DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY

INTRODUCTION

Present interpretations of the stratigraphy and structure of the middle and north Atlantic continental margin are based principally on an extensive network of seismic profiles and gravity and magnetic surveys that have been correlated with the relatively few drill holes in the region. Pertinent studies include those by Grow and Schlee (1976), Schlee and others (1976), Mattick and others (1978), Poag (1978, 1979), Hathaway and others (1979), and Klitgord and Behrendt (1979). Two investigations have focused on the seismic stratigraphy of the outer Shelf, the Slope, and the upper Rise along the Atlantic margin (Grow and others, 1979; Schlee and others, 1979). Until recently, offshore drilling has been limited to approximately 30 coreholes which penetrated to a maximum of 300 m beneath the sea floor on the Shelf and Slope and in submarine canyons. Stratigraphic test wells as deep as 6,000 m were drilled in the Baltimore Canyon Trough off New Jersey and in the Georges Bank Basin off Massachusetts in conjunction with the leasing of tracts on the Atlantic Continental Shelf and Slope for oil and gas exploration (Scholle, 1977, 1980). Studies of these deep wells have elucidated the stratigraphy of uppermost Jurassic, Cretaceous, and younger strata, but geophysical surveys have delineated major structures of unknown age that lie even deeper beneath the margin.

U.S. Geological Survey (USGS) seismic line 5 (fig. 1) crosses the margin over a structure known as the Long Island Platform, which is west of the Georges Bank Basin and north of the Baltimore Canyon Trough off New Jersey. The strike of the margin changes from northeast-southwest in the Baltimore Canyon Trough region to east-west along the Long Island Platform. The seismic profile along line 5 approximates a dip section extending from near Nantucket Island southeastward across the Continental Shelf and Slope to the lower Rise. Line 5 has been used in previous interpretations of the stratigraphic section beneath the Atlantic margin (Grow and Schlee, 1976; Schlee and others, 1976, fig. 5; Grow and others, 1979, figs. 2a, 9, 10; Schlee and others, 1979, figs. 6, 18). In this study, I present a more detailed interpretation of the upper part of the section, chiefly the Upper Cretaceous and younger strata that lie along a 196-km transect beneath the Shelf, Slope, and upper Rise.

No deep drill holes can be correlated with the line 5 profile; the COST G-1 and G-2 wells (fig. 1) are 150 and 210 km, respectively, to the east of line 5 on Georges Bank. The COST B-2 and B-3 wells are even farther from line 5, to the southwest off New Jersey. But several shallow coreholes that have been drilled near the profile and several rock samples that were collected *in situ* from nearby submarine canyons and the Slope provide a basis for interpreting the Upper Cretaceous and Cenozoic part of the section (figs. 1, 2, table 1). Nearshore, stratigraphic control is from a 500-m corehole (USGS 6001) on Nantucket Island that is projected 36 km west to the landward end of the seismic profile. On the Continental Slope, a 300-m corehole (ASP 18) in Veatch Canyon and samples collected from the canyon walls by the submersible *Alvin* (USGS 4554, 4555) are projected 15 km west to line 5. *Alvin* samples (USGS 5109-5111) collected in Atlantis Canyon 40-45 km west of line 5 and a grab sample (USGS 2150) from the lower Slope 3 km from the seismic line also provided control. A 300-m corehole (AMCOR 6013) 78 km east of line 5 furnished information on the thickness of the youngest strata beneath the uppermost Slope. It is one of three coreholes drilled in similar settings on the upper Slope in the middle and north Atlantic region; another (AMCOR 6012) is 130 km west of line 5 (Hathaway and others, 1979).

Line 5 is a 48-channel seismic-reflection profile that has been combined into a 36-fold common-depth-point stack. The energy source was an air-gun array totalling 1,700 $in.^3$, and the shotpoint interval was 100 m with pops every 50 m; streamer length was 3,600 m. Velocity analyses were made every 3 km by the contractor (Geophysical Service, Inc.), and they have been reevaluated by J. A. Grow and D. L. Peeler of the USGS, (unpublished data). The depth section across the outer Shelf, Slope, and upper Rise is based on continuous velocity analyses averaged at 1-km intervals (Grow and others, 1979). Most stratigraphic samples are projected to line 5 along parallels of latitude which also parallel the strike of the margin strata in this region. Velocity analyses were used to determine the placement of projected samples in the line 5 time sections (table 1). Bathymetry on the Shelf is based on echo sounding using the survey vessel; Slope and Rise bathymetry were derived from a single-channel monitor record collected simultaneously with the multichannel profile.

