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HIGH-RESOLUTION SEISMIC STRATIGRAPHY OF THE UPPER CONTINENTAL SHELF SEAWARD OF GEORGES BANK

By

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INTRODUCTION

Georges Bank lies on the trailing edge of a passive continental margin located off the northeastern coast of the United States (sheet 1). The depositional history of this continental margin has been described in a number of reports using both borehole data and analyses of seismic-reflection data (Ballard and Uchupi, 1975; Uchupi and others, 1977; Uchupi and Austin, 1979; Austin and others, 1980; Valentine, 1981; Klitgord and others, 1982; Poag, 1982a,b; Schlee and others, 1985). Lithostratigraphic and biostratigraphic results from the Continental Offshore Stratigraphic Test (COST) Program (Klitgord and others, 1982; Poag, 1982a,b; Schlee and Fritsch, 1983) and Deep Sea Drilling Project (DSDP) (Poag, 1987; Poag and Mountain, 1987) provided the calibration for seismostratigraphic units identified on the seismic-reflection profiles. The deep penetration, multichannel seismic-reflection profiles used in these reports are not of sufficient resolution to allow interpretation of the small-scale stratigraphic relations within the upper 1.0 second (s) (two-way traveltime) of acoustic penetration. Therefore, this study was undertaken to investigate and characterize the continental rise strata seaward of Georges Bank utilizing high-resolution single-channel seismic-reflection profiles (Bailey and Aaron, 1982a,b).

This high-resolution seismic-reflection data was studied by O'Leary (1988) to form a synthesis of the depositional history of the outer shelf, slope, and upper rise from long 65°30' to 71°00' W. O'Leary (1988) attempted to define the seismostratigraphic intervals in the rise section and speculated on the source areas and lithologies for the individual units, but did not provide stratigraphic calibration or present seismostratigraphic maps to accompany his results.

The limits of the study area extend from lat 39°30' to 41°00' N., and from long 66°00' to 71°00' W. (sheets 1 and 2). In this study, we interpreted a series of airgun- and sparker-generated high-resolution, single-channel seismic-reflection profiles, collected along the Georges Bank margin in 1978 and 1979. The primary objectives were to (1) define prominent acoustic unconformities that are laterally extensive, (2) generate a series of structure-contour maps for each unconformity identified, and (3) generate a series of isopach maps of the seismostratigraphic units bounded by these unconformable surfaces. The study was designed not only to complement the work of O'Leary (1988), but also to provide an alternative interpretation of the seismic-reflection data during our analysis.

Below is a list of the sheets included in this report:

Sheet 1—Trackline map
Sheet 2—Trackline map
Sheet 3—Structure-contour map of reflector 8 (R8)
Sheet 4—Single-channel seismic sections from RV *James M. Gilliss*, line 25
Sheet 5—Isopach maps of Units 5W, 6W, and 7W
Sheet 6—Single-channel seismic sections from RV *Columbus Iselin* and RV *James M. Gilliss*
Sheet 7—Structure-contour maps of reflectors 4W, 5W, and 6W
Sheet 8—Isopach maps of Units 1W, 2W, 3W, and 4W
Sheet 9—Seismic facies map
Sheet 10—Structure-contour maps of reflectors 1W, 2W, and 3W
Sheet 11—Isopach maps of Units 1E, 2E, 3E, and 4E, and structure-contour maps of reflectors 1E, 2E, and 3E

