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GEOLOGICAL SURVEY PROFESSIONAL PAPER 581-A

Prepared in cooperation with the Woods Hole Oceanographic Institution and the Joint Oceanographic Institutions' Deep Earth Sampling program

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By K. O. EMERY *and* E. F. K. ZARUDZKI

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A study of the relation of continuous seismic reflection profiles across the continental shelf, the Florida-Hatteras Slope, and the Blake Plateau with the stratigraphy of JOIDES drill-hole samples

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DRILLING
ON THE CONTINENTAL MARGIN
OFF FLORIDA

Drilling on the continental margin off Jacksonville, Fla. in 1965 was the first project undertaken by the Joint Oceanographic Institutions' Deep Earth Sampling (JOIDES) program, sponsored by the National Science Foundation. The U.S. Geological Survey cooperated with the Oceanographic Institutions in this undertaking and is publishing the results of these investigations in a series of professional papers. Professional Paper 581–A is the first of this series.

FOREWORD

For more than a hundred years geologists have speculated about the origin of continental margins on the basis of soundings, dredgings, and corings. These data are derived mainly from the surface of the sea floor, but they permit some extrapolation below the sea floor, particularly along the inferred dip of the strata. About 30 years ago these limited sources of information about the subbottom began to be greatly supplemented by geophysical measurements of sound velocity, magnetism, and gravity. As such measurements are controlled by the composition of deep subsurface materials, they provide indirect information about materials far deeper than can be inferred from surface geology.

The combination of surface geology and subsurface geophysics has helped solve early questions about the composition of the continental margin, but it also raised other questions. In particular, the indirect nature of the geophysical data is a possible source of interpretational error of what materials produce the observed sound velocities, magnetism, and gravity. Direct tests of the interpretations can come only from actual samples of the sediments and rocks that lie deep below the sea floor. The only practicable method of obtaining such samples is by drilling. Oil wells have been drilled on the sea floor for about seventy years but only in water depths of a few tens of meters until about 10 years ago. During 1961 several test wells were drilled at depths of about 3,500 meters (The Experimental Mohole off the west coast of Mexico), but the operation was fairly expensive.

Recognizing the questions of high cost and limited availability of scientific talent, four oceanographic institutions (Lamont Geological Observatory, University of Miami, Scripps Institution of Oceanography, and Woods Hole Oceanographic Institution) formed an association to drill the continental margin and possibly later to drill the deep-sea floor. This association is known as the JOIDES (Joint Oceanographic Institutions' Deep Earth Sampling) program. Its "Memorandum of Agreement" was approved by the directors of each institution on May 10, 1964, after several years of discussion and planning. Consideration of general areas for the first drilling project led to the final choice of an area off Jacksonville, Fla. This choice was based on many factors, such as the availability of a considerable amount of background information for the sea floor accumulated by both Woods Hole Oceanographic Institution and Lamont Geological Observatory and for the adjacent land area compiled largely by the U.S. Geological Survey. Availability of port facilities and the position of the area along the track of a drilling vessel en route to a commercial job also played important roles in the selection.

The wide region off Jacksonville within the depth range of the drilling equipment contained significant geological problems capable of solution by the samples from a half dozen drill holes in the sea floor. The main geological problem was that of the relation of the Blake Plateau to the continental shelf. Does the position of the Blake Plateau, about 600 meters below the level of the shelf, mean that it was down faulted or down folded? If the plateau were once continuous with the shelf, when did the separation occur? What is the composition and depth of deposition of the strata underlying both plateau and shelf? Are the strata of the shelf direct continuations of those that had been found in outcrops and wells on land?

A proposal to National Science Foundation for funds to conduct the drilling program led to the awarding of Grant GP4233 to Lamont Geological Observatory as the operating institution for JOIDES. J. L. Worzel acted as principal investigator, and C. L. Drake and H. A. Gibbon (both also of Lamont Geological Observatory) were program planners. The mutual interests of the several institutions and of the U.S. Geological Survey produced a mixed group of scientists aboard the drilling ship: from Lamont Geological Observatory, R. D. Gerard (project supervisor and chief scientist), Tsunemasa Saito (micropaleontologist), and Mark Salkind (drilling aide); from the Woods Hole Oceanographic Institution or the U.S. Geological Survey based at Woods Hole, John Schlee (principal scientist, U.S. Geol. Survey), J. R. Frothingham, Jr. (laboratory assistant), F. T. Manheim (geochemist, U.S. Geol. Survey), K. O. Emery (marine geologist); from the University of Miami, Louis Lidz (micropaleontologist), W. B. Charm and Herman Hofmann (core curators); and from the U.S. Geological Survey, R. L. Wait and G. W. Leve (hydrologists) and E. M. Shuter (geophysicist). Valuable aid was provided by William Bogert (drilling advisor) from Pan American Petroleum Corp., and by the drillers and crew of MV *Caldrill I*.

Holes were drilled between April 18 and May 16, 1965, at six locations. Water depths ranged from 25 to 1,032 meters, and the drill penetrated 120–320 meters into the sea bottom. Only sedimentary strata were found, and these ranged from Recent to Paleocene, a span of about 60 million years.

Many laboratory investigations of the drill samples are being made at the four original JOIDES institutions, at the U.S. Geological Survey laboratories, and at other laboratories and institutions. The investigations include studies of the stratigraphy, micropaleontology, mineralogy, chemical composition, organic materials, interstitial waters, hydrology, and the relation of the strata to continuous seismic profiles. Technical discussions of these studies form the series of chapters that comprise this professional paper.

This first JOIDES project has already led to the initiation of a second and much larger one that is directed toward learning more about the geological composition, history, and origin of the deep-sea floor in both the Pacific and Atlantic Oceans. Doubtlessly, many old problems will be settled, but the drill results will raise new ones. Solution of these new problems and of old geological questions in other regions probably will result in a more common use of deep-water drilling as an oceanographic method in the future.