STRATIGRAPHY

Continental Shelf

A well drilled on Nantucket Island in 1975-76 by the U.S. Geological Survey (USGS 6001, figs. 1,2) penetrated approximately 450 m of Cenozoic and Upper Cretaceous sedimentary strata and 64 m of saprolite and basalt of probable Triassic and Jurassic age (Folger and others, 1978). The Quaternary and Tertiary beds are coarse sand and gravel approximately 128 m thick. The Pleistocene part of the section is about 85 m thick and contains marine ostracodes and foraminifers. A greensand unit is present from 91 to 107 m below ground level; Eocene dinoflagellates and spores and pollen occur between 91 and 98 m. The Cretaceous-Tertiary boundary was placed at 128 m, coincident with a lithologic change from coarse sand and gravel above to silty clay below. In the silty clay, clay minerals, particularly kaolinite, are dominant. A marked increase in the gamma-ray intensity also occurs at the Cretaceous-Tertiary boundary. The Upper Cretaceous beds between 128 m and 349 m are fossiliferous clay and silty clay, and they include a coal bed 22 cm thick at 328 m. An unfossiliferous sand predominates from 349 m down to the saprolite horizon at 457 m. The fine-grained beds above 349 m contain only spore and pollen assemblages and, presumably, were deposited in a nonmarine environment. A short interval between 309.9 and 321.1 m, however, exhibits agglutinated benthic foraminifers indicative of marginal marine conditions. Saprolite is present at 457 m and grades into weathered basalt which extends from 470 m to the bottom of the hole (514 m). Two samples of basalt (from 485.7 m and 513.8 m) dated using K-Ar methods gave ages of 183 ± 8 m.y. (Early Jurassic) and 164 ± 3 m.y. (Middle Jurassic), respectively; however, the partially altered basalt may be as old as Triassic.

A series of Upper Cretaceous samples (1-7, table 1) containing spores and pollen has been correlated by R. A. Christopher with floras typical of formations present beneath the New Jersey Coastal Plain (Folger and others, 1978), and the ages of these units are based on interpretations by Petters (1976), Christopher (1979), and Valentine (in press). A sample from 128.8 m below ground level has a spore and pollen assemblage equivalent to that found in the Mount Laurel Sand or basal part of the Navesink Formation of Maestrichtian Age; a sample from 133.9 m has an assemblage equivalent to that found in the Wenonah Formation, also of Maestrichtian Age. The Maestrichtian-Campanian boundary is placed at 136.6 m, coincident with a sample characteristic of the Wenonah (Maestrichtian) and Marshalltown (Campanian) Formations. The sample from 141.5 m is correlated with the Englishtown Formation or Woodbury Clay of Campanian Age. Samples from 174.2 and 211.6 m have assemblages of floras equivalent to that of the Magothy Formation of probable Santonian and Coniacian Age. Six samples in the interval from 259.2 to 338.0 m contain assemblages characteristic of the Woodbridge Clay member of the Raritan Formation, which is interpreted to be Turonian in age. The lowest fossiliferous sample is at 345.0 m and is probably correlative with the middle or lower part of the Raritan Formation of Cenomanian Age. The underlying strata down to the saprolite at 457 m are unfossiliferous. The stratigraphy of the Nantucket well (fig. 3) was projected 36 km westward to the landward end of line 5 at shot point 107 (figs. 2, 4). Reflectors thought to represent Upper Cretaceous sedimentary strata and the basalt can be identified in the line 5 profile (fig. 4), but shallow reflectors are obscured; therefore, the seismic record cannot be correlated accurately with the Cenozoic section.

In 1976, the U.S. Geological Survey also drilled well ENW-50 on Martha's Vineyard (fig. 1), about 18 km north of the landward end of line 5 and somewhat updip from the Nantucket well. Although the well did not reach crystalline basement, it penetrated 262 m of Cenozoic and Upper Cretaceous sedimentary strata that are correlative with beds on Nantucket (Hall and others, 1980). The Cretaceous-Tertiary boundary is about 83 m below ground level (73 m below sea level) and coincides with a lithologic change in the section similar to that observed at the same boundary in the Nantucket well. Spore and pollen assemblages characteristic of the Woodbridge Clay and Sayreville Sand Members of the Raritan Formation are present in samples from 167.6 to 254.7 m (R. A. Christopher, 1977, 1978, unpublished data) and represent an interval of probable Turonian Age coeval with the section from 259.2 m to at least 338.0 m in the Nantucket well.

Farther offshore, Upper Cretaceous and Cenozoic strata have been delineated beneath the middle Shelf by tracing dated reflectors both from the inner Shelf and from the outer Shelf and Slope (fig. 5).