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METHODS

Approximately 6,000 km of 40-in^3 airgun and 800-joule minisparker high-resolution, seismic-reflection data were collected along the outer shelf, continental slope, and upper rise off New England aboard the RV *Columbus Iselin* in 1978 and the RV *James M. Gilliss* in 1979 (Bailey and Aaron, 1982a,b) (sheets 1 and 2). Seismic, stratigraphic, and facies interpretations were conducted using the methods outlined in Mitchum and Vail (1977) and Sangree and Widmier (1977). Interpreted multichannel seismic-reflection profiles (Valentine, 1981; Klitgord and others, 1982; Poag, 1982b; Schlee and Klitgord, 1982; Schlee and others, 1985), originally collected by the U.S. Geological Survey (USGS) (1973–1978) and by the Bundesanstalt fur Geowissenschaften und Rohstoffe (BGR) in 1979 (Schlee and Fritsch, 1983), also were used to correlate reflectors identified from the upper 1.0-s interval of the multichannel profiles with reflectors identified in the high-resolution profiles. This comparison of the multichannel and single-channel profiles was conducted only at line crossings of the various cruises in order to measure subbottom depths of reflectors in each of the profiles.

Conversion of two-way traveltime to subbottom depth was accomplished by averaging the internal velocities reported on the USGS multichannel profiles in the upper 1.0 s of subsurface penetration. This averaging was carried out on USGS profiles 1, 4, 18, 19, 20, and 38 (see Schlee and others, 1985, for these trackline locations) which cross or lie close to the locations of the RV *Columbus Iselin* and RV *James M. Gilliss* high-resolution profiles. This analysis yielded an average internal velocity of 1,700 m/s. Because of a lack of seismic-refraction data, the isopach thicknesses and depth to structures presented in this report are only estimates and are not meant to be definitive. Bathymetry along the tracklines was calculated by using a sound velocity in water of 1500 m/s. National Ocean Service bathymetric charts were used for bathymetry between the individual tracklines. Outcrop locations of the acoustic reflectors were laterally extrapolated from individual profiles on the basis of bathymetry and are justified by the relatively horizontal nature of the mapped unconformities within the continental-rise sedimentary wedge.

CONTINENTAL RISE STRATIGRAPHY

Georges Bank and the adjacent continental slope and rise are underlain by thick sections of sedimentary rock that accumulated throughout the Mesozoic and Cenozoic Eras. The Cenozoic section in the upper-rise sedimentary wedge is appreciably thicker than the updip equivalent on the continental shelf, indicating that the focus of sedimentation shifted from the shelf to the upper-rise area in Tertiary times (Valentine, 1981; Poag, 1982b; Schlee and others, 1985). Declining Cenozoic subsidence rates and the advent of canyon cutting on the slope provided conduits for sediment bypassing the shelf, thereby forming the thick onlapping wedge of Tertiary and Quaternary sediments (Schlee and others, 1985). Studies using multichannel seismic-reflection profiles have demonstrated that the Cenozoic upper-rise section seaward of Georges Bank consists of a series of smaller, discrete sedimentary packets that are bounded by laterally extensive unconformities or disconformities that formed in response to fluctuating depositional and erosional environments (Uchupi and others, 1977; Uchupi and Austin, 1979; Valentine, 1981; Poag, 1982b; Schlee and others, 1985).

An estimate of the age of the seismostratigraphic units subdividing the rise deposit was determined by mapping and tracing key reflectors from regions where drill-hole calibration exists to the Georges Bank region, and by comparing the acoustic character of key reflectors within the rise unit with those delineated in the western North Atlantic basin (Tucholke and Mountain, 1979; Klitgord and Grow, 1980; Mountain and Tucholke, 1985; Schlee and others, 1985). One such key reflector, horizon A^u, is a widespread erosional unconformity that separates upper Eocene and lower Miocene strata at its type locality, DSDP Site 105 (Tucholke, 1979). More recent calibration of this unconformity and the surrounding strata by DSDP leg 95 on the slope and rise east of New Jersey (Poag and Mountain, 1987) indicates a Paleocene age for horizon A^u. Within the continental-rise section seaward of Georges Bank, A^u forms a distinctive horizon characterized by channel features that are oriented downslope (Schlee and others, 1985). Depositional patterns above A^u are chaotic and include numerous slump, channel, and basin-fill deposits. An unconformity with less relief than horizon A^u lies about 200 to 600 m above A^u, and forms the lower boundary of the uppermost sequence in the Cenozoic section (D_3) described by Schlee and others (1985). Unit D_3 is an upper Miocene(?) to Holocene sequence of broadly overlapping channel and fan sediments, probably originating from point sources along the slope, and dispersed downslope by gravity flows and laterally by geostrophic currents (Schlee and others, 1985). This uppermost seismostratigraphic sequence is the focus of this study.