MAURICE EWING, PAUL M. FYE, ROGER REVELLE, and F. G. WALTON SMITH

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SEISMIC REFLECTION PROFILES ALONG THE DRILL HOLES ON THE CONTINENTAL MARGIN OFF FLORIDA [1]

By K. O. EMERY and E. F. K. ZARUDZKI

Abstract

Continuous seismic reflection profiles along the line of JOIDES drill holes were adjusted for the velocity of sound at depth, as measured in one of the drill holes and determined at nearby seismic refraction stations. The adjusted reflecting horizons agree in many respects with the stratigraphic section which includes strata of Miocene, Oligocene, Eocene, and Paleocene age, as indicated by samples from the drill holes. The reflection profiles provide continuity of data between the drill holes and extend to much greater depths than the drill; thus they supplement and amplify information derived from the drill samples. Both kinds of data show that the continental shelf is underlain by a Tertiary sequence that has prograded seaward so that the foreset beds form the past and present Florida-Hatteras Slope. No evidence of faulting at the Florida-Hatteras Slope is exhibited by the reflecting horizons. A shallow ridge (or anticline), probably of Cretaceous strata, may underlie the middle part of the continental shelf.

The seismic profile between two drill holes on the Blake Plateau contains reflecting horizons that correspond fairly well to the tops of Oligocene and Paleocene strata that were sampled by the drill. These strata continue beyond the plateau, and they partly mantle the Blake Escarpment. Deeper reflecting horizons lie within the Cretaceous sequence, and some may even be older than Cretaceous; they are truncated by the Tertiary beds that mantle the Blake Escarpment.

INTRODUCTION

Speculation about the stratigraphy and structure of continental margins of the world has increased steadily since about 1930, although occasional recoveries of rock samples by fishermen had provided intermittent interest even during the 19th century. Systematic sampling of sediments and dredging of outcrops off the Atlantic coast was initiated by Shepard, Trefethen, and Cohee (1934) and Stetson (1949). Limitations were imposed by the scarcity of outcrops and the inaccessibility to dredges of bedrock covered by even thin overburden of recent sediments. These limitations were overcome by the adaption of seismic refraction techniques to the marine environment by Ewing, Crary, and Rutherford (1937). The refraction method yielded depths and sound velocities of individual acoustic impedance boundaries as deep as 10 kilometers below the sea floor. Inferences about rock types and their structural attitudes have been drawn from these measurements, but this method is a coarse one because it rarely is able to distinguish layers and structures thinner than several hundred meters.

Seismic reflection techniques developed for oil exploration on land can depict finer detail than can those of refraction. Variations of reflection techniques were adapted to marine use by Ewing and Tirey (1961), Hersey (1963), and others, and they have been used extensively off the Atlantic coast to reveal stratification in the top few tens, few hundreds, or few thousands of meters, according to the design of particular pieces of equipment. A serious limitation of all seismic reflection profilers is their inability to include a direct measurement of the velocity of sound that is needed to convert lapsed traveltime between signal and echo into a depth scale expressed in units of thickness. Indirect velocity-measuring techniques used in reflection profiling on land have rarely been applied to marine profiling. Thus, true depths could be computed only where the profiles passed near refraction stations or where they extended near a well that had been drilled ashore or in shallow water and for which the stratigraphy and the vertical sound velocity function were established.

About 1890, long before the development of seismic surveying, wells were drilled in shallow parts of the sea floor for petroleum and for stratigraphic information. The first deep-water holes were those of the Experimental Mohole drilled in 1961 (National Research Council, AMSOC Committee, 1961). Interest in the results led to the organization of JOIDES (Joint Oceanographic Institutions' Deep Earth Sampling) in 1964 and to the drilling of six holes off northern Florida between April 18 and May 16, 1965, to secure more direct and precise knowledge of the stratigraphy and structure of this

[1] Contribution No. 1699 of the Woods Hole Oceanographic Institution.

part of the continental margin (fig. 1) than is provided by seismic methods alone. Two of the holes were in the continental shelf, three in the Blake Plateau at water depths as great as 1,032 meters, and one was near the top of the Florida-Hatteras Slope, which separates the shelf from the plateau (Joint Oceanographic Institutions' Deep Earth Sampling Program, 1965).

ACKNOWLEDGMENTS

The continuous seismic reflection profiles described in this report are the results of several different programs at Woods Hole Oceanographic Institution. Two profiles were made aboard R/V *Chain* during cruises 46 (by E. T. Bunce and S. T. Knott) and 51 (by Zarudzki), both supported by Office of Naval Research contract Nonr 4029. Another was obtained by Elazar Uchupi and A. R. Tagg as part of a general study of the structure of the Atlantic continental margin supported by the U.S. Geological Survey. Both authors are indebted to their associates for aid in watch-standing and in reduction of the field data. They also thank the National Science Foundation for its grant GP4233 to Lamont Geological Observatory on behalf of JOIDES to finance the drilling of the six off-shore holes.

REFLECTION PROFILES

Two continuous seismic reflection profiles cross the continental shelf and the Florida-Hatteras Slope along the line of JOIDES drill holes 1, 2, 5, and 6. The first profile was made by E. T. Bunce and S. T. Knott (in Joint Oceanographic Institutions' Deep Earth Sampling Program, 1965) during April 4–5, 1965, prior to JOIDES drilling, using a 100,000-joule sparker aboard R/V *Chain*; it is a composite profile based on one passage along the western half and two along the eastern half of the route (fig. 2). The second profile (Uchupi and Emery, 1967), made during June 17–18, 1965, after completion of the drilling, extends somewhat farther east and west to the vicinity of both holes 1 and 6 (fig. 2); it was obtained with a 10,500-joule sparker aboard R/V *Gosnold*. The separately made interpretations are similar in exhibiting (1) nearly horizontal reflectors in the sediments beneath the continental shelf that were penetrated in the first 0.1 second, (2) irregular reflectors at greater depth, some of them indicating unconformable strata, and (3) a general steepening of reflectors below the outer part of the shelf to parallel the Florida-Hatteras Slope. Differences between the profiles are minor and attributable to methods of interpretation and to several kilometers separation between the profiles, particularly at the Florida-Hatteras Slope. The second and longer profile reveals nearly horizontal reflectors beneath the Blake Plateau, some of which are continuous with ones shown in both profiles beneath the base of the Florida-Hatteras Slope.