Continental Slope and Submarine Canyons

The shallow stratigraphy of the upper Continental Slope has been revealed in several 300-m coreholes (fig. 1) that were drilled on the middle and north Atlantic margin during the U.S. Geological Survey's AMCOR Project (Atlantic Margin Coring Project) (Hathaway and others, 1979). Corehole AMCOR 6013, 78 km east of line 5 at a water depth of 244 m, penetrated a 304.8-m section of Pleistocene sand, silty sand, and several distinctive layers of clay and silty clay containing calcareous nannofossils and foraminifers. Another corehole (AMCOR 6012), off Long Island 130 km to the west of line 5 in water 262.7 m deep, penetrated 303.9 m of Pleistocene clay and silty clay. The stratigraphy of these two cores and the configuration of reflecting horizons in seismic profiles that cross the Shelf and Slope indicate that a wedge of marine Pleistocene silty sand and clay is present beneath the outer Shelf and upper Slope in this region. A third corehole (AMCOR 6021), far south of line 5 off New Jersey, was drilled on the upper Slope at a water depth of 301.2 m and penetrated 304.8 m of Pleistocene clay and silty clay. The Pleistocene wedge probably extends laterally along most of the middle and north Atlantic margin. AMCOR 6013 has been projected along the upper Continental Slope to line 5 at shotpoint 1682 (fig. 6) at a water depth that approximates that of the drill site.

Veatch Canyon incises the continental margin east of line 5 exposing Upper Cretaceous and Cenozoic strata that have been sampled there by means of both coring and collecting from a submersible (fig. 2, table 1). In 1967, Exxon, Chevron, Gulf, and Mobil drilled two coreholes in Veatch Canyon as part of their Atlantic Slope Project (ASP). A 300-m core (ASP 18) drilled at a water depth of 1,070 m on the west wall of the canyon revealed 90 m of Quaternary silty sand that unconformably overlies approximately 200 m of Maestrichtian, Campanian, and Santonian calcareous siltstone (fig. 7). The Upper Cretaceous strata are rich in calcareous nannofossils and were probably deposited at outer Shelf to upper Slope depths. Four of the samples (14-17) studied from ASP 18 have been projected 15 km west to line 5 at shotpoint 1740 (figs. 2, 6). The youngest Late Cretaceous sample is from 1,162 m below sea level and contains an early Maestrichtian nannoflora, and a sample of late Campanian age is from 1,223 m, just below the Maestrichtian-Campanian boundary in the corehole. Santonian strata are delineated by a sample from 1,238 m and one from 1,374 m, the lowest sample in the section.

Several stratigraphically important samples containing calcareous nannofossils were collected in Veatch Canyon by J. S. Schlee of the USGS from the submersible *Alvin*; two of them (11, 12) have been used in this study and contain rich assemblages of calcareous nannofossils. A sample from lower Maestrichtian strata that crop out at 1,055 m on the opposite (east) wall and somewhat upcanyon from ASP 18 has been projected to a point on line 5 between shotpoints 1732 and 1733, and a sample from upper Eocene argillaceous limestone that crops out at 950 m on the east wall has been projected to line 5 at shotpoint 1730 (figs. 2, 6).

Atlantis Canyon is 40-45 km west of line 5. Collecting there has been limited to a single dredge sample of Quaternary age (Gibson and others, 1968) and eleven Quaternary and Upper Cretaceous samples collected from the submersible *Alvin* by J. S. Schlee and D. W. Folger of the USGS. Eight of the *Alvin* samples are Quaternary clay from the upper reaches of the canyon, but three samples of calcareous siltstone (18-20; table 1) from deeper water (1,698, 1,839, and 1,875 m) contain a Coniacian calcareous nannoflora. These three samples are the oldest rocks so far collected from the Slope and canyons of this area, and they have been projected to locations on line 5 between shotpoints 1790 and 1838 (figs. 2, 6, 8).

Seismic profiles across the Atlantic margin have shown that in several areas beds that lie at depth beneath the outer Shelf and upper Slope are exposed on the lower Slope (Schlee and others, 1979). These strata were sampled in a corehole (DSDP 108) on the lower Slope off New Jersey where a siliceous chalk of middle Eocene age was encountered when coring was initiated about 50 m below the sea floor (Hollister and others, 1972a, fig. 2). Near Veatch Canyon, a grab sample (13) of calcareous and siliceous mudstone which was collected from the upper Slope at a water depth of 1,675 m was dated as early Eocene on the basis of planktic foraminifers (Gibson, 1965). Sample 13 was collected just 3 km west of line 5 (fig. 2), and it has been projected to an equivalent water depth at shotpoint 1838 (figs. 6, 8). This sample is older than the Eocene beds that crop out updip in Veatch Canyon.