COMPARISON OF THE CONTINENTAL RISE STRATIGRAPHY WITH LEG 95 DSDP RESULTS

Recent DSDP drilling activity on the continental slope and upper continental rise off the New Jersey margin, accompanied by seismic-reflection profiling, have established a detailed history of the development of a passive, sediment-rich continental margin (Miller and others, 1987; Poag, 1987; Poag and Low, 1987; Poag and Mountain, 1987). High-resolution seismic-reflection profiles show that the acoustic character of the upper continental rise along the New Jersey transect (Poag, 1987; Poag and Mountain, 1987) is remarkably similar to the seismostratigraphy displayed within the upper-rise section south of Georges Bank, 200 km to the northeast.

A prominent and laterally extensive acoustic interface mapped in this study, reflector 8 (R8 on seismic sections and maps) (sheet 3), forms the base of a sediment wedge that onlaps the continental slope. Poag and Mountain (1987) describe an upper Miocene and younger sedimentary wedge seaward of the New Jersey continental margin that onlaps a widespread unconformable horizon (which in certain locations outcrops at the slope-rise transition) similar to the setting of reflector R8 and the overlying lower slope-upper rise strata seaward of Georges Bank. Poag (1987) indicates that a middle Miocene erosional event sculpted the New Jersey continental margin and may correlate with the widespread middle Miocene deep-sea erosional unconformity horizon Merlin (Mountain and Tucholke, 1985). In addition, Miller and others (1987) described a middle to late Miocene canyon-cutting event that affected the continental slope seaward of New Jersey. If a middle Miocene erosional event was widespread in the North Atlantic basin, the continental margin seaward of Georges Bank also may have been affected, as demonstrated by reflector R8.

SEISMOSTRATIGRAPHY

Reflector 8 (R8)

A widespread acoustic reflector, R8, was identified in the high-resolution profiles used for this study. R8 is a prominent high-amplitude, highly continuous acoustic interface that truncates underlying reflectors in certain areas and is the acoustic surface onto which all overlying reflectors onlap updip. R8 is the first in a sequence of unconformities lying above horizon A^u and lies at the same seismostratigraphic level as a middle to late Miocene(?) unconformity described by Schlee and others (1985, figs. 7–11, 7–12, 7–20) that forms the base of their Unit D3. Ties along USGS Multichannel Seismic (MCS) lines from the Baltimore Canyon Trough (K. Klitgord, oral commun.), as well as direct comparison with other interpreted seismic lines from the Georges Bank margin (Valentine, 1981; Poag, 1982b, figs. 6, 7) show that a major

Table 1.—Well and dredge sample data collected by various authors as shown on sheets 1 and 2

[Abbreviations used: c. core, Camera core; COST, Continental Offshore Stratigraphic Test; AMCOR, Atlantic Margin Coring Project; ASP, Atlantic Slope Project]

