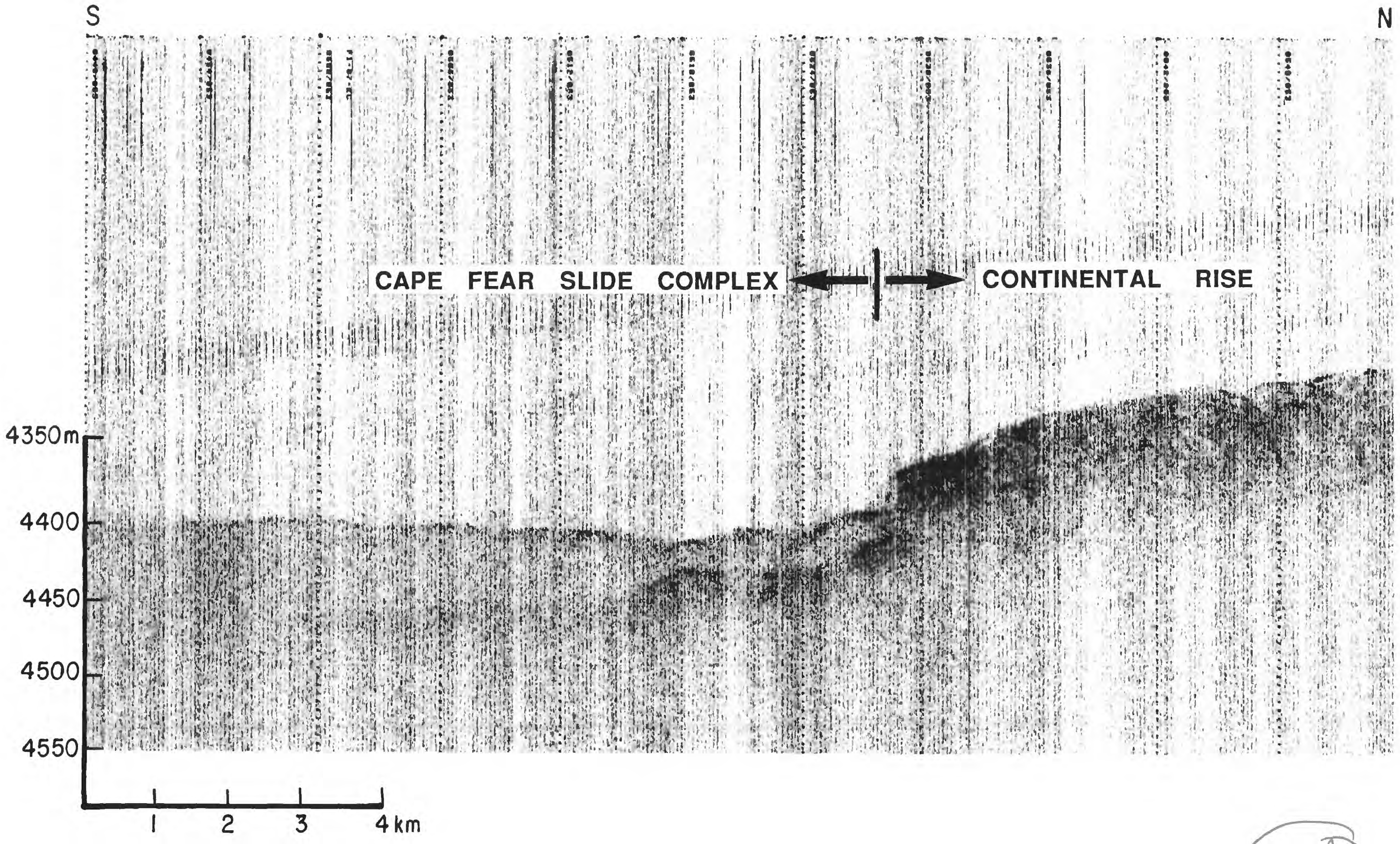
8B


NE
SW
IOS/USGS FRNL-87-4
0900
125
4300m
0830
125
4385 M
4360m
FRNL 87-4
LINE 10
3.5KHZ
SWEEP=1
4300 m
4350
4400
4450
4500
1
2
3
4
5 km