SEDIMENTATION AT THE OCEANIC-CONTINENTAL CRUSTAL BOUNDARY

The oceanic-continental crustal boundary zone along line 5, as delineated by Grow and others (1979, figs. 2a, 10), is beneath a buried reef or carbonate platform of probable Jurassic age at the landward edge of the East Coast Magnetic Anomaly. This Shelf-Slope-Rise transition area of the margin has experienced an increase in water depth and a change in environment of deposition at least since the formation of the Jurassic reef structure.

Two broad styles of deposition are evident on the margin beneath line 5 (fig. 9) (Schlee and others, 1979, fig. 20). During the Jurassic and Early Cretaceous, the margin developed as a result of the progradation and aggradation of the Continental Shelf that was separated by a depositional hiatus from an onlapping Rise wedge at the base of the Continental Slope. In Late Cretaceous and early Tertiary time, however, a different depositional style prevailed; the outer Shelf, Slope, and Rise built upward and seaward, both the Slope and Rise became sites of active deposition, and a separate Rise wedge did not form. During the late Tertiary and Quaternary, the margin again experienced disjunct sedimentation. The Shelf- and upper-Slope prism formed as a result of progradation, and it is separated from a thick wedge of onlapping Rise deposits that has advanced landward over the eroded surfaces of the Late Cretaceous and early Tertiary Rise and lower Slope. At present, the small volume of sediment that is derived from continental runoff is trapped in estuaries or is transported beyond the Shelf to deeper water (Meade, 1969; Milliman, 1972), and the Shelf is presumably not building seaward. Future outbuilding of the Shelf and continued advancement of the Rise up the Slope could result in the reestablishment of the Shelf edge at or near its position in the Early Cretaceous and in the early Tertiary.

The changes in developmental style of the margin are undoubtedly due to the interaction of many factors including the sedimentation rate, sediment source, subsidence rate, and the erosional and depositional action of submarine currents and turbidity flows. Recent studies of several deep stratigraphic test wells have revealed the ages and general lithologies of the sedimentary rocks beneath the outer Shelf and upper Slope of the middle and north Atlantic margin (Scholle, 1977, 1980; Amato and Bebout, 1980; Amato and Simonis, 1980). Only a few shallow holes have been drilled on the lower slope and upper rise (Hollister and others, 1972a, b), and little is known about strata at depth there.

The following summary outlines the post-rifting history of the outer margin beneath line 5. During the Jurassic, a reef complex was established on the edge of the margin at the oceanic-continental crustal boundary. Landward of the reef, shallow-water carbonate and clastic sediments were deposited on a broad subsiding shelf underlain by Jurassic and Triassic grabens and continental basement; seaward, fore-reef deposits and possibly pelagic carbonate and fine-grained clastic strata formed an onlapping wedge in the oceanic crustal province. In Early Cretaceous time, deposition of shallow-water clastic sediments prograded the Shelf seaward, finally burying the reef and causing the Shelf to coalesce with the onlapping Rise wedge, which is probably composed of finer grained hemipelagic sediments.

In Late Cretaceous and early Tertiary time, the Shelf-Slope-Rise region maintained a sigmoidal configuration. A separate Rise wedge did not form, and the Slope probably had a gentler inclination than before and after this period. Marine calcareous shale and argillaceous limestone were laid down beneath the Shelf and upper Slope during Late Cretaceous and early Tertiary time, and sediments of similar compositon probably were deposited on the Rise.

A major change in depositional style occurred late in early Tertiary time, perhaps in the Oligocene. Terrigenous clastic sediments, particularly of Miocene age and younger, were deposited in a progradational wedge on the outer Shelf and upper Slope. Seaward, the slope may have become steeper as a result of subsidence in the lower Slope and upper Rise area that overlies oceanic basement. The lower Slope and upper Rise were eroded by submarine currents and (or) slumping, and the late Tertiary and Quaternary Rise began to form and climb landward up the eroded surface. The present Rise beneath line 5 is probably composed of hemipelagic sediments and turbidite deposits derived in large part from glacial runoff during Neogene and Quaternary time.

