Reports

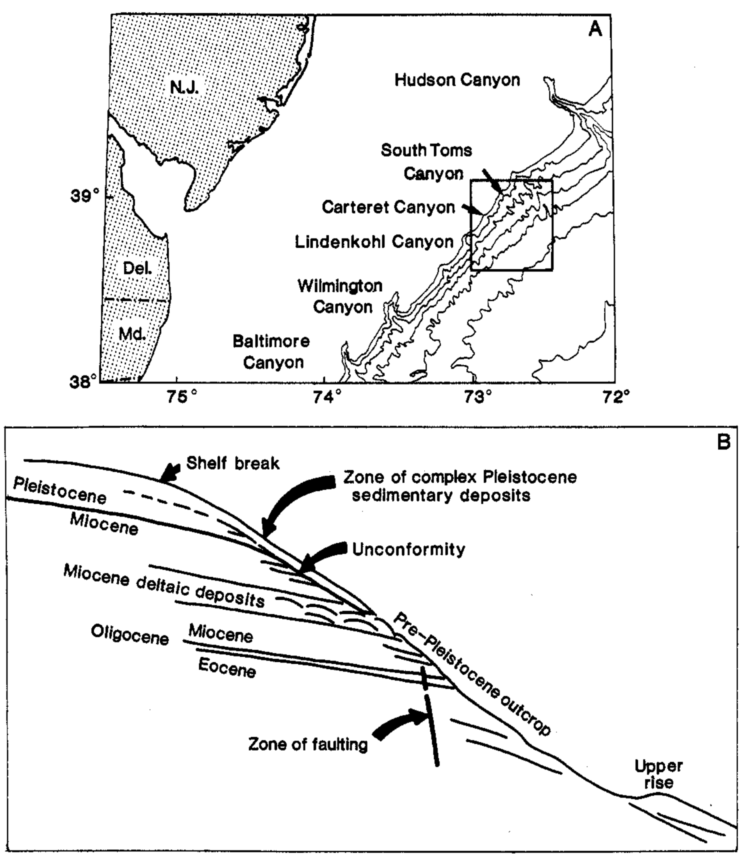
Geomorphology and Sediment Stability of a Segment of the U.S. Continental Slope off New Jersey

Abstract. *The morphology of complex deposits of Pleistocene sediments covering the upper continental slope between Lindenkohl Canyon and South Toms Canyon results from both depositional and erosional processes. Small slump or slide features were detected primarily on the flanks of canyons or valleys and were observed to occur only within Pleistocene-aged sediments. Eocene to Miocene sediments are exposed over much of the mid- and lower slope in this area.*

Slumps, slides, and other features associated with the mass movement of sediment have been reported to occur on the continental slope off the eastern United States (*1*, *2*). If mass sediment movement is an ongoing process on the continental slope, such movement, especially if catastrophic, could present a threat to petroleum exploration and development activities. In an effort to investigate the scale and frequency of slumping and sliding in an area of resource potential, the U.S. Geological Survey (USGS) collected high-resolution, seismic-reflection data (40-inch^3 air gun, 800-J sparker, 3.5-kHz sources) along 2250 km of track lines in a 40 by 35 km segment of the continental slope and upper continental rise between Lindenkohl and South Toms canyons (Fig. 1A). Loran-C was the primary navigation technique for a 900 by 1700 m survey grid. Six wells and 20 piston cores located within the area provide stratigraphic control for the seismic data. Underwater observations on the upper slope (*3*) and long-range side-scan sonar data (*4*) acquired by the USGS along the continental slope between Hudson and Baltimore canyons also were considered in our interpretation of the morphology of the slope.

The surface of the uppermost continental slope between Lindenkohl and South Toms canyons (from the shelf break at a depth of 130 m to a depth of about 400 m) is generally smooth, cut only by the canyons and the largest valleys. However, the upper slope and midslope (400 to 1500 m) have a surface of complex relief, with many small valleys and ridges.