NE
SW
1400/125 4516 m
1330/125 4530 m
1300/125 4525 m
1230/125 4495 m
4350 m
4400
4450
4500
4550
1
2
3
4
5 km
G1

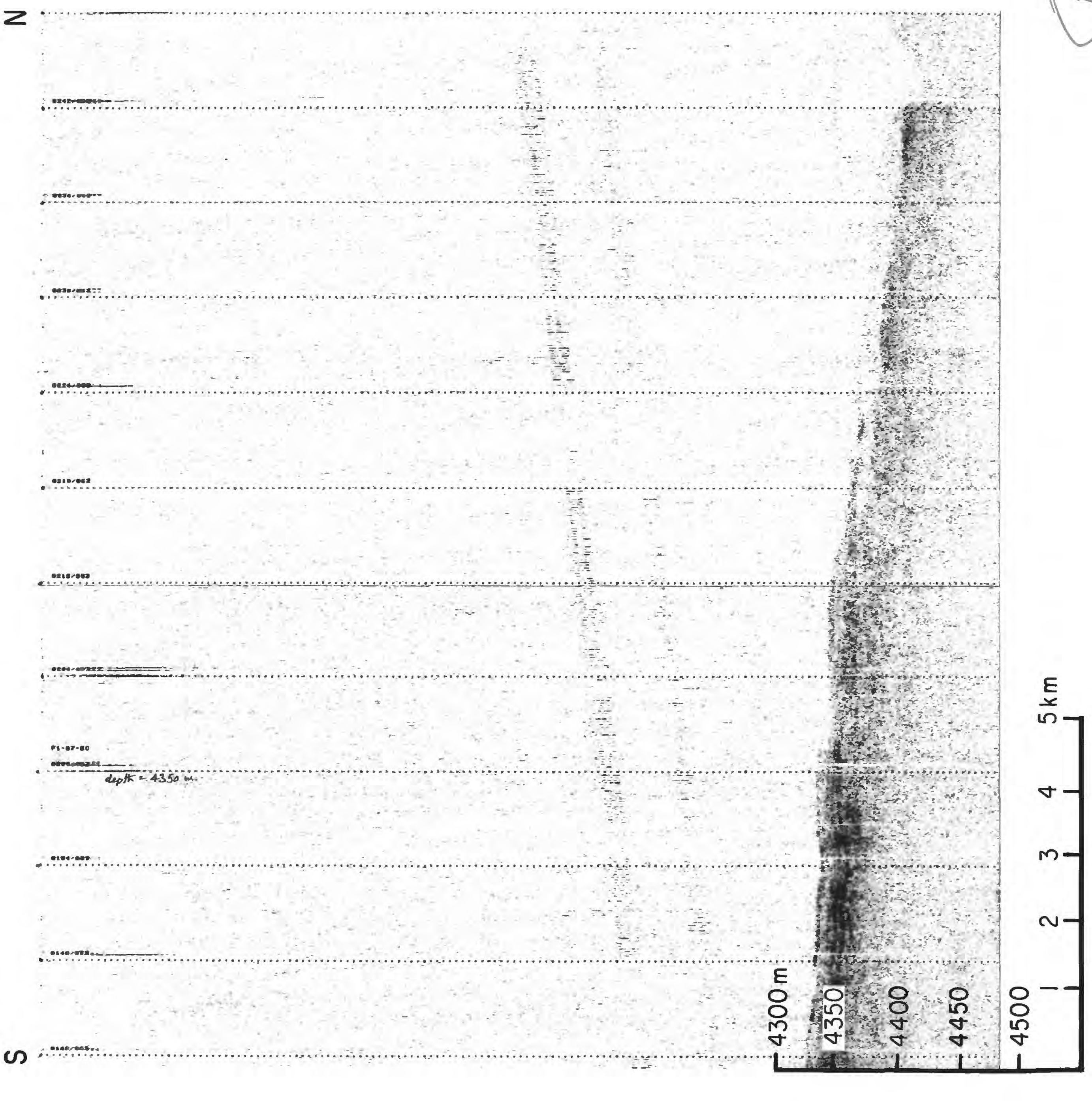