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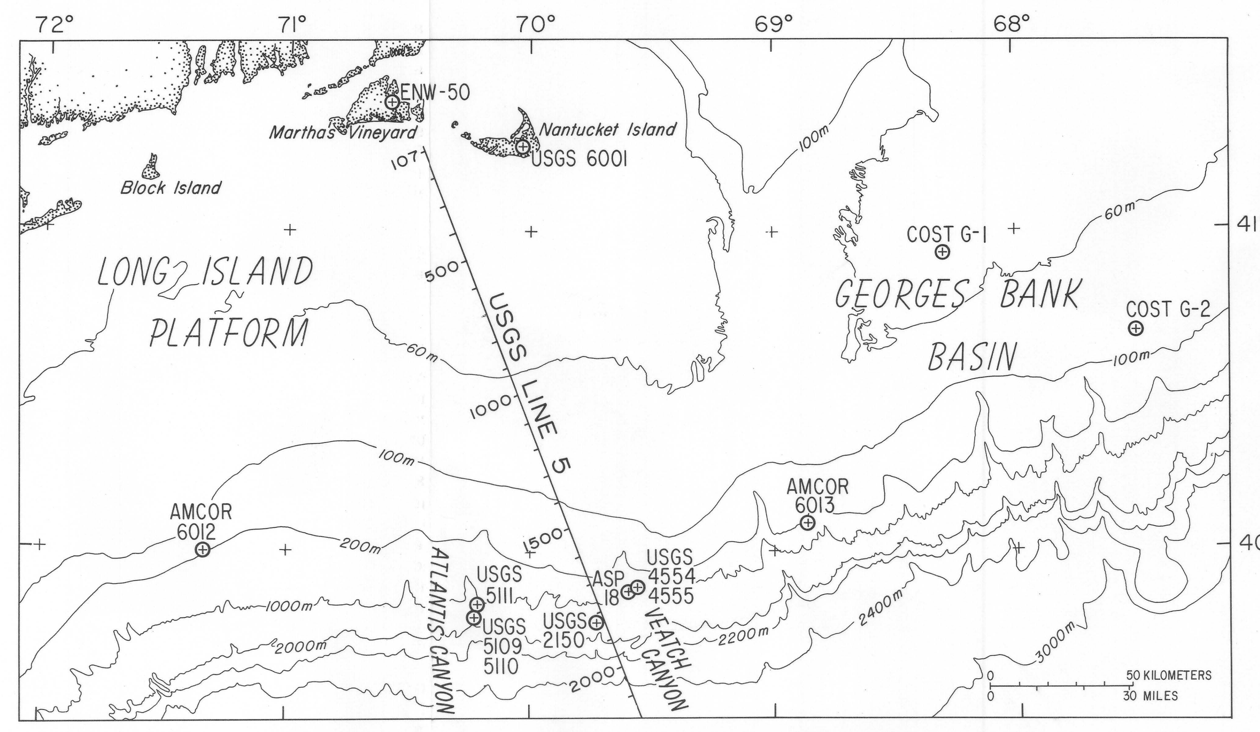

Figure 1.—Map of U.S. North Atlantic continental margin showing location of USGS seismic line 5 and of drill holes and sample sites (table 1). Numbers along line 5 are shotpoints. Map base modified from Uchupi (1965).