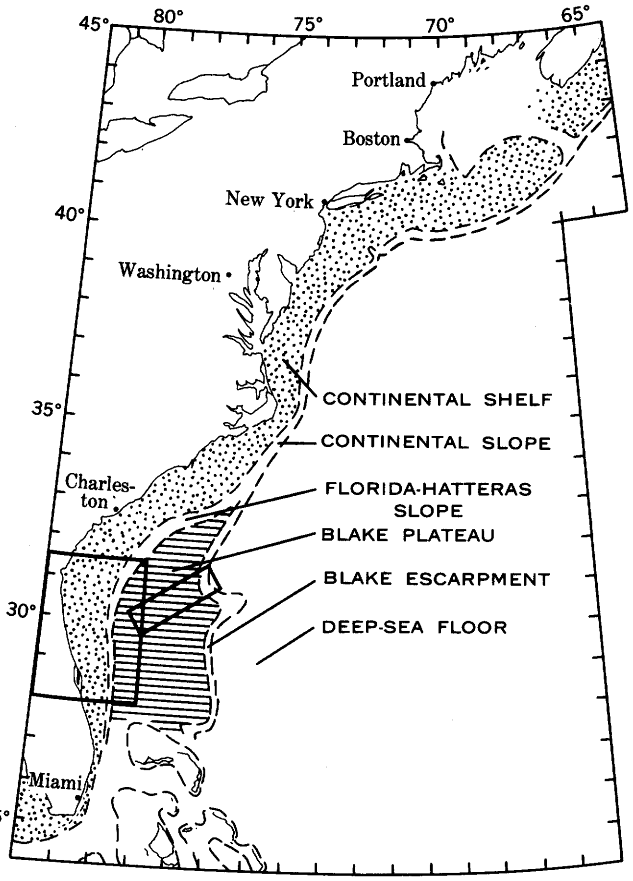

FIGURE 1.—General index map. Rectangles depict areas shown by figure 2 (left) and 3 (right).

A third continuous seismic profile (fig. 3) was made during August 28–29, 1965, by Zarudzki across the Blake Plateau from JOIDES holes 6 through 4 and farther eastward across the Blake Escarpment; a 100,000-joule sparker aboard R/V *Chain* was used. The profile joins the east end of the one by Uchupi and Emery (fig. 2); and the reflecting horizons match well, considering that interpretations were made separately and by different people. The results show (1) subhorizontal reflectors at shallow depth, the shallowest ones exhibiting irregularities attributed to erosion, (2) gently arched reflectors at depth, and (3) a steepening of shallow reflectors at the seaward edge of the Blake Plateau to parallel the Blake Escarpment and to cover the ends of truncated deeper reflectors.

SOUND VELOCITIES

Measurements were made by R. D. Gerard (in Joint Oceanographic Institutions' Deep Earth Sampling Program, 1965), W. B. Bogert, and H. A. Gibbons (unpub.

data) of the time required for sound to travel from small charges exploded at the ocean surface to a geophone placed at successively different depths in the uncased part of JOIDES hole 2b (same position as hole 2). These data indicate a sound velocity of 1.64 km per sec (kilometers per second) between 75 and 150 m below the sea floor and of 1.95 km per sec at depths between 150 and 238 m (fig. 4). Collapse of the hole prevented measurements at greater depths. The change of velocity at 150 m occurs near the Oligocene-upper Eocene boundary that separates silts and clays above from limestone below. Even though the velocities obtained by refraction measurements are somewhat lower than the inhole measurements at depth, they constitute the best available basis for estimating the true depths of seismic reflecting horizons deeper than the JOIDES holes.

Seismic velocities for depths greater than 192 m beneath the continental shelf and for all depths beneath the Blake Plateau are available only from refraction surveys. Plots of the velocities from 112 published refraction stations throughout the entire continental shelf between Cape Cod and Cape Kennedy revealed a wide range of values, from 1.6 to 3.7 km per sec at 0.5 km depth (Drake and others, 1959; Hersey and others, 1959; Antoine and Henry, 1965). Ten refraction stations within 75 km of the drill-hole sites were segregated for special attention. Seismic velocities and layer thicknesses at these stations are plotted on figure 4 (left) as a mass of superimposed lines. The velocities are clearly greater at all depths than are those from parts of the shelf that are farther north, as indicated by L symbols on figure 4. A mean velocity-depth relation was assumed for the entire width of the continental shelf crossed by the JOIDES drill holes. The velocity from depths of 0 to 192 m was taken from measurements in hole 2b. A large increase, to 3.0 km per sec, was assumed from refraction stations to begin at 300 m and extend to at least 1,000 m depth.

Velocities given for the Blake Plateau are taken entirely from refraction surveys of Hersey, Bunce, Wyrick, and Dietz (1959). Only three stations in the area of figure 3 contain actual measurements for near-surface layers, according to the traveltime plots. These plots yield a general velocity of 1.75 km per sec for all depths between 0 and about 650 m. At other stations on the Blake Plateau, a velocity of 1.83 km per sec is listed as most probable, but it is not supported by time-distance plots. For depths greater than 650 m the plots indicate that 3.85 km per sec is a reasonable average velocity.