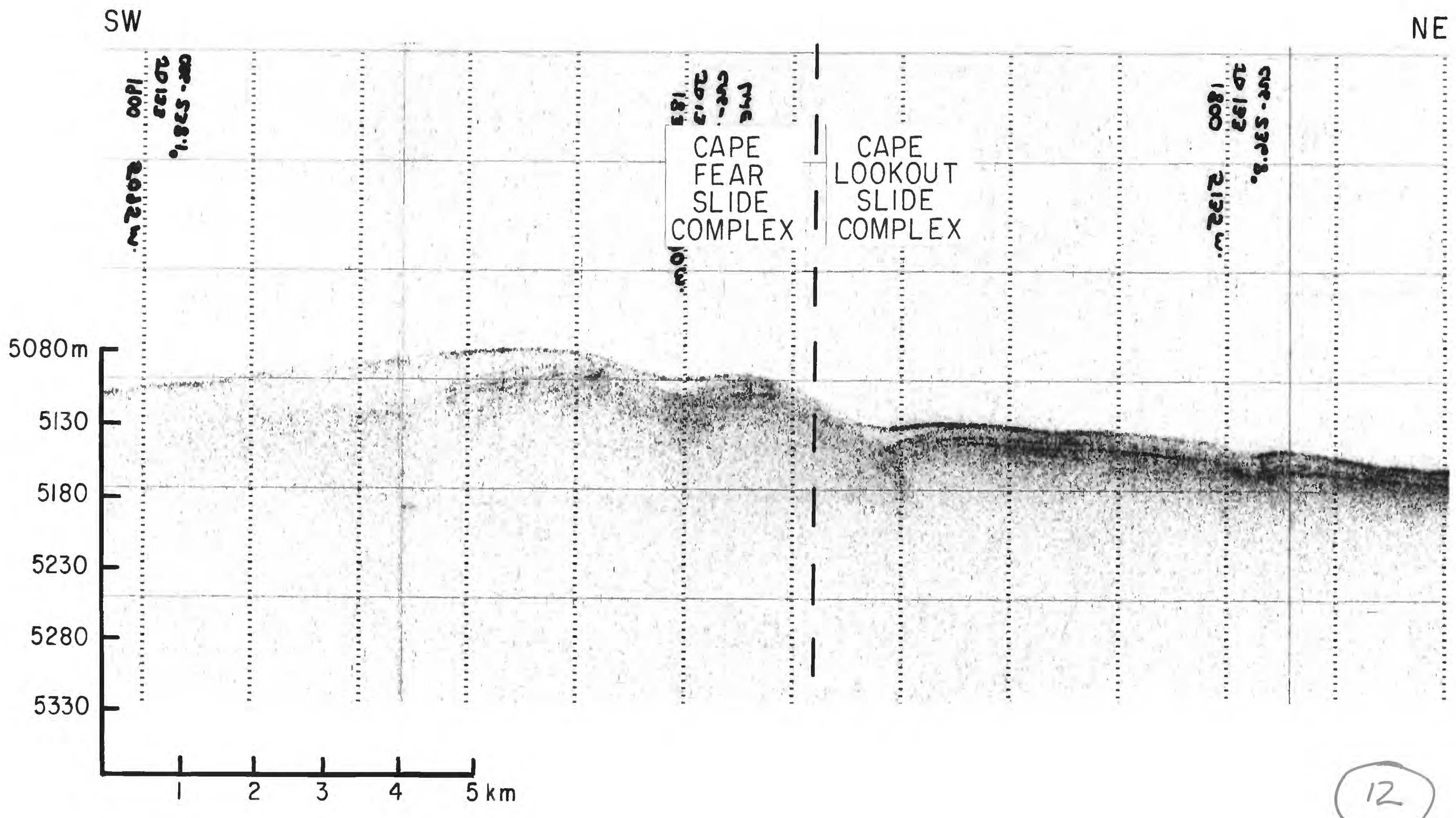
Hatteras Canyon
Pamlico Canyon
Cape Lookout Slide
Hatteras Cone
Cape Fear Slide
0
50 km