Sample	Age	Location		Water depth (meters)	Sample source[1]
		Latitude North	Longitude West		
2–39	Late Cretaceous	40°17′00″	68°06′18″	950	Stetson (1949)
5–34	Late Cretaceous	40°24′30″	68°07′30″	596–480	Do.
14–36	Late Cretaceous	40°19′00″	67°51′30″	758	Do.
20–36	Miocene	40°23′00″	67°38′30″	283	Do.
12–36	Eocene	39°50′00″	70°57′30″	880	Do.
c.core	Eocene	39°43′00″	70°48′00″	1,000	Do.
2150	Early Eocene	39°46′30″	69°44′18″	1,675	Gibson (1968)
2656B	Paleocene	40°16′12″	68°08′00″	950	Do.
2697	Maestrichtian	40°15′30″	68°07′30″	940	Do.
2698	Oligocene	40°15′30″	68°07′36″	886	Do.
4554	Early Maestrichtian	39°52′48″	69°34′12″	1,055	1
4555	Late Eocene	39°52′54″	69°34′06″	950	Do.
5109	Coniacian	39°47′30″	70°14′12″	1,875	2
5110	Coniacian	39°47′48″	70°14′06″	1,839	Do.
5111	Coniacian	39°49′48″	70°13′12″	1,698	Do.
779–1	Holocene	40°14′23″	68°05′47″	1,567	Ryan (1978)
779–2	Pleistocene	40°14′19″	68°06′01″	1,483	Do.
779–3	Pleistocene	40°14′18″	68°06′02″	1,473	Do.
779–4	Pleistocene	40°14′18″	68°06′04″	1,464	Do.
779–6	Holocene	40°13′44″	68°06′35″	1,154	Do.
779–8	Pleistocene	40°13′42″	68°06′37″	1,124	Do.
779–9	Pleistocene	40°13′25″	68°06′47″	1,072	Do.
784–2–1	Middle Cretaceous	40°14′39″	68°06′03″	1,553	Do.
784–3B	Pleistocene	40°14′45″	68°06′00″	1,571	Do.
784–6	Holocene	40°15′18″	68°06′19″	1,497	Do.
5121	Quaternary	40°23′30″	68°08′42″	690	Valentine (1981)
5122	Quaternary	40°23′30″	68°08′42″	645	Do.
5124	Santonian	40°17′18″	68°07′18″	1,255	Do.
5125	Santonian	40°17′23″	68°07′12″	1,255	Do.
5126	Santonian	40°17′26″	68°07′06″	1,167	Do.
5127	Santonian	40°17′30″	68°07′00″	1,142	Do.
COST G2	Middle-Late Miocene	40°50′16″	67°30′29″	81.7	Scholle and others (1980)
Exxon 133–1	*	40°49′05″	67°56′03″	69	**
Mobil 312–1	*	40°39′06″	67°46′54″	84	**
Shell 357–1	*	40°37′34″	67°44′46″	82	**
Mobil 273–1	*	40°41′05″	67°30′13″	98	**
Tenneco 187–1	*	40°46′15″	67°23′19″	94	**
Conoco 145–1	*	40°50′44″	67°17′34″	91	**
Shell 410–1	*	40°34′23″	67°12′32″	136	**
AMCOR 6013	Pleistocene	40°05′02″	68°52′08″	244	Hathaway and others (1979)
AMCOR 6014	Quaternary	40°48′20″	67°53′38″	69.8	Do.
AMCOR 6015	Pleistocene	40°23′07″	67°35′51″	209.1	Do.
ASP 17	Late Cretaceous	39°52′18″	69°35′06″	139.3	3
ASP 18	Early Maestrichtian	39°52′25″	69°36′14″	1,070	Do.

* Surface interval not recovered.
** Unpublished data.
[1] 1—J.S. Schlee, 1976, collector, Alvin dive 668. 2—J.S. Schlee, 1977, collector, Alvin dive 789. 3—Caldrill, 1967, Exxon Co., U.S.A.; Mobil Oil Corp.; Gulf Oil Corp.; and Chevron Oil Corp.

unconformity of middle Miocene(?) age lies at the same seismostratigraphic level as R8. Additionally, this widespread acoustic unconformity was tentatively correlated with reflector Merlin on MCS line 19 (Mountain and Tulcholke, 1985).

