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SMALL-SCALE SLUMP DEPOSITS, MIDDLE ATLANTIC CONTINENTAL SLOPE, OFF EASTERN UNITED STATES

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ABSTRACT

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Analyses of 24 high-resolution seismic-reflection profiles that were collected during local and regional surveys show that small-scale slump deposits are ubiquitous within the intercanyon areas of the Continental Slope of the Middle Atlantic Bight. The deposits involve the upper 10—90 m of sediments, extend downslope for 1.8—7.2 km, and are present at water depths ranging from 545 to 1500 m. The characteristics of the deposits vary from thin, homogeneous or fairly regularly bedded lenses of sediment, to masses of intermediate thickness with contorted bedding, to relatively large slump blocks. A detailed survey of one slump mass just south of Hudson Canyon (by means of close-spaced Minisparker profiles and sediment cores) showed that it had a thickness of about 30 m and a volume of at least 0.4 km^3 and consisted of homogeneous clay which accumulated rapidly during the late Pleistocene or Holocene. Although some of the slump deposits undoubtedly are relict, stemming from sediment instability produced by rapid deposition during Pleistocene sea-level regressions, others were formed relatively recently. Possible causes of modern slumps include gas generation in the sediments, bottom-water turbulence on the upper slope, and shallow faulting. This study indicates that small-scale slumping in the intercanyon areas may be an important process in transporting sediments to the deep sea and suggests that recent mass movements may constitute a geologic hazard to future economic development of this part of the Continental Slope.

INTRODUCTION

Submarine slumping is common on the North American east coast continental margin. Mass movements that have been described previously range from the dislocation of large coherent blocks (Rona and Clay, 1967; Uchupi, 1967; Emery et al., 1970; Kelling and Stanley, 1970; MacIlvaine, 1973), to slumps associated with submarine canyons (Stanley and Silverberg, 1969; Kelling and Stanley, 1970), to translational slides and debris flows (Heezen and Drake, 1964; MacIlvaine, 1973; Embley, 1976; Embley and Jacobi, 1977).

Those mass movements that have been reported are primarily large-scale features that involve a significant volume (>10 km^3) of sediments. Few or no data are available on thin, small-scale slumps or slides, especially those on the open Continental Slope away from large submarine canyons. This lack of information may reflect the paucity of small-scale slumps, the tendency among investigators to ignore such small features, or the inability of conventional low-frequency seismic-reflection systems to resolve these deposits.

In this study, we looked for small-scale slump deposits* in the intercanyon areas of the Continental Slope of the Middle Atlantic Bight. The purposes of the study were to determine the distribution and characteristics of these features and to make some inferences about their ages, causes, and environmental significance.

METHODS

Shallow-subbottom data were obtained from both local and regional surveys. During the local surveys, nine high-resolution seismic-reflection profiles were collected within subareas 2 and 3 (Figs.1, 2) which have contrasting bottom gradients ($< 4°$ versus 6—12°). Within each subarea, the profiles were obtained perpendicular to the Continental Slope and were spaced 2—5 km apart. Water depths along the cruise tracks ranged from 115 to 1960 m. A Minisparker acoustic system (1.5 kJ; 200—500 Hz band pass) was used to collect the profiles.

In order to gain a regional perspective of small-scale slumping, we examined fifteen shallow-subbottom (3.5-kHz) profiles that had been obtained across the intercanyon areas (Fig.1) during a recent reconnaissance survey of the Middle Atlantic continental margin. Water depths along the traverses ranged from 108 to 1500 m. Profile locations were not biased towards areas expected to have slumps.

The bottom sediments along the tracklines in subarea 2 were sampled with six short (<70 cm) gravity cores and one relatively long (4.2 m) vibracore (Fig.3). Size analyses were run on subsamples from the cores by using standard sieve and pipette techniques (Galehouse, 1970; Ingraham, 1970). Navigational control for all tracklines and station locations was provided by Loran-C and satellite fixes.

RESULTS

Local surveys

A small ($\leqslant 30$ m thick) slump is outlined in the two northern profiles from subarea 2 (Fig.3; Legs 1, 3). The slump is present between water depths of 480 and 780 m and is part of an acoustically transparent wedge of

*In this paper, slump deposits refer to submarine sediment masses that have moved downslope in a more or less coherent manner. Several variant processes that produce deposits which can be included under this general definition are discussed by Kelling and Stanley (1976) and Middleton and Hampton (1976).