Subbottom profiles between Lindenkohl and South Toms canyons show that the continental slope is underlain by strong, continuous, seaward-dipping reflectors that are truncated below the sea floor by an unconformity. Above the unconformity is stratified material showing less continuous reflections (Fig. 1, B and C). The unconformity surface has relief as great as 120 m. Paleontologic dates from stratigraphic wells and piston cores (*5*, *6*) indicate that this unconformity is probably of Pliocene or early Pleistocene age. A similar unconformity south of this area near Wilmington Canyon was in-



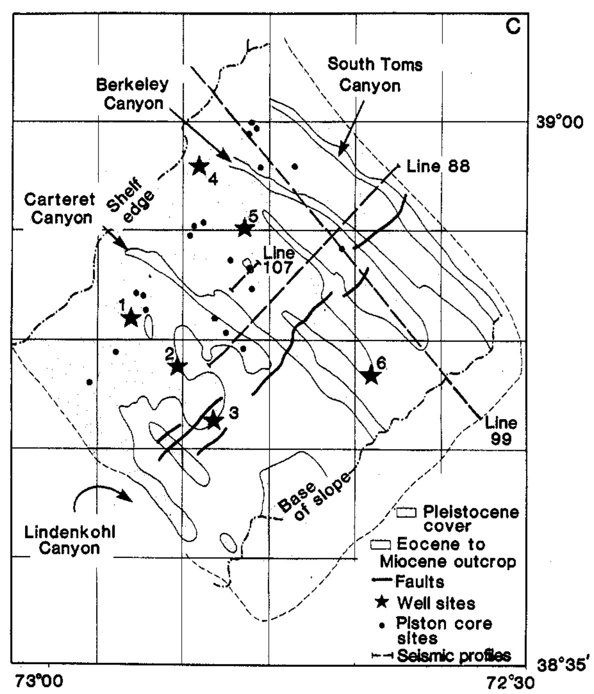


Fig. 1. (A) Location map showing the study area. (B) Generalized cross section of the continental slope in the study area. (C) Map showing areas of Pleistocene cover and Eocene to Miocene outcrop. Mapping is based on a 900 by 1700 m seismic profile grid. Well site locations (*5*) are identified by number: *1*, Atlantic Stratigraphic Project (ASP) 13; *2*, ASP 14; *3*, ASP 15; *4*, Atlantic Margin Coring Project 6021; *5*, Continental Offshore Stratigraphic Testing B-3; and *6*, Deep Sea Drilling Project 108.

0036-8075/81/0227-0935$00.50/0

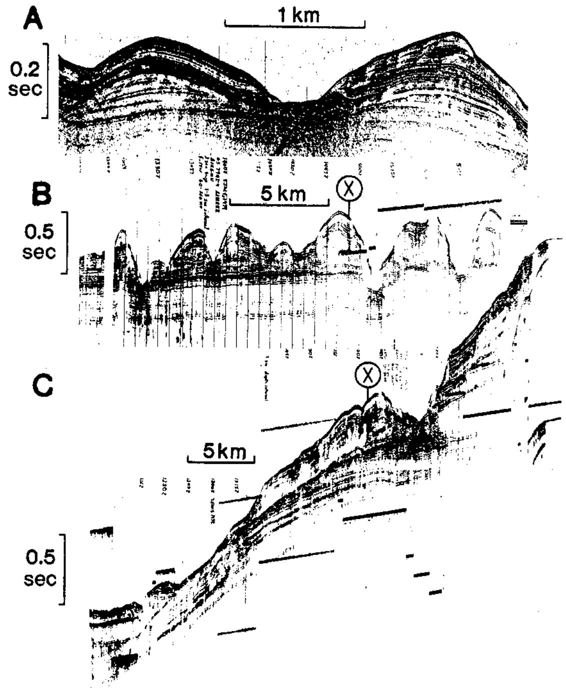


Fig. 2. Photographs of seismic-reflection profiles. Locations are shown on Fig. 1C. See text for discussion. (A) Deep-towed hydrophone profile made with the use of an 800-J sparker sound source along line 107. Vertical exaggeration, 3.6. (B) Air-gun profile along line 88. South is to the left, north to the right; vertical exaggeration, 8.7. Line 99 crosses at X. (C) Air-gun profile along line 99. Shelf break is at the right, uppermost continental rise at the left. Note canyon crossing and Pleistocene materials deposited on the Pliocene(?) erosional unconformity (see text). Vertical exaggeration, 13.7. Line 88 (B) crosses at X.

ferred to be Pliocene by McGregor and Bennett (*2*). A delta-front sequence of channeled and cross-bedded sediments exists within the mid-Miocene (*5*) that should not be confused in seismic outcrop with slump or slide deposits (Fig. 1B) A zone of faulting is observed within the Tertiary sediments of the lower slope that does not appear to extend through the Pliocene(?) unconformity.