VELOCITY CORRECTION OF REFLECTION PROFILES

METHODS

Depths of the reflecting horizons of continuous seismic reflecting profiles shown by figures 2 and 3 were adjusted to true depths through use of the velocities indicated by the wide lines of figure 4. For the shelf, the reflectors shallower than 0.091-second traveltime (150 m $\div$1,640 m per sec) were plotted at 1.64 km per sec; those between 0.091 and 0.136 second were plotted at 1.95 km per sec; and those deeper than 0.136 second were plotted at 3.00 km per sec. For the base of the Florida-Hatteras Slope, the Blake Plateau, and the Blake Escarpment, the reflectors shallower than a prominent widespread reflector at about 0.4-second traveltime below the sea floor were plotted at 1.75 km per sec and deeper reflectors at 3.85 km per sec. Circumstantial evidence of the general correctness of the 1.75 km per sec velocity used for the top 650 m of the Blake Plateau is provided by the nearly horizontal and straight character of the deepest reflector that is cut by the swale at the base of the Florida-Hatteras Slope (fig. 2). At the swale an assumed velocity of 1.50 km per sec causes the deepest reflector to bend downward and one of 2.00 km per sec causes it to bend upward. Further discussion of this general technique was given by Roberson (1964).

CONTINENTAL SHELF AND FLORIDA-HATTERAS SLOPE

When the stratigraphic units found in the drill holes are superimposed on the adjusted reflection cross section (figs. 2 and 3, bottom), the tops of some of them approximately correspond to reflecting horizons. The most reasonable correlation between stratigraphic age and reflecting horizon is exhibited by the base of the post-Miocene (probably mostly Quaternary) sediments. The top of the Oligocene beds corresponds fairly well to another discontinuous reflecting horizon. The top of the Eocene sequence may be identified with a third reflecting horizon, but this horizon is so discontinuous that it may not be the same one at each drill site. There is also considerable uncertainty whether or not this horizon is overlain by Quaternary or Oligocene sediments where it steepens at the Florida-Hatteras Slope (fig. 2, bottom).

Correlations of reflecting horizons with the top of the Paleocene strata and the top of the Cretaceous sequence are less direct, as they are based on long-range comparison with wells on shore, on Paleocene samples from JOIDES hole 6, and on moderately high refraction velocities between JOIDES holes 1 and 2, with an arched but poorly defined reflecting horizon in the same area. The arched reflecting horizon between JOIDES holes 1 and 2 suggests the presence of a pronounced shallow ridge or