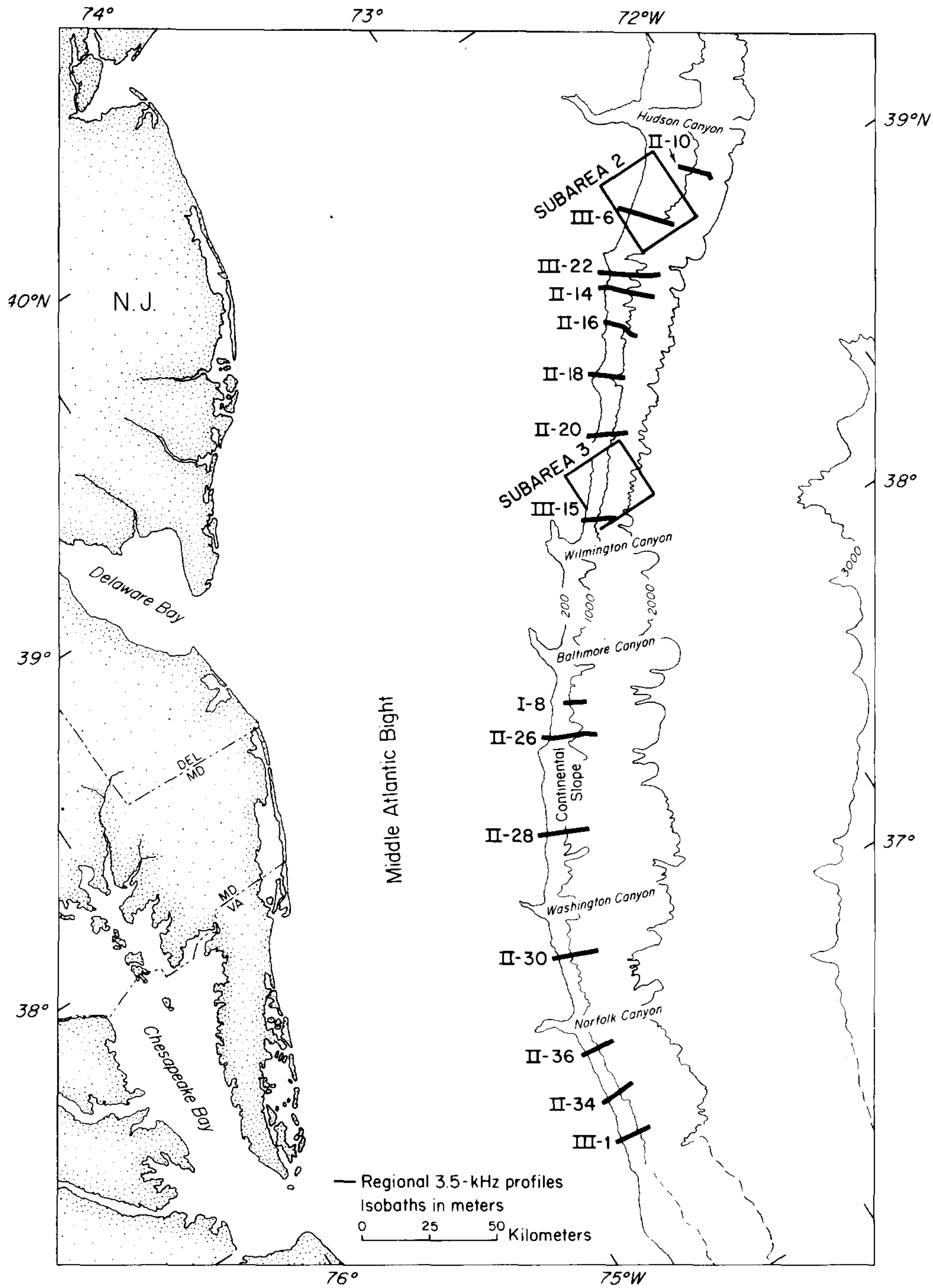

Fig.1. Index map showing locations of *subareas 2 and 3* and regional 3.5-kHz profiles within the Middle Atlantic Bight area. Profile numbers are given. Bathymetry from Uchupi (1965).

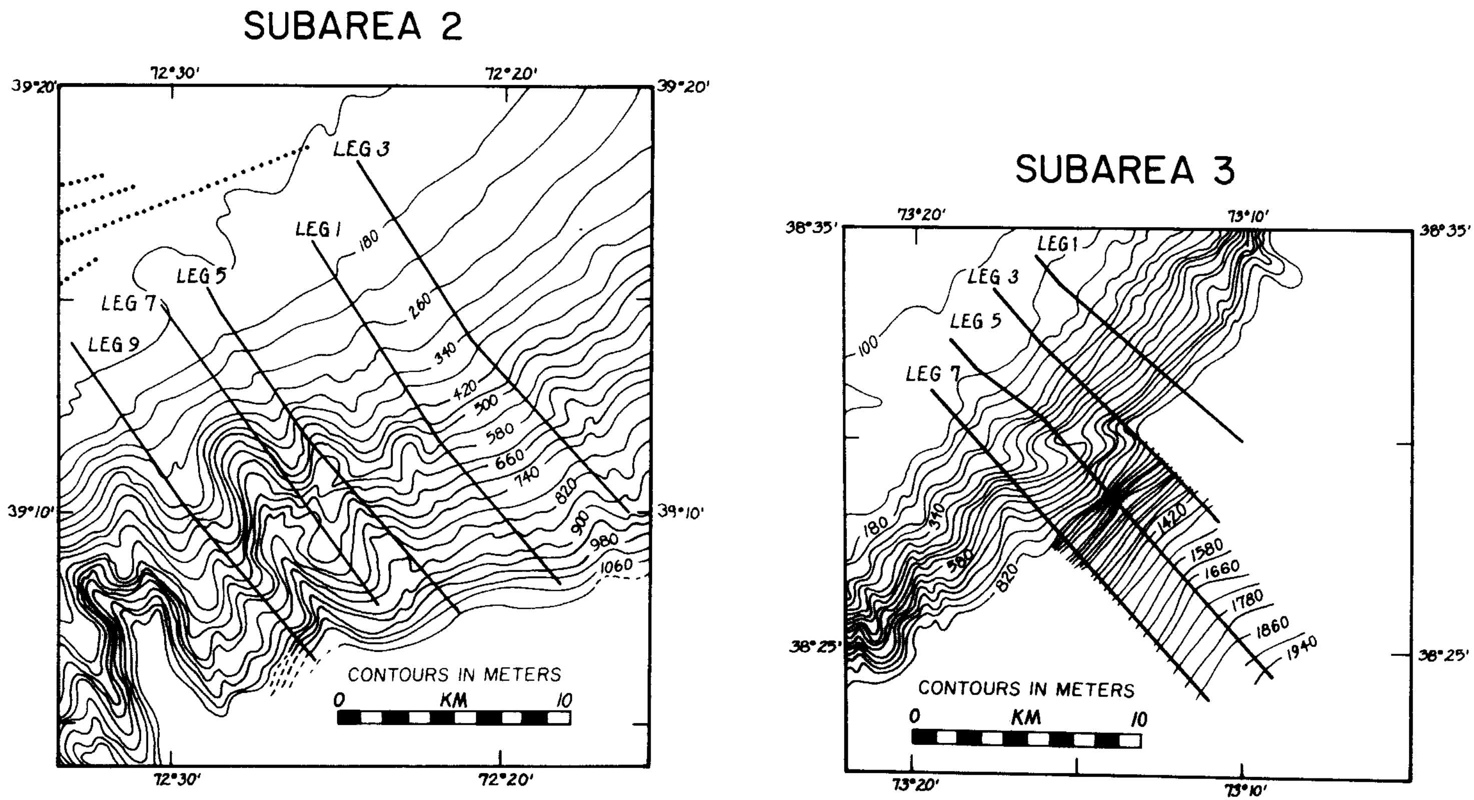

Fig.2. Bathymetry and locations of Minisparker seismic-reflection profiles (Legs) within subareas 2 and 3. Bathymetry in meters from U.S. Coast and Geodetic Survey and U.S. Bureau of Commercial Fisheries (1967a, b, c, d). Contour interval = 40 m. Dotted lines within subarea 2 indicate locations of fault planes described by Sheridan and Knebel (1976).