Piston cores (*6*), underwater observations (*3*), and 3.5-kHz profile data indicate that fine-grained Holocene sediments occur as a thin surface layer, generally less than 2 m thick. Topographic features that are mappable at the scale of this study are composed of Pleistocene sediments having a thin Holocene cover.

The Pleistocene sediments cover the continental slope as a seaward-thinning wedge, distributed on the midslope as fingerlike ridges trending downslope, separated by outcrops of Eocene to Miocene sediments (Fig. 1C) in canyon or valley bottoms. Most of the Pleistocene sediments are silts and clays having relatively little structure in cores (*6, 7*). Foraminiferal assemblages in piston cores (penetration, 8 m or less) from these upper slope deposits are Pleistocene shelf faunas or mixed shelf and slope faunas (*6*). We have not as yet discerned a pattern in the distribution of the few sandy layers we have detected. The thickness of the Pleistocene sediments ranges from about 450 m at the top of the slope to zero or very thin over large areas of the lower slope. The limit of resolution of our identification of Pleistocene surface material from seismic data [limited by identification of the Pliocene(?) unconformity] is probably about 15 m.

Erosion and the removal of material from valley and canyon axes have taken place particularly on the upper slope where truncated strata underlie the thin Holocene cover. On the mid- and lower slope the ridges appear to be primarily constructional features, although they have complex internal structures including mid-Pleistocene(?) unconformities and cuts and fills. The cores of these ridges are of pre-Pleistocene age on the midslope but appear to be largely Pleistocene on the lower slope where the pre-Pleistocene uncomformity is more planar. Figure 2A, part of a profile taken with a deep-towed hydrophone for better resolution than surface-towed instruments achieve, shows undisturbed beds of Pleistocene material draped over the Pliocene(?) unconformity on two downslope-trending ridges separated by a flat-floored valley. Truncations of reflectors at the base of the valley walls show the apparent removal of about 30 m of material from the valley axis. Figure 2B shows a conventional air-gun profile located farther downslope. Here these ridges have cores of pre-Pleistocene age, but the degree of depositional downlapping in contrast to erosional truncation on the ridge flanks is less clearly shown.

Detailed studies of the continental slope are hampered by the lack of accurate, large-scale bathymetric maps. The complex morphology, with valleys of various trends, and the unconformities having overlying sedimentation can easily create the appearance of allochthonous masses emplaced on the continental slope, if the surface is viewed in two-dimensional cross section on isolated seismic profiles (for example, Fig. 2C). Flanks of valleys crossed by a seismic profile can be confused with scars or heads of slumps. Cut and fill structures, undecipherable from slump or slide deposits on single profiles, are common in the slope deposits of Miocene and younger age (Fig. 2C; upslope wall of canyon shows truncated fill). It is essential to map the three-dimensional geometry of the slope surface and subsurface to understand the complexities of its structures.

Slumped blocks and scars forming nearly vertical walls have been reported from underwater observations in a number of submarine canyons along the east coast of the United States (*8*). In our study area, features appearing to be slump or slide deposits are identified from seismic profiles in a few places on the side slopes of valleys and canyons. Small features attributable to slumping (scarps and blocks 1 to 2 m high) were observed from a research submersible in the head of Carteret Canyon (*3*) at water depths of about 300 m. One probable deposit of failed material identified on our seismic profiles occupies about 5 km^2 on the side of Berkeley Canyon. Samples from Deep Sea Drilling Project (DSDP) site 108 (Fig. 1C) were identified as "displaced Pleistocene," containing sublittoral foraminifera (*9*). If the accumulation of material at the base of the continental slope, on the uppermost continental rise (Fig. 1B), results from mass-wasting processes, it probably originated from the canyon head areas of the upper slope and from canyon axes. Alternatively, it may represent the deposition of sediment that bypassed the slope. Because the present-day submarine landforms are composed largely of Pleistocene or pre-Pleistocene deposits conformable with sea-floor topography (particularly on the mid- and lower slope) and are covered by thin Holocene sediments (particularly on the upper slope), we infer that present processes of landscape modification are minimal. Although uncertainties remain to be resolved, a hypothetical explanation of the formation of the slope surface is that during periods of lowered sea level before and during the Pleistocene large volumes of fine-grained material were transported to the edge of the continental shelf and deposited on the upper continental slope over the Pliocene(?) erosional surface. Turbidity currents localized by bathymetric and oceanographic conditions swept channel areas clean and, in part, eroded them. We suggest that the ridges flanking valleys and canyons on the mid- and lower slope were probably formed by the overbank deposition of material being transported downslope. Although the ridges do not conform to the classical model of levees, thinning away from primary channels on deep-sea fans (*10*), deposition from closely spaced valleys on the continental slope would not have allowed complete development to occur. Slumping played a greater role among processes extending and eroding canyons in the late Pleistocene than it does now. As the sea reached present levels, deposition slowed, conditions became more stable, and Holocene deposition took place at low rates, mantling the Pleistocene deposits with a thin veneer of fine-grained sediment.