Age correlation of R8 with lithologic data from the lower slope and upper rise is difficult because of a lack of borehole and (or) dredge data from the upper continental rise; however, sampling studies along the continental slope in Atlantis, Veatch, and Oceanographer Canyons, in addition to Atlantic Slope Project (ASP) and Atlantic Margin Coring Project (AMCOR) borehole data, yielded a Pleistocene sediment veneer (<300 m) overlying Oligocene or lower strata and outcrops of Upper Cretaceous and upper Eocene rocks (Gibson and others, 1968; Hathaway and others, 1976; Ryan and others, 1978; Hathaway and others 1979; Valentine and others, 1980; Valentine, 1981; table 1). Outcrops of Upper Cretaceous, upper Eocene, and Oligocene rocks in canyons stratigraphically below the inferred outcrop pattern of R8 (sheets 1–3), in addition to borehole data, indicate a possible Oligocene to Pliocene age for R8. Generalizations concerning the age of R8 are complicated by the updip stratigraphic relations of unconformities near the slope-rise transition. Although R8 appears to be a smooth continuous surface onto which all overlying sequences onlap, the unconformity represented by R8 may have been modified at different time intervals as the overlying sequences were deposited, particularly when erosion was an integral part of downslope sediment movement (sediment gravity-flow processes); therefore, R8 is probably time-transgressive upslope.

The seismic character and structured surface of R8 (sheet 3) demonstrates that the intersection of the New England Seamount Chain with the continental margin influenced the depositional environment in the post-R8 section. R8, a laterally extensive reflector, comes to within 85 m of the sea floor in profiles located 20 km northwest of Bear Seamount (sheet 4), producing a saddle feature on strike profiles, across which direct correlation of reflectors from the northeast to the southwest was impossible. Schlee and others (1985) noted this saddle area in their report, and suggested that the formation of Bear Seamount created a structural high in the area northwest of the seamount upon which younger sequences were draped and, in some cases, thinned and tectonically disturbed. The Bear Seamount saddle divides the mapped area into two distinct depositional basins northeast and southwest of the seamount. For this reason, we present the seismostratigraphic units and associated acoustic unconformities identified seaward of Georges Bank in two sections: a northeast section from long 66°00' to 67°40' W., and a southwest section from long 67°50' to 71°00' W.

Seven reflectors were mapped in the southwest section, beginning with R1W and continuing down-section to reflectors R2W, R3W, R4W, R5W, R6W, and R8. Seven mapped seismostratigraphic units are bounded by these reflectors. In the northeast section, four reflectors were mapped: reflectors R1E, R2E, R3E, and R8 (fig. 1). Acoustic reflectors mapped in the northeast are not time correlative with reflectors mapped in the southwest; however, the time interval represented by the seismic section above the basal unconformity (R8) in the two areas is equivalent as shown by the correlation of R8 to unconformities mapped on USGS MCS lines. Figure 1 shows the stratigraphic comparison between the seismic units described in this study with those delineated by Schlee and others (1985) and O'Leary (1988). Terms describing the external configurations of seismic units, slope-front fill, onlap fill, channel fill, and sheet drape are taken from Mitchum and others (1977).

Southwest Section

Unit 7W

Unit 7W (U7W on seismic sections and maps), the lowest sequence in the mapped section, is interpreted to be onlapping basin fill. The unit is a seaward-thickening wedge, exceeding 500 m in thickness at the seaward margin of the study area (sheet 5), and lies in a slope-front basin between the western edge of the Bear Seamount saddle and a large-scale mass movement deposit below R8 described by Uchupi (1967) at approximately long 71°00' W. (sheet 4, RV *James M. Gilliss* line 25). Unit 7W exhibits moderately discontinuous to discontinuous, parallel internal reflections of variable amplitude near the top of the sequence, and grades down to incoherent returns near the base (sheet 4); incoherent returns appear to be a function of the limit of acoustic penetration.

The basal internal reflectors of Unit 7W onlap both updip and laterally onto the lower boundary of the unit, reflector R8 (sheets 4, 6). R8 can be traced updip under the present continental slope and outer shelf, particularly west of long 69°00' W. (sheet 6), although the actual location of R8 is tenuous near the shelf break. R8 may represent a middle Miocene paleoslope and rise configuration (sheet 3).