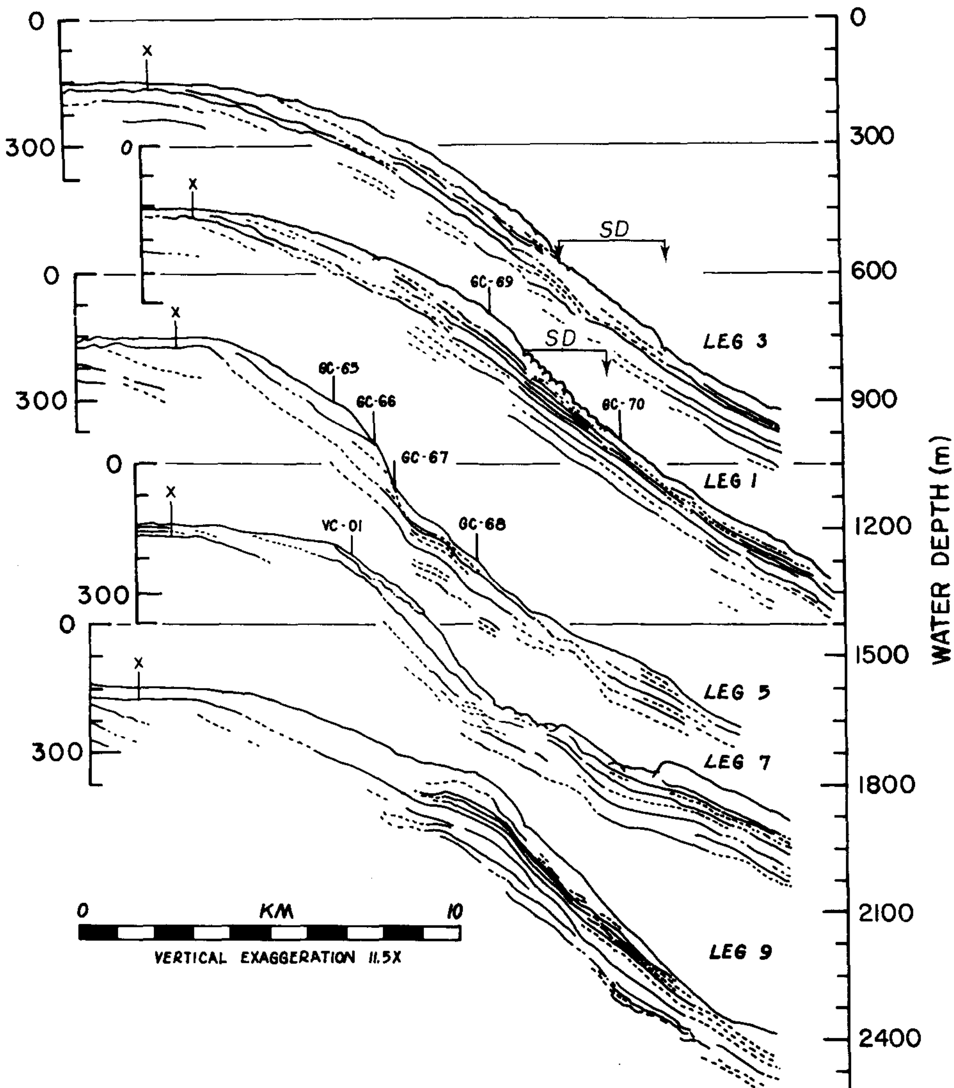

Fig.3. Line drawings of Minisparker seismic-reflection profiles (Legs) from subarea 2. Dashed lines represent poorly defined or spatially incoherent reflecting horizons. Locations of gravity cores (*GC*) and vibracore (*VC*) are indicated. *Reflector X* defines a prominent unconformity beneath the Continental Shelf. See Fig.1 for location of subarea 2 within the Middle Atlantic Bight. Water-depth scales computed using a sound velocity of 1500 m/sec. *SD* = Slump Deposit.

sediments that lies beneath the shelf edge. In Leg 1, the slumped mass is represented by broad hyperbolic reflectors having variable vertical positions that presumably represent blocky or hummocky topography; the slump extends downslope approximately 3 km. Just to the north (Leg 3), the slump apparently has taken the form of a debris flow or translational slide because it forms a structureless lens of sediments about 3.5 km long that is devoid of hyperbolic reflections. The bathymetric positions and the similarity of sizes of the deposits indicate that they are parts of a single feature crossed by both lines; the lateral change in the character of the deposit is not an uncommon phenomenon (Embley and Jacobi, 1977). Although its boundaries are undefined, the slump clearly does not extend as far south as Leg 5 (Fig.2). We estimate, therefore, that it covers at least 13 km^2 and contains a minimum of 0.4 km^3 of sediments.

The sediments within the cores from subarea 2 (see Fig.3 for core locations) may be divided into two units on the basis of the lithology. The upper unit (20—60 cm thick) consists of medium-to-fine, olive-gray sand with minor amounts (<10%) of silt plus clay, although, in two cores from a bathymetric depression (GC-67, -68), it was a coarse-to-medium silt. The lower unit, on the other hand, is a homogeneous greenish-gray silty clay that has dark gray (hydrotroilite) mottles. The contact between the two units is abrupt and usually is angular; in some places it is complex and is characterized by alternating sand and clay layers. Sand clasts were found within the clay unit in core VC-01.

In subarea 3, hyperbolae near the base of the slope (Fig.4, Legs 5, 7) also suggest an accumulation of slumped sediments. However, we cannot define the origin, the transport distance, or the volume of the sediments that are involved. The profile along Leg 5 (Fig.4) does show a possible scar (indicated by a steeper gradient and truncated shallow reflectors) about 5 km upslope of the slumped mass in water depths of 760—1355 m. Some of the sediments may have come from this part of the slope.