On the basis of our study of closely spaced seismic-reflection profiles, we conclude that the continental slope between Lindenkohl and South Toms canyons has a complex surface formed largely by Pleistocene-aged deposits of variable thickness and complex structure. Tertiary sediments crop out on large areas of the lower slope. Slumping may have been an important process extending submarine canyons and valleys during the Pleistocene and perhaps early Holocene, but it appears to be less active currently. Small slump features are present in the heads and in places along the flanks of canyons or valleys, but the present subaqueous landscape in this area is primarily relict, and present-day landscape modification appears to be active only at low rates. Where identified, slumping occurs within deposits of Quaternary age. Tertiary sediments are flat-lying and undisturbed and show no evidence of slumps or slides. We should emphasize that mapping and geotechnical testing is necessary to determine the potential hazard of any specific area intended for exploitation. Our findings should be applied with prudence, and extrapolation to other areas is open to question.

JAMES M. ROBB
JOHN C. HAMPSON, JR.
DAVID C. TWICHELL
U.S. Geological Survey, Woods Hole, Massachusetts 02543

References and Notes

1. E. Uchupi, *Deep-Sea Res.* **14**, 635 (1967); J. C. McIlvaine and D. A. Ross, *J. Sediment. Petrol.* **49**, 563 (1979); R. W. Embley and R. Jacobi, *Mar. Geotechnol.* **2**, 205 (1977); H. J. Knebel and B. Carson, *Mar. Geol.* **29**, 221 (1979); G. H. Keller *et al.*, in *Geology of Continental Slopes*, L. J. Doyle and O. H. Pilkey, Eds. (Special Publication 27, Society of Economic Paleontologists and Mineralogists, Tulsa, 1979), p. 131.
2. B. A. McGregor and R. H. Bennett, *Mar. Geol.* **33**, 163 (1979).
3. R. A. Slater and D. C. Twichell, dives in the submersible *Diaphus*, August 1978 (personal communication).
4. M. L. Somers, R. M. Carson, J. A. Revie, R. H. Edge, B. J. Barrow, A. G. Andrews, in *Oceanology International 78* (1978), Technical Session J, p. 16.
5. C. W. Poag, *Bull. Am. Assoc. Pet. Geol.* **63**, 1452 (1979).
6. C. W. Poag, personal communication (1979); USGS piston cores taken August and September 1979.
7. J. C. Hathaway, C. W. Poag, P. C. Valentine, R. E. Miller, D. M. Schultz, F. T. Manheim, F. A. Kohout, M. H. Bothner, D. A. Sangrey, *Science* **206**, 515 (1979); L. J. Doyle, O. H. Pilkey, C. C. Woo, in *Geology of Continental Slopes*, L. J. Doyle and O. H. Pilkey, Eds. (Special Publication 27, Society of Economic Paleontologists and Mineralogists, Tulsa, Okla., 1979), pp. 119–129.
8. R. A. Slater, D. C. Twichell, C. V. G. Phipps, J. A. Aaron, *Bull. Am. Assoc. Pet. Geol.* **63**, 529 (1979); W. P. Dillon and H. B. Zimmerman, *J. Sediment. Petrol.* **40**, 524 (1970); W. B. F. Ryan, M. B. Cita, E. L. Miller, D. Hanselman, W. D. Nesteroff, B. Hecker, M. Nibbelink, *Oceanol. Acta* **1**, 233 (1978).
9. C. D. Hollister *et al.*, *Init. Rep. Deep Sea Drill. Proj.* **11**, 351 (1972).
10. H. W. Menard, Jr., *Bull. Am. Assoc. Pet. Geol.* **39**, 236 (1955); W. R. Normark, in *Modern and Ancient Geosynclinal Sedimentation*, R. H. Dott, Jr., and R. H. Shaver, Eds. (Special Publication 19, Society of Economic Paleontologists and Mineralogists, Tulsa, Okla., 1974), pp. 56–68.
11. Funding for this project was provided by the Bureau of Land Management under Memoranda of Understanding AA551-MU8-21 and AA551-MU9-4 between the USGS and the Bureau of Land Management. The seismic profiles were collected aboard R.V. *Iselin* in 1978 and R.V. *Gillis* in 1979. We thank W. P. Dillon, J. S. Booth, H. J. Knebel, C. W. Poag, and B. McGregor-Stubblefield who read the manuscript and made valuable suggestions. Responsibility for the interpretations remains with the authors.