S
N
CAPE FEAR SLIDE COMPLEX
CONTINENTAL RISE
4350m
4400
4450
4500
4550
1
2
3
4 km

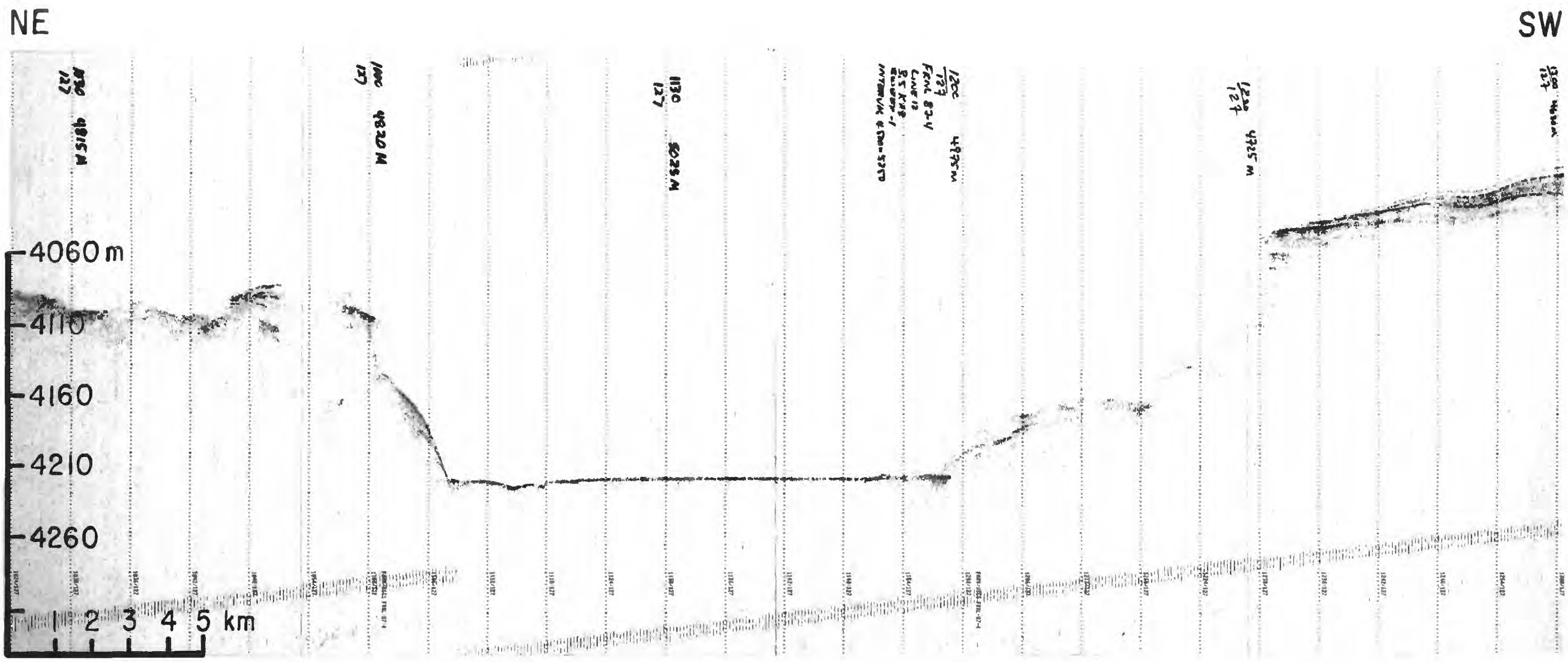
11A

11B



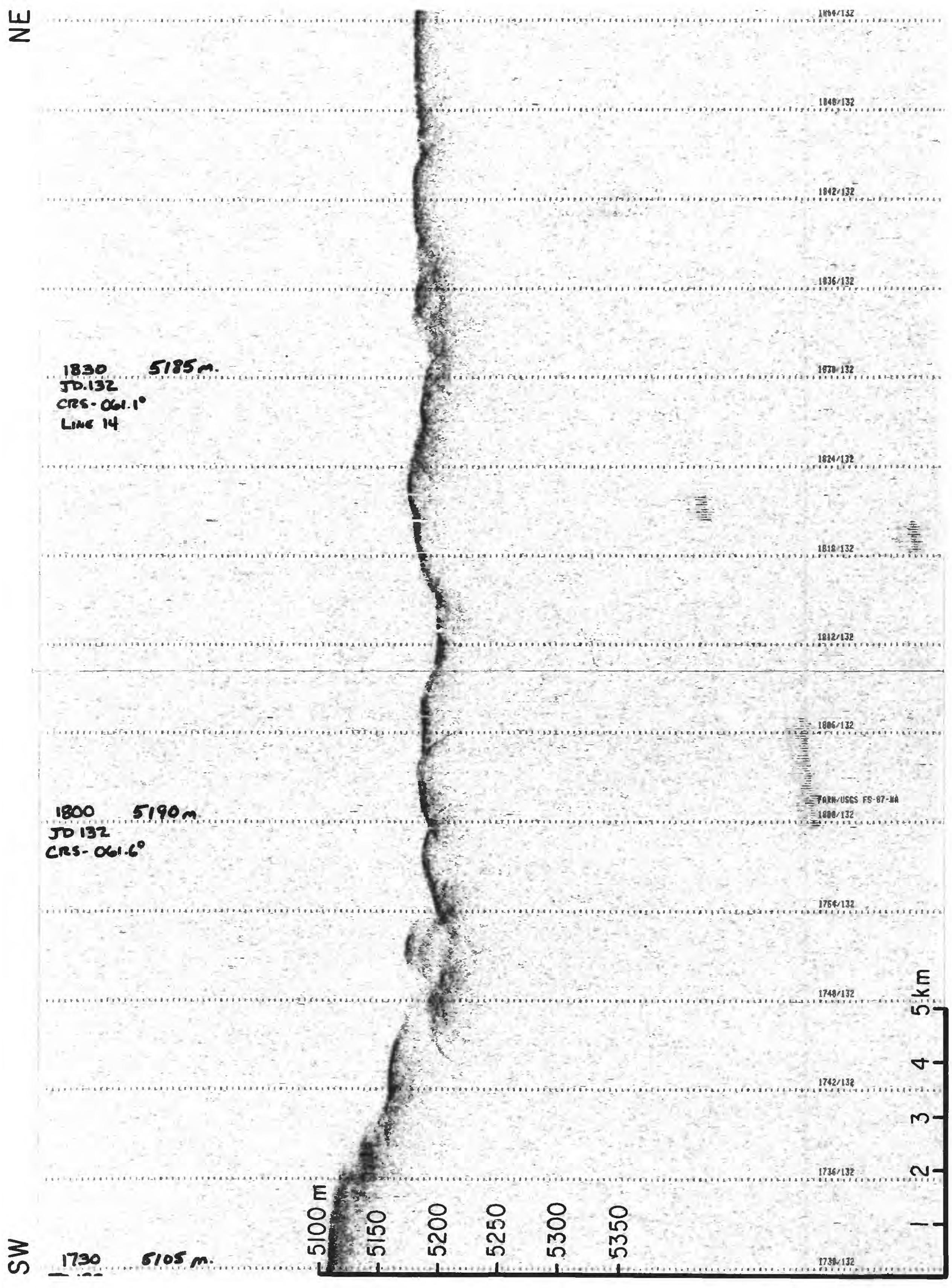

SW
NE
CAPE
FEAR
SLIDE
COMPLEX
CAPE
LOOKOUT
SLIDE
COMPLEX
5080m
5130
5180
5230
5280
5330
1
2
3
4
5 km

12