Regional survey

The regional 3.5-kHz profiles were examined for two kinds of evidence that suggest mass movements of sediments. These are: (1) the occurrence of structures indicative of slump deposits and (2) the truncation of shallow-subbottom reflectors at the sea floor. The latter is considered to be a characteristic of slump scars (Embley and Jacobi, 1977; McGregor and Bennett, 1977).

In turn, three criteria were used to identify the slump deposits in the profiles. First, the deposits were recognized by bathymetric changes, either by a decrease in the bottom gradient or by an increase in the bottom roughness (e.g. Fig.5, Profile II-14). Second, the slumped masses generally had irregular or discontinuous internal reflectors (e.g. Fig.5, Profile III-6). Finally, most slump deposits were discordant with the surrounding strata being separated by either a shallow slip surface or by a fairly-continuous basal horizon (e.g. Fig.5, Profile III-6).

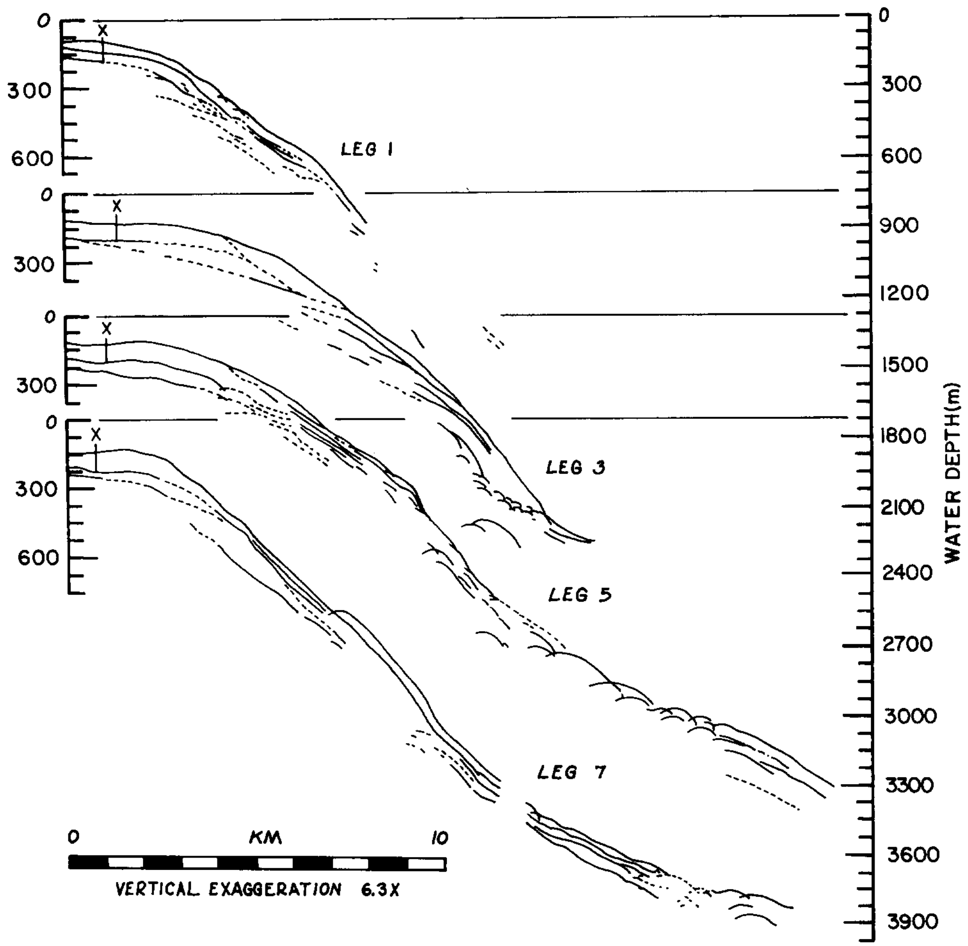

Fig.4. Line drawings of Minisparker seismic-reflection profiles (Legs) from subarea 3. Dashed lines represent poorly defined or spatially incoherent reflecting horizons. *Reflector X* defines a prominent unconformity beneath the Continental Shelf. See Fig.1 for location of subarea 3 within the Middle Atlantic Bight. Water-depth scales computed using a sound velocity of 1500 m/sec.

The profiles show that small-scale slump deposits are ubiquitous on this part of the Continental Slope. Slumped sediments were identified in twelve of the fifteen profiles (80%) that were examined; two profiles defined more than one deposit (Figs.5—7; Table I). In addition, the slumped masses are present at a variety of water depths ranging from 545 to 1500 m. Most, however, were deeper than 800 m.

The characteristics of the slump deposits are quite diverse. The configurations vary from thin, homogeneous or fairly regularly bedded lenses of sediments (Fig.5, Profile II-10; Fig.6, Profile II-26; Fig.7, Profiles II-28, II-34), to masses of intermediate thickness with more irregular bedding (Fig.5,