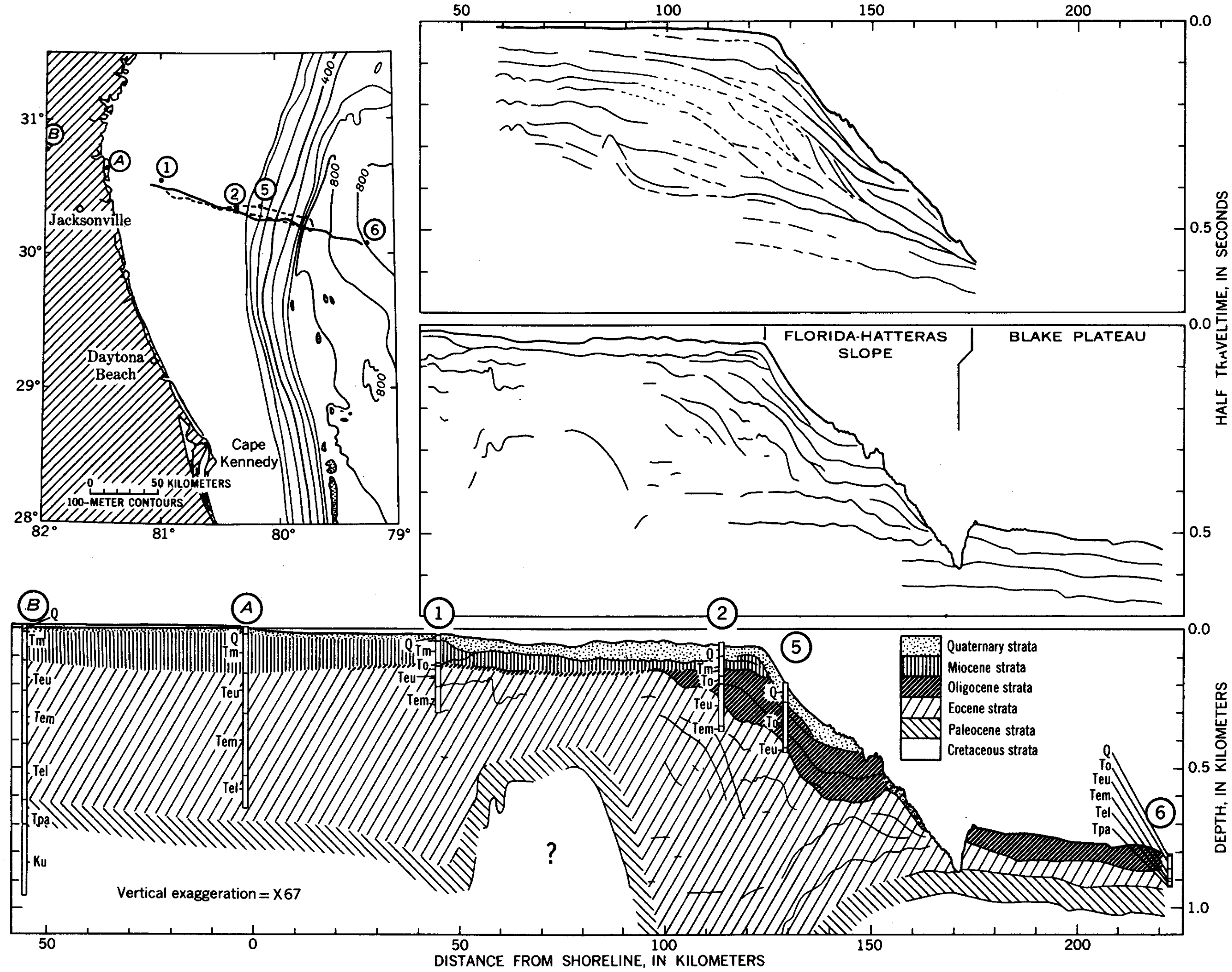

FIGURE 2.—Continuous seismic reflection profiles near JOIDES drill holes 1, 2, 5, and 6. The top right panel is a composite profile made by E. T. Bunce and S. T. Knott (in Joint Oceanographic Institutions' Deep Earth Sampling Program, 1965) just prior to drilling and along the route marked by a dashed line on the insert map. The middle panel is a profile made by Elazar Uchupi and A. R. Tagg (Uchupi and Emery, 1967) after the drilling and along the route marked by a solid line on the insert map. The bottom panel was constructed by adjusting the depths of the reflecting horizons in the middle panel for measured and estimated sound velocities (fig. 4) and correlating them with stratigraphic information from JOIDES drill holes and from wells on land (A, B) that were described by Herrick and Wait (1965) and Leve (1961).

possibly an anticline of Cretaceous strata. If such a feature is present, it could be the site of some probably minor accumulations of petroleum, as is suggested by the presence of oily odors and asphaltic specks in sections of the cores from holes 1 and 2 and, to a lesser extent, from hole 5 (fig. 5).

Examination of figure 2 fails to reveal offsets of the reflecting horizons that might be due to faults. No evidence of the fault postulated by Sheridan, Drake, Nafe, and Hennion, (1965) at the outer edge of the continental shelf is suggested by the reflecting horizons.

BLAKE PLATEAU AND BLAKE ESCARPMENT

Reflecting horizons near the surface of the Blake Plateau correspond closely to the tops of Oligocene and Paleocene strata found in JOIDES holes 6 and 4. The post-Paleocene strata appear to thin eastward, and they pinch out (or were eroded away) about 350 km from shore (fig. 3). Seaward prograding is exhibited as far as 250 km from shore. Many long, narrow depressions (Pratt and Heezen, 1964) have dissected the surface as deeply as 60 m, especially near the Blake Escarpment, and they have cut deeply into the Oligocene and Eocene

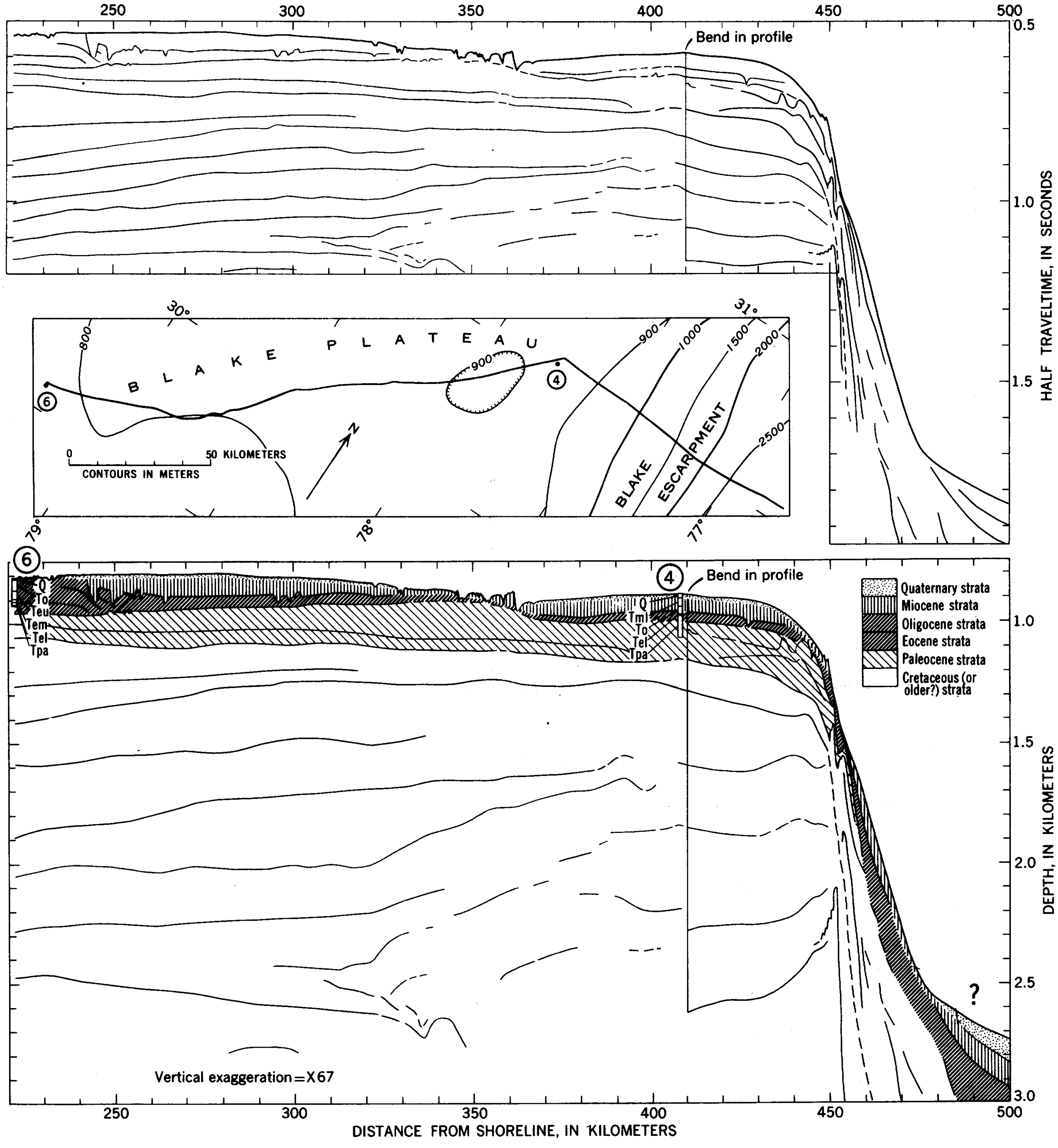

FIGURE 3.—Continuous seismic reflection profile made by Zarudzki from JOIDES holes 6 through 4 and eastward across the Blake Escarpment, as shown on the insert map. The bottom panel shows the time section converted to a depth section, using the sound velocities of figure 4 for the Blake Plateau.

strata. The depressions may even have exposed the underlying Paleocene beds where they are gently arched about 350 km from shore. Near the Blake Escarpment the shallow reflectors representing the Tertiary section steepen and continue down the escarpment. Evidently, Tertiary strata form a blanketing deposit on both plateau and escarpment.