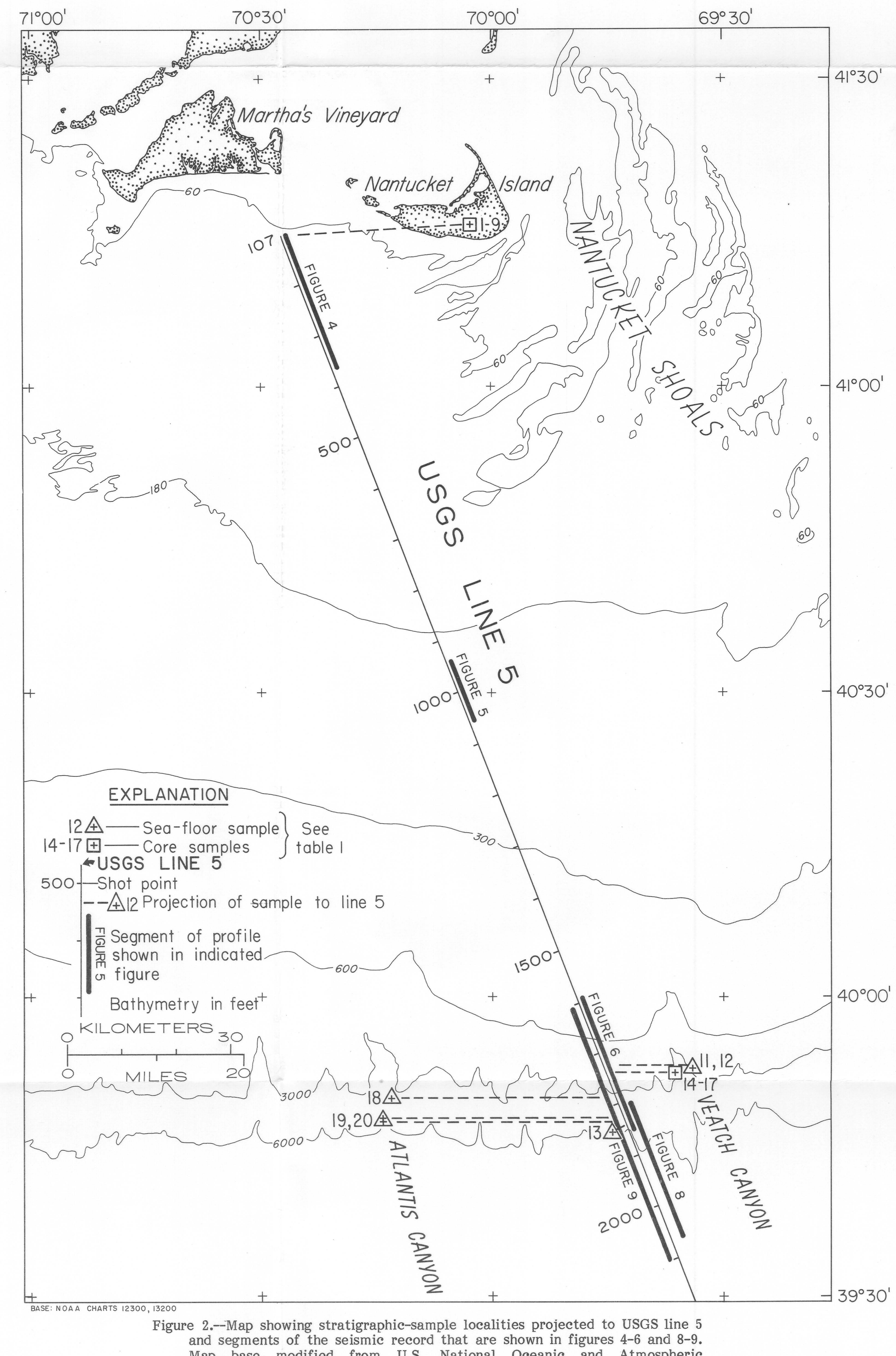

Figure 2.—Map showing stratigraphic-sample localities projected to USGS line 5 and segments of the seismic record that are shown in figures 4-6 and 8-9. Map base modified from U.S. National Oceanic and Atmospheric Administration (1979a, b).

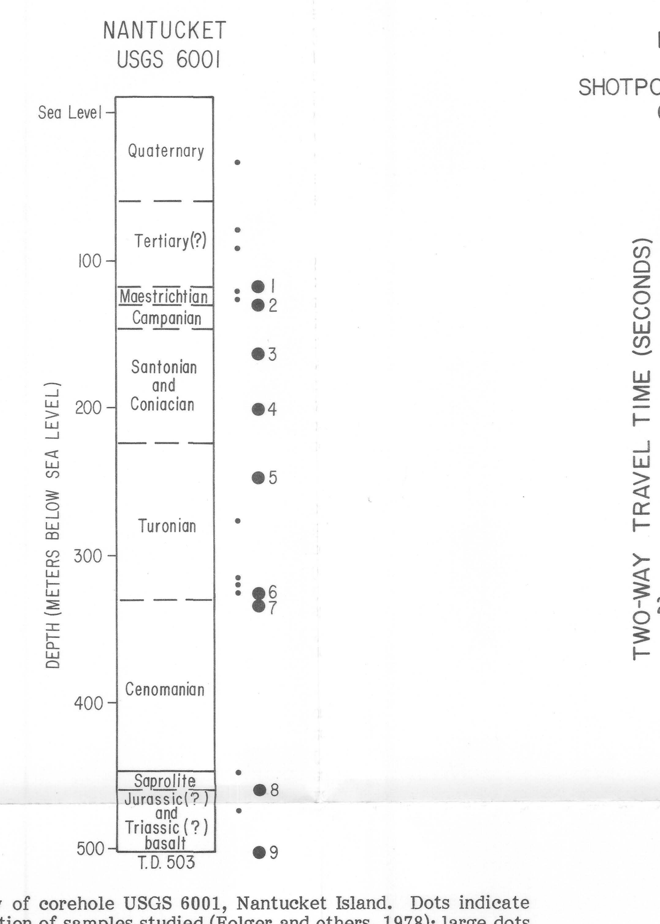

Figure 3.—Stratigraphy of corehole USGS 6001, Nantucket Island. Dots indicate stratigraphic position of samples studied (Folger and others, 1978); large dots are samples projected onto line 5 (fig. 2, table 1). Upper Cretaceous samples (1-7) contain spores and pollen studied by R. A. Christopher of the USGS. Datum is sea level.