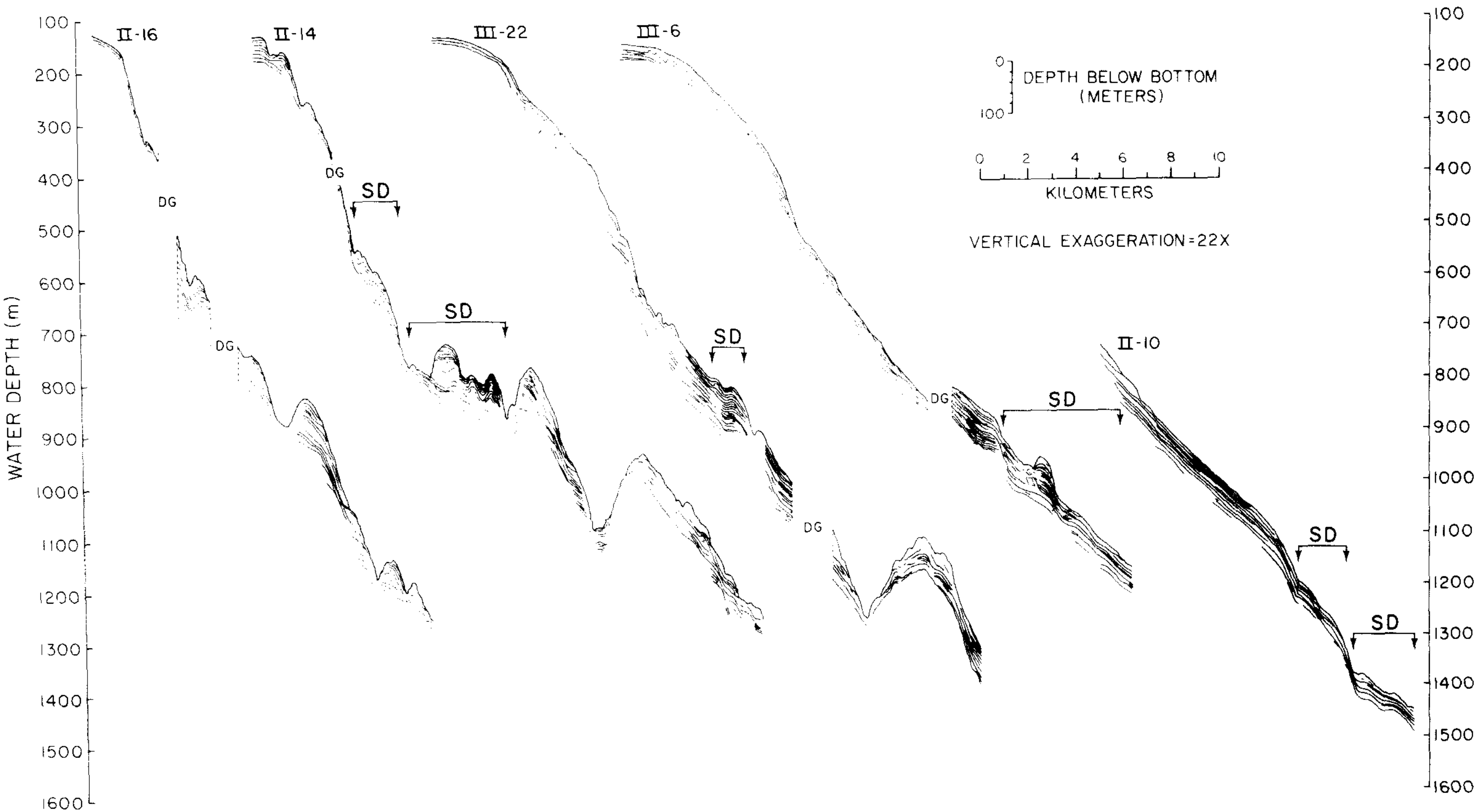

Fig.5. Line drawings of 3.5-kHz seismic-reflection profiles that were obtained in the northern part of the Middle Atlantic Bight. Locations of profiles shown in Fig.1. Water- and subbottom-depth scales computed using a sound velocity of 1500 m/sec. *SD* = Slump Deposit. *DG* = Data Gap.