Unit 6W

Unit 6W (U6W on seismic sections and maps) is inferred to be sheet drape that lies concordantly above Unit 7W. Unit 7W consists of highly continuous, high-amplitude, lenticular, parallel to subparallel reflectors that stand out prominently on all seismic-reflection profiles west of Hydrographer Canyon (sheet 4). East of Hydrographer Canyon, the internal configuration of Unit 6W consists of moderately continuous, subparallel reflections with localized chaotic or reflection-free areas (sheet 4). Unit 6W is as much as 240 m thick at the slope-rise transition; it pinches out upslope on R8 and thins in a seaward direction (sheet 5).

The lower boundary of Unit 6W is reflector 6W (R6W), a smooth, gently seaward-dipping surface (sheet 7). West of Hydrographer Canyon, R6W marks a concordant change from the variably continuous, parallel internal reflectors of Unit 7W to the highly continuous, high-amplitude internal reflectors of Unit 6W (sheet 4). East of Hydrographer Canyon, basal onlap of Unit 6W internal reflectors onto R6W is evident (sheet 4).

Unit 6W shows little variability in thickness west of Hydrographer Canyon (sheet 5) although localized thickening is displayed at the downslope continuations of some present-day submarine canyon systems (for example, Atlantis and Veatch canyons). The thickening suggests that these canyons may have been point sources for transporting sediment to the lower slope and upper rise during the deposition of Unit 6W. Angular relationships between internal reflections of Unit 6W indicate that deposition of the unit was a product of episodic downslope sediment transport (mass movement) resulting in overlapping subfacies.

Unit 5W

Unit 5W (U5W on seismic sections and maps) is restricted to the area west of Hydrographer Canyon (sheet 5) and exhibits a mounded external configuration. The internal reflections of Unit 5W consist of a thin (<0.1 s) basal section of parallel reflectors grading upward to a complex of hummocky and chaotic reflectors (sheets 4, 6). Unit 5W pinches out eastward at long 69°00' W. onto reflector R5W and upslope on R8. The western termination of Unit 5W is outside the study area.

The lower boundary of Unit 5W is reflector 5W (R5W) (sheet 7). R5W is a gently rolling surface that dips to the southwest under Unit 5W and terminates upslope at R8. R5W is characterized by a concordant transition from Unit 6W to Unit 5W where the basal subunit occurs; otherwise, internal reflectors of Unit 5W downlap laterally and onlap upslope. East of Hydrographer Canyon, R5W is characterized by localized truncation of the upper reflectors of Unit 6W (sheet 4).

Unit 5W displays a localized characteristic that is unique among other upper-rise sequences seaward of Georges Bank. Sheet 4, line 25 shows that the unit is disrupted by several reflection-free zones. Offsets appear to affect overlying sequences and are interpreted to be localized diapirism possibly caused by salt or mud flow. Alternatively, these acoustic anomalies may be the result of localized areas of gas-charged strata.

The Unit 5W isopach map (sheet 5) shows that the unit is thickest (300 m) near the base of the continental slope downslope from the Alvin, Atlantis, and Nantucket Canyon systems. The chaotic internal reflections and mounded external form of Unit 5W, in addition to the location of the thickest portions of the unit directly downslope from several canyon axes, suggests that Unit 5W was deposited as a deep-sea-fan system.

Unit 4W

Unit 4W (U4W on seismic sections and maps) is a widespread blanket of sediment (sheet 8) that directly overlies both Units 5W and 6W and is inferred to be slope-front fill transitional to sheet drape away from the slope-rise break. Unit 4W grades laterally from a basin area with an essentially reflection-free internal configuration west of long 69°30' W. to an area of wavy subparallel internal reflectors with localized zones of chaotic reflectors (sheets 4, 6). Between long 69°00' W. and 69°30' W., there is a slight arch in the lower boundary of Unit 4W (R5W; sheet 7) that separates the unit into the two distinct seismic facies described above, suggesting different but contemporaneous depositional environments and (or) source areas. West of long 69°00' W., Unit 4W is mostly acoustically transparent and is inferred to represent a nearly homogeneous lithology (Sangree and Widmier, 1977), although local zones of discontinuous,