One of the moderately deep seismic reflectors (fig. 3) probably marks the top of the Cretaceous sequence because the reflector is overlain by a reasonable thickness

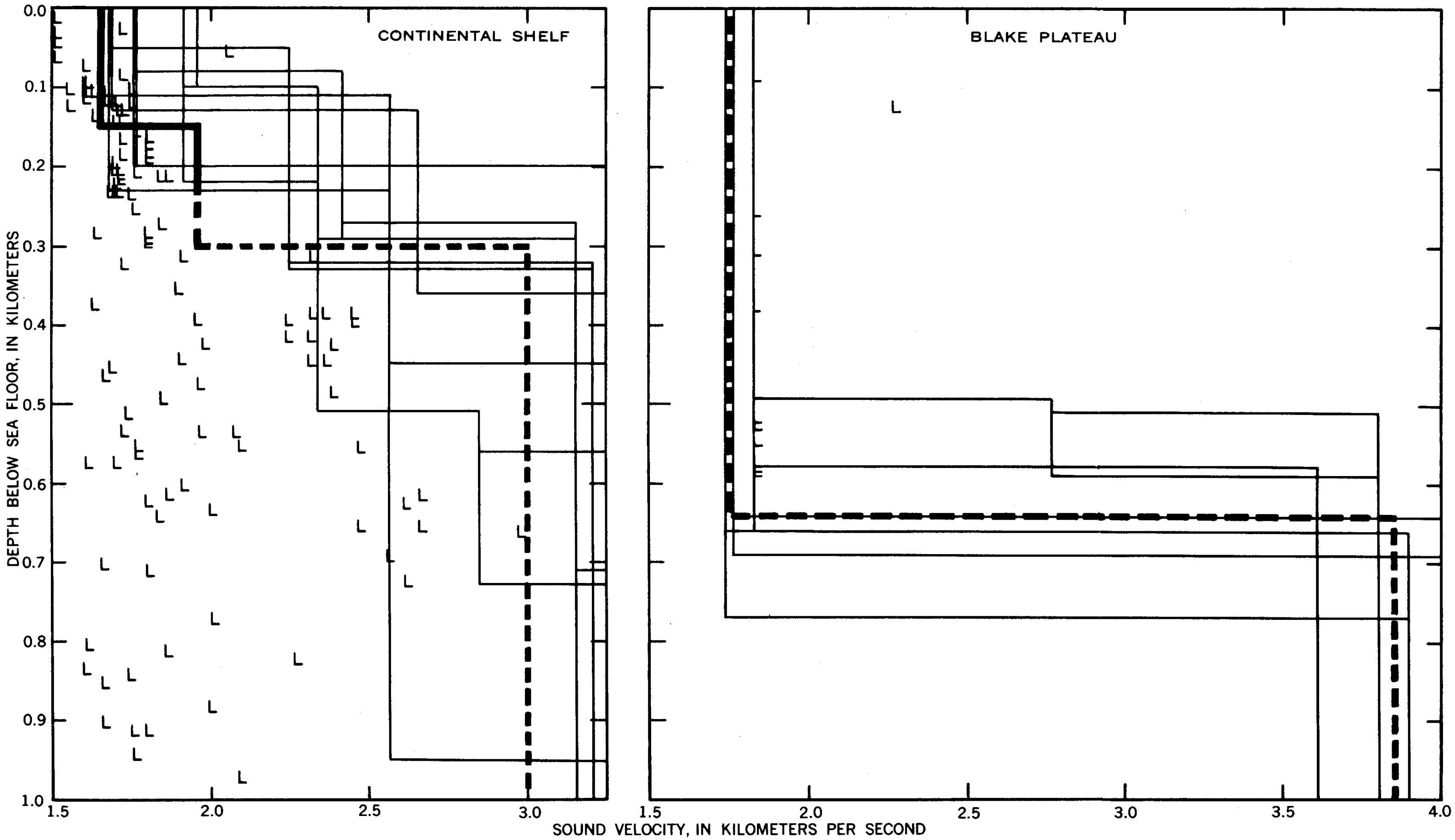

FIGURE 4.—Sound velocity at depth beneath the continental shelf (left panel) and beneath the Blake Plateau (right panel). The narrow lines depict superimposed velocity-depth relations that were measured from seismic refraction surveys by Hersey, Bunce, Wyrick, and Dietz, (1959) at 10 stations on the shelf and 6 stations on the Blake Plateau, all between 29°30′ N. and 31°15′ N. L symbols mark the bottoms of layers having the indicated sound velocities, but these are for stations more distant from the JOIDES holes (Hersey and others, 1959; Drake and others, 1959; and Antoine and Henry, 1965). The wide solid line shows the depth variation of sound velocity measured in JOIDES hole 2b (R. D. Gerard, W. B. Bogert, and H. A. Gibbons, unpub. data), and the wide dashed lines show the sound velocities at depth as assumed for computational purposes.