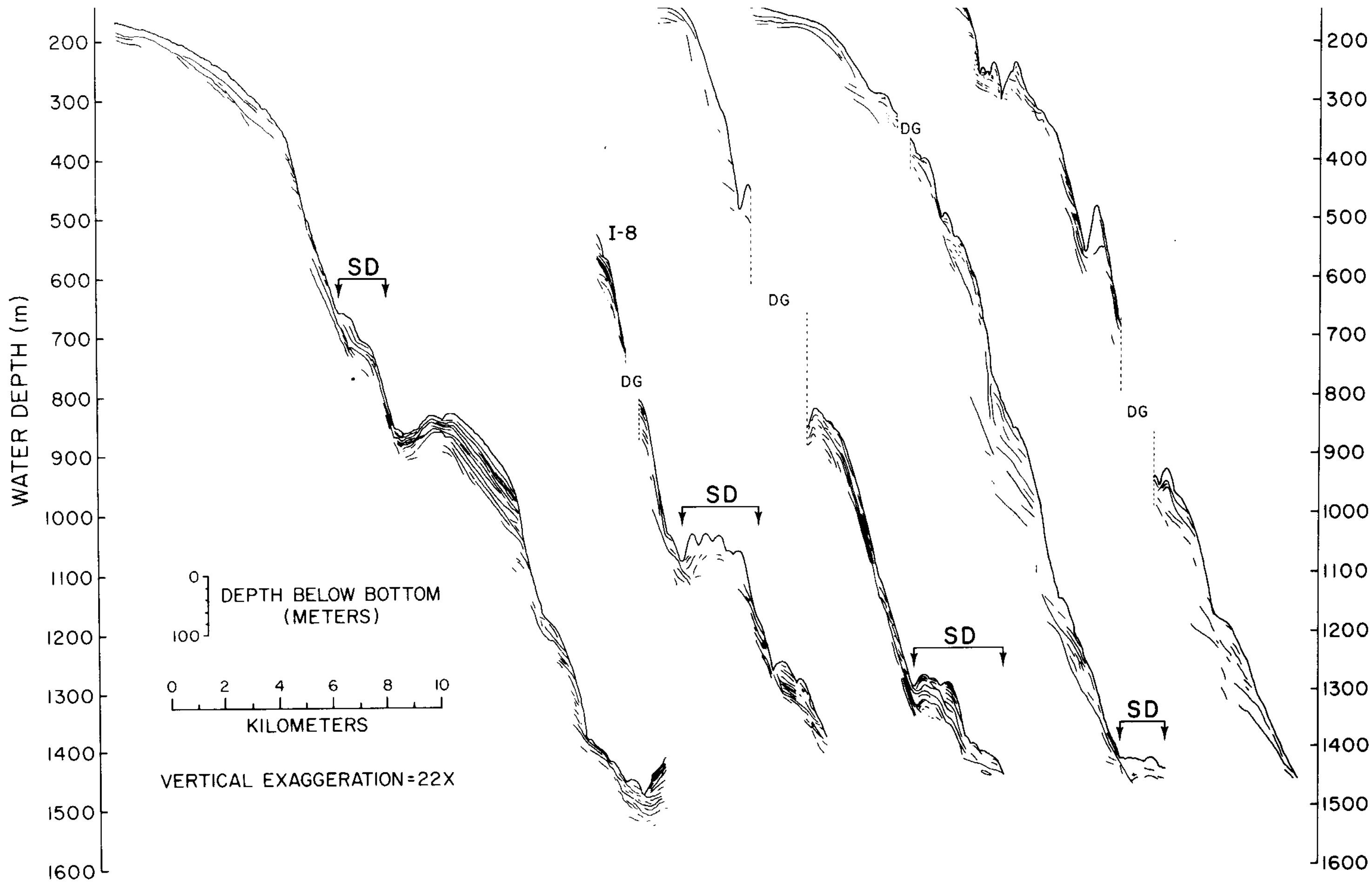

Fig.6. Line drawings of 3.5-kHz seismic-reflection profiles that were obtained in the central part of the Middle Atlantic Bight. Locations of profiles shown in Fig.1. Water- and subbottom-depth scales computed using a sound velocity of 1500 m/sec. *SD* = Slump Deposit.

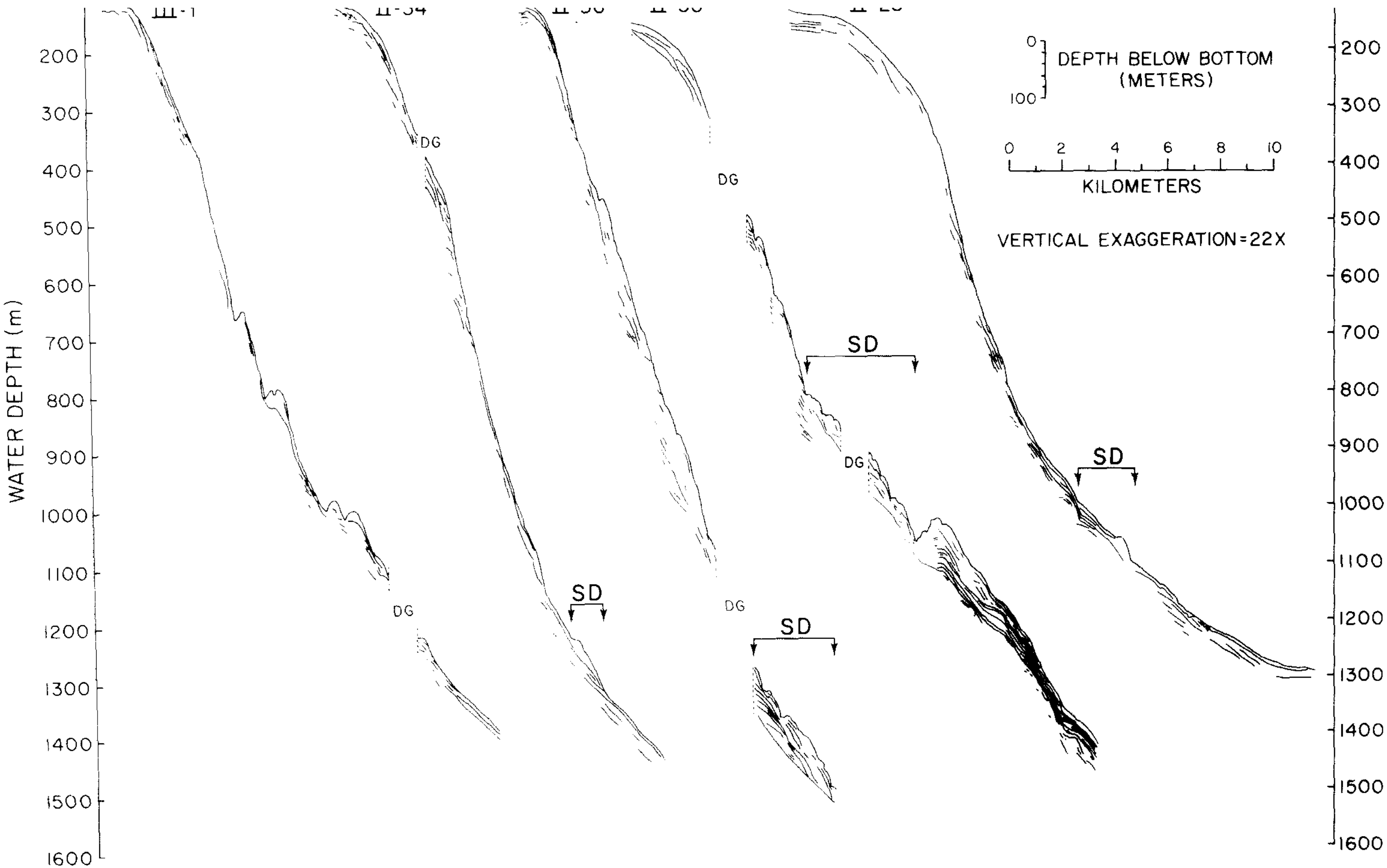

Fig.7. Line drawings of 3.5-kHz seismic-reflection profiles that were obtained in the southern part of the Middle Atlantic Bight. Locations of profiles shown in Fig.1. Water- and subbottom-depth scales computed using a sound velocity of 1500 m/sec. *SD* = Slump Deposit.

Profiles II-10, II-14, Fig.7, Profiles II-30, II-36; Fig.8), to relatively large slump blocks or salients (Fig.5, Profiles III-6, II-14; Fig.6, Profiles III-15, I-8). One profile (Fig.5, Profile III-22) showed small folds within a well-bedded section of sediments that may be indicative of incipient sediment failure. Overall, the slump masses extend downslope for 1.8—7.2 km and involve the upper 10—90 m of sediments (Table I).