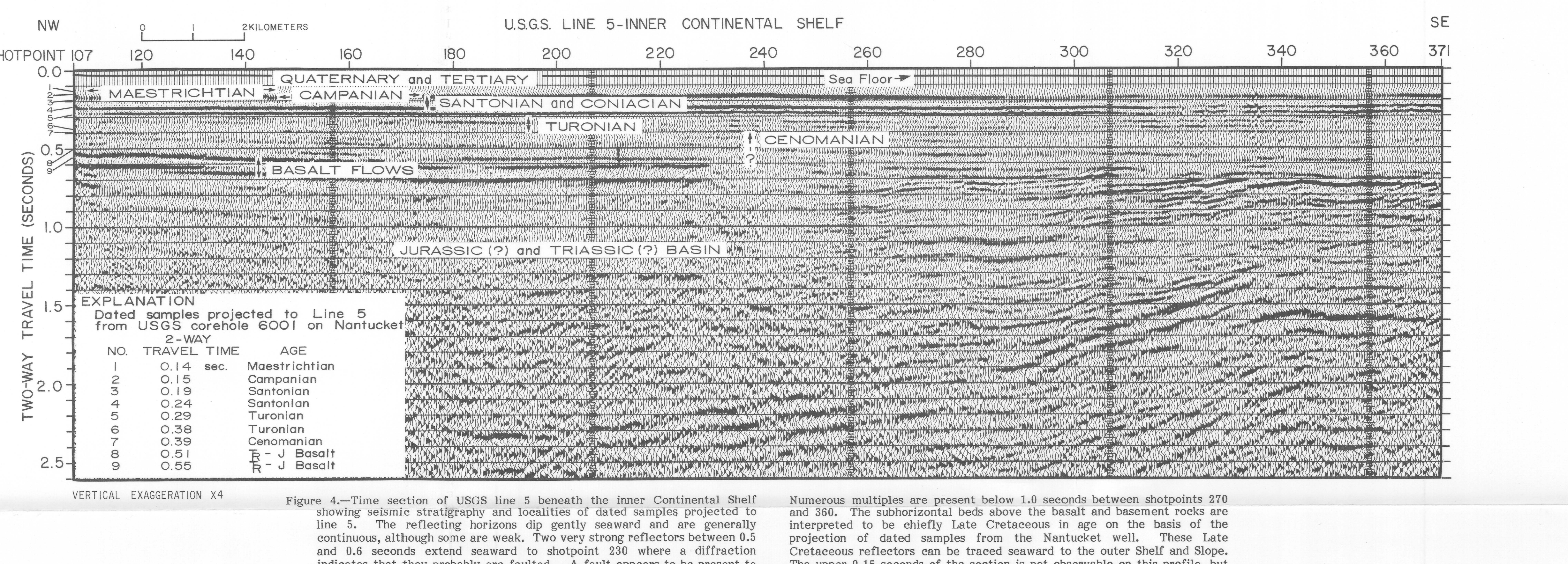

Figure 4.—Time section of USGS line 5 beneath the inner Continental Shelf showing seismic stratigraphy and localities of dated samples projected to line 5. The reflecting horizons dip gently seaward and are generally continuous, although some are weak. Two very strong reflectors between 0.5 and 0.6 seconds extend seaward to shotpoint 230 where a diffraction indicates that they probably are faulted. A fault appears to be present to seaward at 0.7 seconds beneath shot point 265. These strong reflectors are interpreted to be basalt because they are at approximately the same depth as Jurassic(?) and Triassic(?) basalt in the Nantucket well. The basalt flows overlie the northern half of a sedimentary basin of probable Jurassic and Triassic age that is delineated on gravity and magnetic maps of the region (Grow and others, 1976; Klitgord and Behrendt, 1979, figs. 7a, b, c). Numerous multiples are present below 1.0 seconds between shotpoints 270 and 360. The subhorizontal beds above the basalt and basement rocks are interpreted to be chiefly Late Cretaceous in age on the basis of the projection of dated samples from the Nantucket well. These Late Cretaceous reflectors can be traced seaward to the outer Shelf and Slope. The upper 0.15 seconds of the section is not observable on this profile, but Tertiary and Quaternary beds, probably largely Pleistocene sand and gravel, are present above the Maestrichtian. Water depth was determined by means of echo soundings from the survey vessel. Vertical arrows indicate upper and lower boundaries of stratigraphic units. Horizontal arrows indicate dated levels in the record. Vertical exaggeration is known only at the sea floor.

Table 1.--*Sample age, location, and source, and summary of horizontal and vertical projection points of samples onto USGS seismic line 5*

[Interval velocities interpolated from analyses by J. A. Grow and D. L. Peeler of the U.S.G.S.]