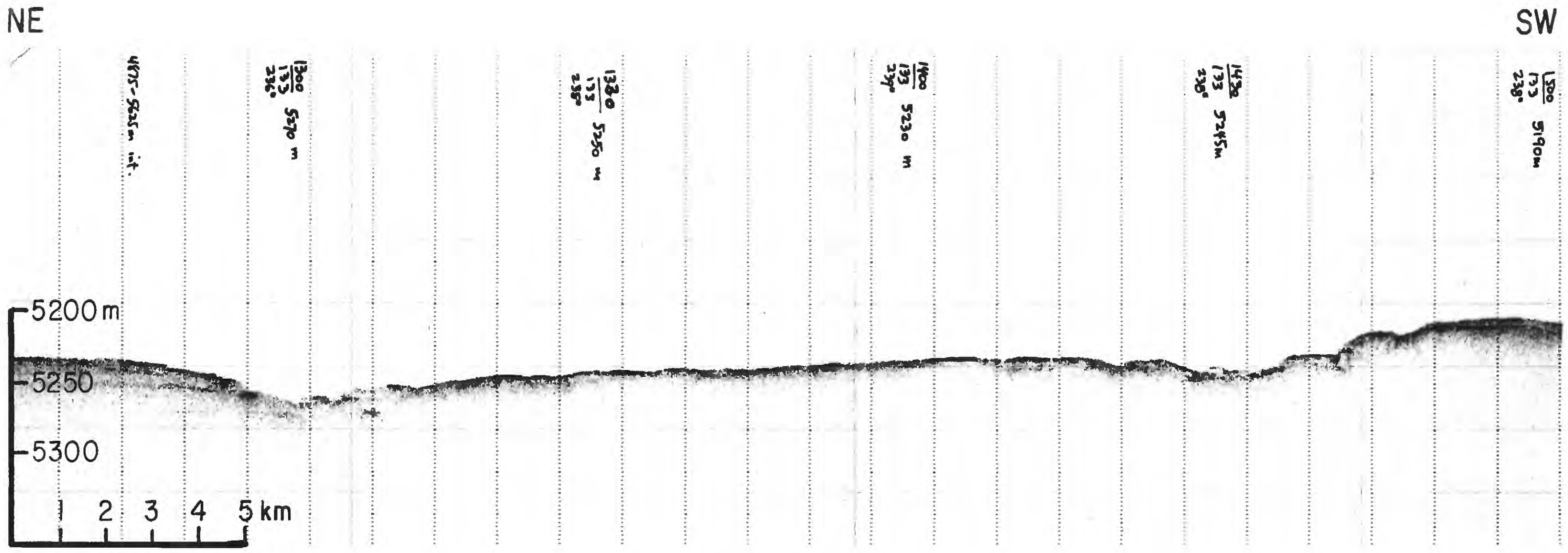


13

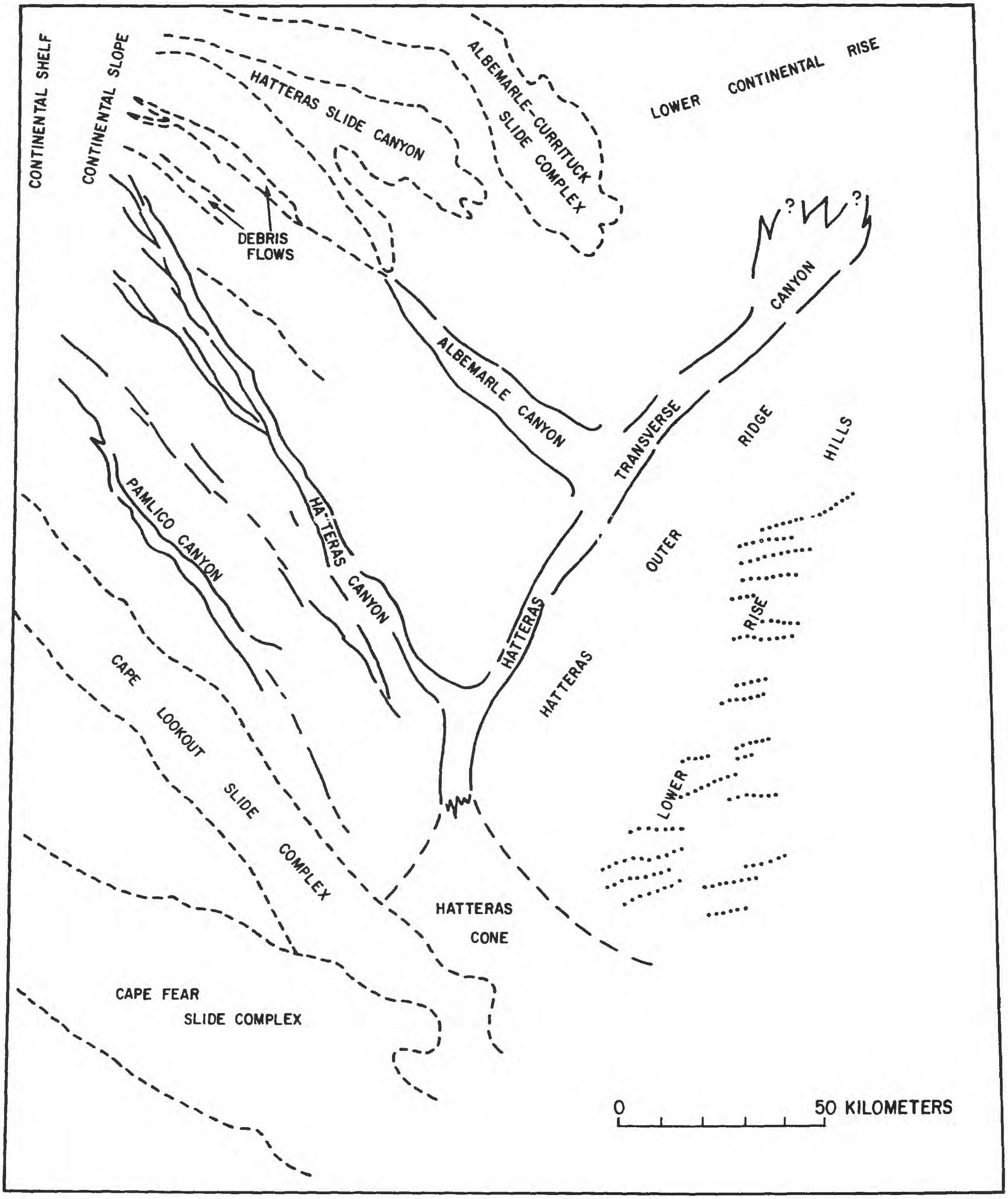
14A



NE
SW
1830 5185m.
JD.132
CRS-061.1°
LINE 14
1800 5190m.
JD 132
CRS-061.6°
1730 5105m.
5100 m
5150
5200
5250
5300
5350
1
2
3
4
5 km
1854/132
1848/132
1842/132
1836/132
1830/132
1824/132
1818/132
1812/132
1806/132
1800/132
1754/132
1748/132
1742/132
1736/132
1730/132


NE
SW
4875-5625m int.
1300 / 133 / 236° 5270 m
1330 / 133 / 238° 5250 m
1400 / 133 / 239° 5230 m
1430 / 133 / 238° 5245m
1500 / 133 / 238° 5190m
5200 m
5250
5300
1 2 3 4 5 km

14B


CONTINENTAL SHELF
CONTINENTAL SLOPE
HATTERAS SLIDE CANYON
ALBEMARLE-CURRITUCK SLIDE COMPLEX
LOWER CONTINENTAL RISE
DEBRIS FLOWS
ALBEMARLE CANYON
TRANSVERSE CANYON
RIDGE
HILLS
OUTER
RISE
HATTERAS CANYON
HATTERAS
PAMLICO CANYON
HATTERAS
LOWER
CAPE LOOKOUT SLIDE COMPLEX
HATTERAS CONE
CAPE FEAR SLIDE COMPLEX
0
50 KILOMETERS