Shallow-subbottom reflectors were found to crop out in numerous places. Many of these localities are on the steep parts of the uppermost slope between the shelf break and water depths of about 700 m (Fig.5, Profiles III-6, III-22; Fig.6, Profiles II-18, II-26; Fig.7, Profile II-34); several are upslope of slump deposits. Shallow reflectors also were found to crop out along the sides of many of the gullies that incise the slope in this area (Fig.1; Fig.5, Profiles III-22, II-14, II-16; Fig.6, Profile II-26). The truncation of reflectors at these places may be due to slumping on the relatively steep side walls, although the gullies themselves may be slump scars (Moore, 1961; Moore and Curray, 1963).

DISCUSSION AND IMPLICATIONS

The slump deposits that were found in this study probably are younger than late Pleistocene. The slumped sediments in subarea 2 (Fig.3), for example, are above reflector X that defines a conspicuous unconformity on the Continental Shelf (Knott and Hoskins, 1968; Sheridan and Knebel, 1976). This unconformity represents a low stand of sea level during either Illinoian or Wisconsin time (Ewing et al., 1963; Knott and Hoskins, 1968). Furthermore, the foraminiferal assemblages within cores GC-69 and -70, which presumably sampled the parent stratum of the slump in subarea 2 were found to be typical of the late Pleistocene or Holocene (C.W. Poag, personal communication, 1977).

Other evidence suggests that some slump deposits were formed relatively recently or are active at present. The evidence includes: (1) the lack of sediment accumulations on slip surfaces that are exposed at the sea floor (Fig.5, Profile II-10; Fig.7, Profile II-28; Fig.8); (2) the absence of conformable sedimentary blankets across the irregular surfaces of some deposits (Fig.5, Profiles III-6, II-14; Fig.6, Profiles III-15, I-8; Fig.7, Profiles II-30, II-36); (3) the widespread occurrence of exposed slump scars (truncated shallow reflectors), especially along the uppermost slope (<700 m water depth); and (4) the folds within shallow strata (Fig.5, Profile III-22) that may be indicative of incipient sediment failure. Observations similar to these were made by McGregor and Bennett (1977) during their detailed study of sediment instability on the Continental Slope northeast of Wilmington Canyon. From their observations and also from measurements of the geotechnical properties of core sediments, they concluded that mass wasting appears to be taking place at present. Doyle et al. (1975, 1976) have shown that the intercanyon areas in this region are active depositional sites.

The possible causes of the slump deposits are numerous. Large-scale slumping in or near the study area has been attributed (at least in part) to

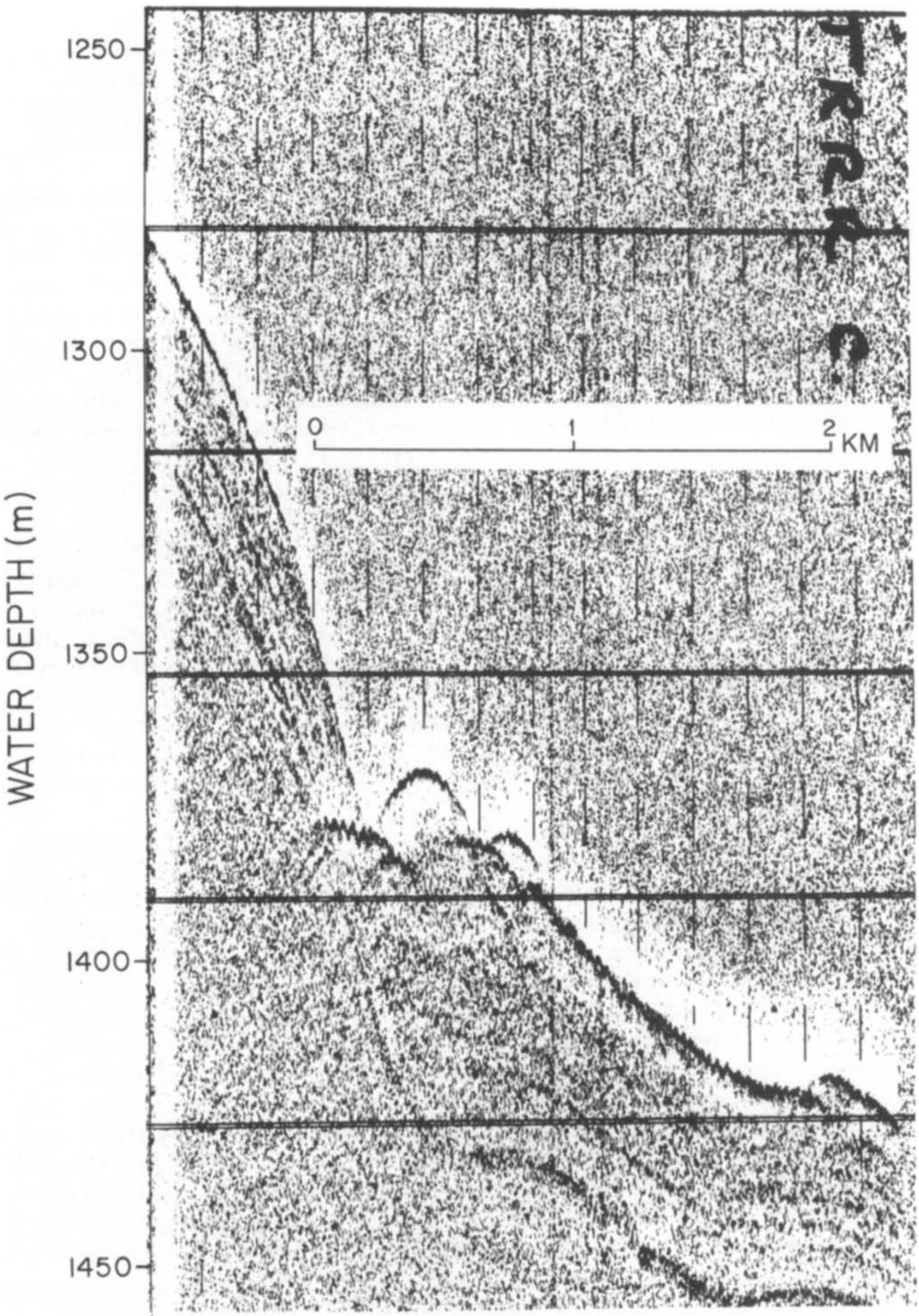

Fig.8. Photograph of original 3.5-kHz record showing the slump deposit at the seaward end of Profile II-10 in Fig.5. Vertical exaggeration is about 23 ×. Water-depth scale computed using a sound velocity of 1500 m/sec.