Sample Number	Sample Site	Age	Location: Geographic	Latitude North	Longitude West	Elevation (meters)	Sample depth: Below sea level (meters)	(feet)	Projected onto line 5 at: Shot-point	Water depth (meters)	Subbottom depth (meters)	Velocity interval: Number	Velocity (meters/second)	Depth from top (meters)	Two-way travel time (seconds) from: Top of interval	Sea level	Sample source
1	USGS 6001	Maestrichtian	Nantucket Is.	41°15.90'	70°02.34'	11	117.8	386.5	107	24	94	2A	1734	94	0.11	0.14	Corehole USGS 6001, 1975-76; Folger and others (1978).[1]
2	Do.	Campanian	Do.	41°15.90'	70°02.34'	11	130.5	428.1	107	24	106	2A	1734	106	0.12	0.15	Do.
3	Do.	Santonian and Coniacian	Do.	41°15.90'	70°02.34'	11	163.2	535.4	107	24	139	2A	1734	139	0.16	0.19	Do.
4	Do.	Do.	Do.	41°15.90'	70°02.34'	11	200.6	658.1	107	24	177	2A	1734	177	0.20	0.23	Do.
5	Do.	Turonian	Do.	41°15.90'	70°02.34'	11	248.2	814.3	107	24	224	2A	1734	224	0.26	0.29	Do.
6	Do.	Do.	Do.	41°15.90'	70°02.34'	11	327.0	1072.8	107	24	303	2A	1734	303	0.35	0.38	Do.
7	Do.	Cenomanian	Do.	41°15.90'	70°02.34'	11	334.0	1095.8	107	24	310	2A	1734	310	0.36	0.39	Do.
8	Do.	Jurassic and Triassic	Do.	41°15.90'	70°02.34'	11	459.0	1505.9	107	24	435	2	2060	125	0.12	0.51	Do.
9	Do.	Do.	Do.	41°15.90'	70°02.34'	11	503.0	1650.3	107	24	479	4A	2239	16	0.01	0.55	Do.
						Depth of sea floor below sea level (meters) (feet)	Below sea floor (meters)	(feet)									
10	AMCOR 6013	Pleistocene	Continental Slope	40°05.04'	68°52.13'	244 799	305	1000	1682	239	305	3	1694	305	0.36	0.68	Corehole AMCOR 6013, 1976; Hathaway and others (1979).
11	USGS 4555	late Eocene	Veatch Canyon	39°52.9'	69°34.1'	950 3117			1730	466	484	4	1681	484	0.58	1.20	*Alvin* dive 668, 1976; J. S. Schlee collector.
12	USGS 4554	early Maestrichtian	Do.	39°52.8'	69°34.2'	1055 3461			1732.5	481	574	5	1948	11	0.01	1.33	Do.
13	USGS 2150	early Eocene	Continental Slope	39°46.5'	69°44.3'	1675 5495			1838	1675							USGS 2150 grab sample, 1964; Gibson (1965).
14	ASP 18	early Maestrichtian	Veatch Canyon	39°52.42'	69°36.23'	1070 3510	92	302.4	1740	570	593	5	1916	93	0.96	1.46	Corehole ASP 18, Caldrill 1967; Exxon, Mobil, Gulf,
15	Do.	late Campanian	Do.	39°52.42'	69°36.23'	1070 3510	153	501.8	1740	570	654	5	1916	154	0.16	1.52	Do.
16	Do.	Santonian	Do.	39°52.42'	69°36.23'	1070 3510	168	550.8	1740	570	668	5	1916	168	0.18	1.54	Do.
17	Do.	Do.	Do.	39°52.42'	69°36.23'	1070 3510	304	998.8	1740	570	805	6	2530	8	0.01	1.68	Do.
18	USGS 5111	Coniacian	Atlantis Canyon	39°49.8'	70°13.2'	1698 5571			1790	1011	687	6	2354	122	0.10	2.14	*Alvin* dive 789, 1977; J. S. Schlee collector.
19	USGS 5110	Do.	Do.	39°47.8'	70°14.1'	1839 6033			1832.5	1579	260	5	1778	143	0.16	2.42	Do.
20	USGS 5109	Do.	Do.	39°47.5'	70°14.2'	1875 6152			1837.5	1657	218	5	1812	109	0.12	2.47	Do.

[1] Well was originally logged using the English system of measurement. Data have been converted to metric units for this report.

CONTINENTAL MARGIN STRATIGRAPHY ALONG THE U.S. GEOLOGICAL SURVEY SEISMIC LINE 5-- LONG ISLAND PLATFORM AND WESTERN GEORGES BANK BASIN

By
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1981

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