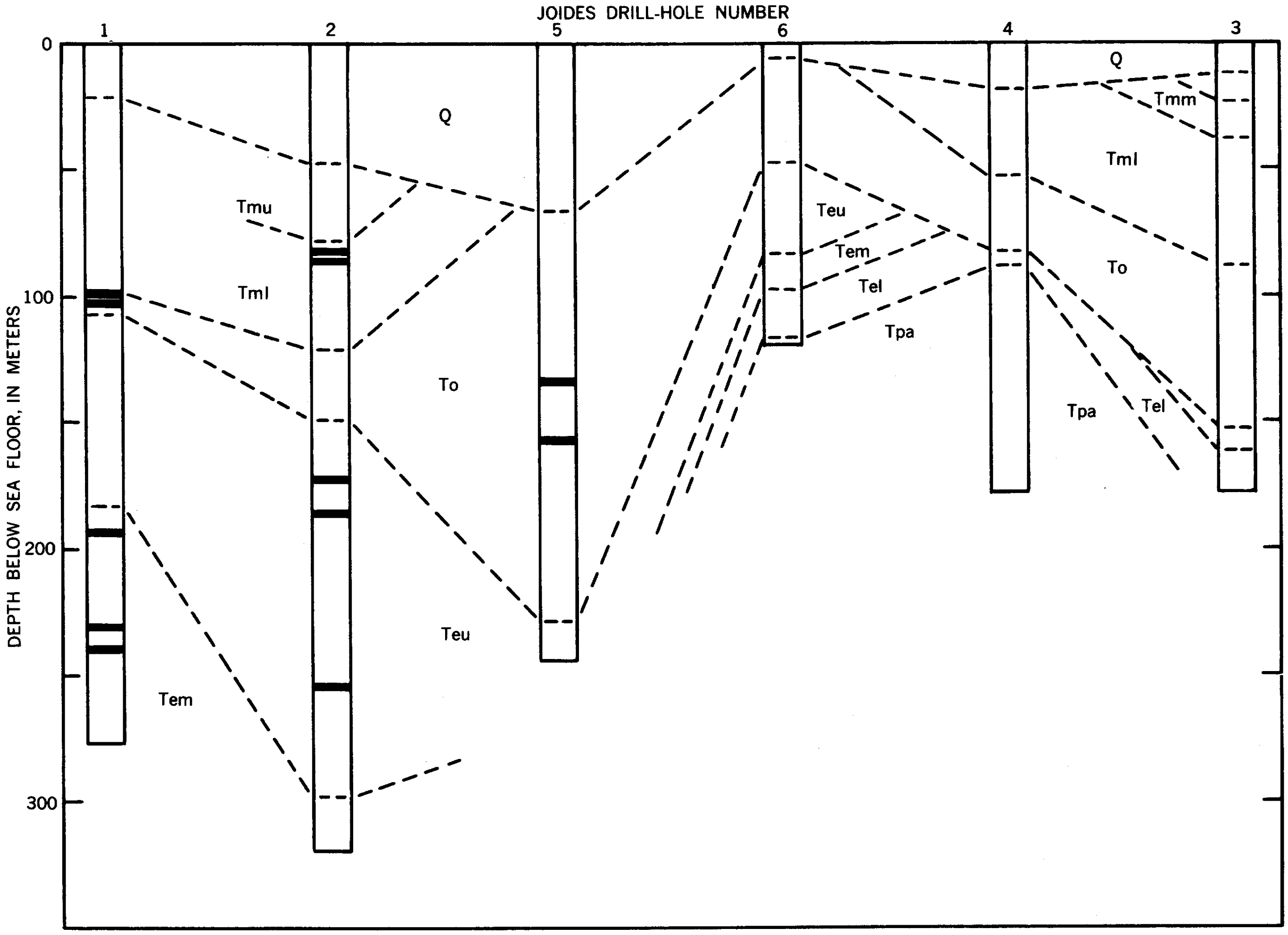

FIGURE 5.—Depths of oily odors or asphalt specks (shown by black bar) noted in fresh cores from the JOIDES holes. From Schlee and Gerard (1965).

of Paleocene strata. Beneath this reflector is an even stronger reflector that continues without interruption to the vicinity of the Blake Escarpment. The deeper reflector lies approximately 1.4 km below sea level near JOIDES hole 6, and it rises to a 1.25-km level at 310 km from shore and to a 1.22-km level at 395 km from shore. Near the Blake Escarpment it deepens to 1.4 km and terminates with a curious local rise. The underlying presumed Cretaceous strata are approximately horizontal to a distance of 310 km from shore. Farther northeastward they rise and converge near the Blake Escarpment, which truncates them. The seaward convergence suggests a seaward decrease in rate of subsidence during deposition of the strata.

An increase in seismic velocity from an average of 1.75 km per sec to between 3.6 and 4.4 km per sec (Hersey and others, 1959) occurs well below the top of the Cretaceous sequence inferred from the drill-hole data but near the stronger second reflecting surface. Perhaps this change in velocity and the corresponding reflector mark a lithologic break deep within the Cretaceous strata. A still deeper reflector, at a depth of approximately 2.5 km, near JOIDES hole 6 dips steadily to a depth of about 2.7 km about 120 km farther northeast. There the continuity is broken, and only a tentative correlation can be made across a 60-km gap to a reflector near JOIDES hole 4. If this correlation is valid, the underlying strata of Early Cretaceous or older age rise toward the Blake Escarpment and terminate in irregular features suggestive of bioherm reefs. Refraction data of Hersey, Bunce, Wyrick, and Dietz (1959) include several velocity determinations at comparable depths; these velocities range from 4.5 to 5.0 km per sec and, according to Nafe and Hennion (in Hersey and others, 1959, as unpub. data), this velocity range identifies the refractors (and the associated reflectors) as being probably Cretaceous in age.

The Blake Escarpment appears to truncate the reflectors deeper than the reflector believed to mark the top of the Cretaceous strata. A reasonable interpretation of the cross section shown at the bottom of figure 3 is the occurrence of a Late Cretaceous or Paleocene fault at the Blake Escarpment. As indicated by the question mark on figure 3, the assigned ages of shallower strata on the escarpment are only speculative.