sediment instability that was produced by rapid deposition on the Continental Slope during Pleistocene sea-level regressions (Uchupi, 1967; MacIlvaine, 1973; Embley and Jacobi, 1977; McGregor and Bennett, 1977). Indeed, the sediments that have failed in subarea 2 (Fig.3) are part of the thick ($\leqslant$112 m) acoustically transparent wedge of clay that lies above reflector X just south of Hudson Canyon. If reflector X represents an Illinoian sea-level low stand (i.e., 100,000—125,000 years B.P.; Knott and Hoskins, 1968), the accumulation rate for this clay could have been about 1.1 m per 1000 years. If, on the other hand, reflector X represents a Wisconsin low stand (i.e., 35,000—40,000 years B.P.; Ewing et al., 1963), then the maximum rate of accumulation may have been as high as 3.2 m per 1000 years. In either case, the deposition of clay above reflector X has been quite rapid. This fact and the homogeneous, fine-grained nature of the deposit suggest that the slump is due, in part, to a metastable accumulation of sediments.

In addition to the rate of sediment supply, changes in the bottom gradient have been suggested as a factor in the formation of slump deposits on the Continental Slope. Haner and Gorsline (1978), for example, in a recent study of the Continental Slope off Santa Monica Bay, found a correlation between the bottom gradient, the rate of sediment supply, and the presence of slump deposits. They found that relatively steep slopes (6—12°) without a supply of sediments were stable, whereas slopes with lesser gradients (<6°) and high sediment-supply rates were subject to mass wasting. In order to discern a similar correlation for the Middle Atlantic Continental Slope, we computed the bottom gradients along the profiles that were obtained during our regional survey (Table I). Although the bottom gradients ranged from 3 to 7° and were generally greater in the southern half of the area, we found no definite relationship between the declivity and either the kind or number of slump deposits.

Two other factors also have been suggested as possible causes of slumping in this area. These are: (1) stress release associated with earthquakes and faults (Uchupi, 1967; McGregor and Bennett, 1977) and (2) increased wave energy to the upper slope during lower stands of sea level (McGregor and Bennett, 1977). The slump in subarea 2 might well be related, in part, to post-Pleistocene faults that have been traced on the adjacent Continental Shelf by Sheridan and Knebel (1976). These faults have a throw of about 1.5 m, displace shelf sediments that probably are coeval with the slumped deposit (Knebel and Spiker, 1977), and are located as close as 13 km to the slump zone (Figs.2, 3).

Other possible causes of the slump deposits include instability due to: (1) gas generation in the sediments; (2) bottom-water movements near the shelf break; and (3) removal of downslope (supportive) sediments. For example, the gas content recently was measured in cores (obtained by drilling) from the upper slope south of Hudson Canyon and near Profile II-14 (Fig.1). Methane concentrations in the Pleistocene silty-clay sediments at this location were very high, ranging from 4755 ppm to as much as 412,000 ppm (Hathaway et al., 1976). Concerning bottom-water movements, Southard

TABLE I

Locations and characteristics of possible slump deposits and average bottom gradients from regional 3.5-kHz profiles, Middle Atlantic Continental Slope

Profile number	Water-depth* range of slump deposit (m)	Observed downslope extent (km)	Observed* thickness (m)	Average gradient along profile (°)	Remarks
II-10	1200-1332	3.5	10	3.1	slip surface apparent
	1382-1451	>3.0	40	3.1	slip surface apparent
III-6	915-1160	7.2	72	3.1	slip surface apparent; slump block
III-22	796-841	1.8	60	3.3	incipient-motion folds
II-14	545-715	4.1	30	3.1	
	772-875	4.6	90	3.1	slip surface apparent; slump block
II-20	1390-1442	>1.8	40	5.7	
III-15	1303-1464	>4.7	70	6.3	slump block?
I-8	1081-1184	4.8	80	5.7	slump block
II-26	659-802	3.4	30	3.8	
II-28	997-1098	3.0	21	3.7	slip surface apparent
II-30	803-1061	7.0	28	4.4	
II-36	1281-1500	>5.7	50	7.0	slip surface apparent
II-34	1231-1332	2.3	18	6.8	acoustically transparent lens

*Sound velocity in the water and shallow sediments is assumed to be 1500 m/sec.

and Stanley (1976) postulate that the shelf edge may be a locus of relatively strong turbulence due to enhanced tidal and atmospheric-pressure-induced currents, to internal waves, and to currents produced at the shear zone between major water masses. When superimposed on other bottom currents (such as wind driven), which are typical of the outer shelf or upper slope environments, these currents may cause sediment to move more frequently and at greater depths than previously imagined. Finally, Profile I-8 (Fig.6) fortuitously crossed the boundary of a large slump scar that recently has been outlined by Embley and Jacobi (1977) just south of Baltimore Canyon. The large slump block depicted in Profile I-8 apparently slid downslope and onto the slide scar after its supporting sediments had been removed.

This study suggests that small-scale slumping in the intercanyon areas may be an important process in transporting sediments to the deep sea in the Middle Atlantic Bight. Altogether, we identified sixteen possible slump deposits in the profiles from the local and regional surveys. Furthermore, these deposits were widely distributed across the slope. We cannot estimate accurately, however, either the lateral extent or the volume of these slumped sediments. The regional profiles could not be used for such estimates because they were widely distributed and displayed limited subbottom penetration. The profiles from our detailed surveys, on the other hand, indicate that some slump deposits may extend laterally for 4—6 km and contain at least 0.4 km^3 of sediments.

Finally, small-scale slumping may constitute a geologic hazard to economic development of this part of the Continental Slope. The study area is just seaward of the Baltimore Canyon Trough (Maher and Applin, 1971; Knebel, 1974) that soon may be leased for oil and gas exploration. If leasing and exploration are extended subsequently to the upper slope, then the possible recency of mass movements of sediments may become important in assessing the stability of structures that may be emplaced on the sea floor in this area.

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