8 May 1980; revised 7 November 1980

Azidoatrazine: Photoaffinity Label for the Site of Triazine Herbicide Action in Chloroplasts

Abstract. *Binding of the 4-azido analog of the herbicide atrazine to pea chloroplast membranes was compared with that of atrazine. When [^{14}C]azidoatrazine was treated with 300-nanometer ultraviolet light in situ, reversibility of binding was lost in proportion to the duration of irradiation. Sodium dodecyl sulfate-polyacrylamide gel electrophoresis of chloroplast membranes irradiated in the presence of [^{14}C]-azidoatrazine indicated radioactivity in only one region, corresponding to a protein with a molecular weight of approximately 32,000. Azidoatrazine is a photoaffinity reagent for the triazine binding site in chloroplasts and serves as a label to identify this site, which may be the apoprotein of the secondary electron acceptor in photosystem II.*

Many commercial herbicides act as photosynthetic inhibitors. Some of them, including the chemical groups of ureas, amides, triazines, triazinones, pyridazinones, carbamates, and nitrophenols block photosystem II–dependent Hill reactions. These compounds appear to act at the second electron carrier on the reducing side of photosystem II (*1*). This carrier, called B, is presumed to be a quinone molecule that is bound to a specific polypeptide in the reaction center complex. The carrier, B, is reduced by electrons from the primary electron acceptor, Q, and, in turn, donates electrons to the plastoquinone pool that connects photosystems II and I. In herbicide-inhibited chloroplasts, Q is functional as an electron carrier, but B is no longer active as a functional electron acceptor.

The identity of the apoprotein of B is not known. Binding to chloroplasts of radioactively labeled herbicides, especially atrazine and diuron, has been studied (*2, 3*). This binding is reversible, and all photosystem II inhibitors appear to compete for the same site. The binding affinity of herbicides for this site is closely correlated with inhibition of photosystem II. These results, together with comparisons of chloroplasts from triazine-resistant and triazine-susceptible biotypes of the same species, indicate that the herbicide binding site is probably the apoprotein of B (*1*).

Photoaffinity labeling is a method by which the herbicide binding site may be specifically identified. This technique has recently become important for identifying complex biological receptors (*4*). A photolabile reagent is anchored to the macromolecule; photolysis of the complex then leads to the generation of a highly reactive species that, by reacting rapidly with its immediate environment, covalently labels the macromolecule or specifically labels the active site.

I now report that a photolabile azido analog of the herbicide atrazine competes with atrazine at the herbicide binding site in pea chloroplasts and serves as a photoaffinity label for that site. Alaska peas (*Pisum sativum* L. cultivar Alaska; Burpee) were grown on vermiculite for 7 to 8 days under Cool White fluorescent lights during an 11:13 light-dark photoperiod. Chloroplasts were prepared and chlorophyll was determined (*3*). Azidoatrazine (4-azido-2-isopropylamino-6-ethylamino-*s*-triazine) was synthesized from atrazine (4-chloro-2-isopropyl-

0036-8075/81/0227-0937$01.00/0