CONCLUSIONS

When the continuous seismic reflection profiles are adjusted for the velocity of sound in the substrate, some of the reflecting horizons correspond with the tops of some of the stratigraphic units identified from samples of the JOIDES drill holes. Many stratigraphic units based on ages of enclosed planktonic fossils have no associated contrasts in lithology; thus, reflecting horizons may be more or less parallel to age boundaries but they can lie at greater or lesser depths. Better correlations between drill-hole data and seismic profiles may be provided in the future if the holes are drilled to the deepest reflector displayed by seismic profiles. Measurement of sound velocity throughout the length of all drill holes is also highly desirable.

The reflecting horizons indicate no breaks in continuity such as might be expected of pronounced faulting at the Florida-Hatteras Slope. Instead, the parallelism of reflecting horizons with the present 1.5-degree declivity of the Florida-Hatteras Slope indicates that the continental shelf is a depositional feature that prograded seaward throughout the Tertiary Period. The progradation appears to have buried a shallow ridge or anticline of probable Cretaceous strata about halfway across the continental shelf. Additional detailed seismic profiles or drill holes must be made in this area if the presence and characteristics of this feature are to be established.

The continuous seismic profile on the Blake Plateau between JOIDES holes 6 and 4 and then eastward across the Blake Escarpment reveals the presence of a blanket of Tertiary strata across the plateau and probably across the escarpment. A good reflecting horizon satisfactorily correlates the top of the Paleocene strata between the two drill holes. Seaward convergence of reflectors below the presumed top of the Cretaceous strata indicate that the Blake Plateau subsided differentially during the Cretaceous Period, faster at the landward than at the seaward side. Deeper reflectors also reveal a sharp ridge, possibly a reef, near the Blake Escarpment. Probably near the end of the Cretaceous Period the strata were truncated at the ancestral Blake Escarpment by faulting or submarine erosion, and they later were discontinuously buried by Tertiary sediments.

REFERENCES CITED

Antoine, J. W., and Henry, V. J., Jr., 1965, Seismic refraction study of shallow part of continental shelf off Georgia coast: Am. Assoc. Petroleum Geologists Bull., v. 49, no. 5, p. 601–609.

Drake, C. L., Ewing, Maurice, and Sutton, G. H., 1959, Continental margins and geosynclines: The east coast of North America north of Cape Hatteras, *in* Ahrens, L. H., and others, eds., Physics and chemistry of the earth, v. 3: New York, Pergamon Press, p. 110–198.

Ewing, J. I., and Tirey, G. B., 1961, Seismic profiler: Jour. Geophys. Research, v. 66, no. 9, p. 2917–2927.

Ewing, Maurice, Crary, A. P., and Rutherford, H. M., 1937, Geophysical investigations in the emerged and submerged Atlantic Coastal Plain; Part 1, Methods and results: Geol. Soc. America Bull., v. 48, no. 6, p. 753–801.

Herrick, S. M., and Wait, R. L., 1965, Subsurface stratigraphy of coastal Georgia and South Carolina [abs.]: Am. Assoc. Petroleum Geologists Bull., v. 49, no. 3, p. 344.

Hersey, J. B., 1963, Continuous reflection profiling, *in* Hill, M. N., ed., The sea, ideas and observations on progress in the study of the sea; volume 3, The earth beneath the sea: New York, Interscience Publishers, p. 47–72.

Hersey, J. B., Bunce, E. T., Wyrick, R. F., and Dietz, F. T., 1959, Geophysical investigation of the continental margin between Cape Henry, Virginia, and Jacksonville, Florida: Geol. Soc. America Bull., v. 70, no. 4, p. 437–465.

Joint Oceanographic Institutions' Deep Earth Sampling Program, 1965, Ocean drilling on the continental margin: Science, v. 150, no. 3697, p. 709–716.

Leve, G. W., 1961, Reconnaissance of the ground-water resources of the Fernandina area, Nassau County, Florida: Florida Geol. Survey Inf. Circ. 28, 24 p.

National Research Council, AMSOC Committee, 1961, Experimental drilling in deep water at La Jolla and Guadalupe sites: Natl. Acad. Sci.-Natl. Research Council Pub. 914, 183 p.

Pratt, R. M., and Heezen, B. C., 1964, Topography of the Blake Plateau: Deep-Sea Research, v. 11, no. 5, p. 721–728.

Roberson, M. I., 1964, Continuous seismic profiler survey of Oceanographer, Gilbert, and Lydonia submarine canyons, Georges Bank: Jour. Geophys. Research, v. 69, no. 22, p. 4779–4789.

Schlee, John, and Gerard, Robert, 1965, Cruise report and preliminary core log MV *Caldrill I*—17 April to 17 May 1965: Joint Oceanog. Inst. Deep Earth Sampling Program, Blake Panel Rept., 64 p.

Shepard, F. P., Trefethen, J. M., and Cohee, G. V., 1934, Origin of Georges Bank: Geol. Soc. America Bull., v. 45, no. 2, p. 281–302.

Sheridan, R. E., Drake, C. L., Nafe, J. E., and Hennion, J., 1965, Seismic refraction measurements of the continental margin east of Florida: Geol. Soc. America Spec. Paper 82, 183 p.

Stetson, H. C., 1949, The sediments and stratigraphy of the east coast continental margin: Georges Bank to Norfolk Canyon: Massachusetts Inst. Technology and Woods Hole Oceanog. Inst., Papers in Physical Oceanography and Meteorology, v. 11, no. 2, p. 1–60.

Uchupi, Elazar, and Emery, K. O., 1967, Structure of the Atlantic continental margin between Nova Scotia and Key West: Am. Assoc. Petroleum Geologists Bull., v. 51, p. 223–234.

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