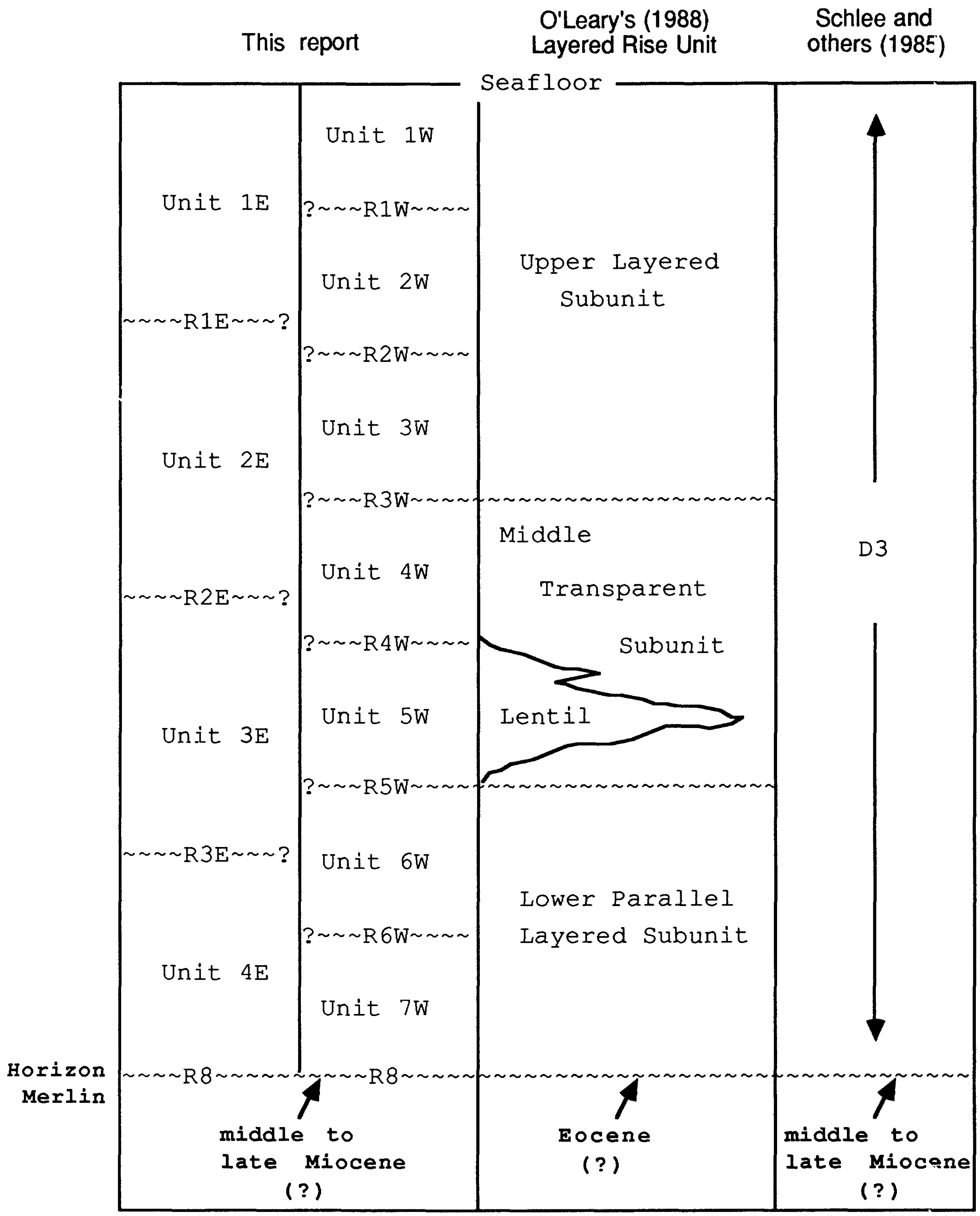

Figure 1.—Comparison of seismostratigraphic units with previous interpretations.

parallel internal reflectors are evident at the top of the unit (sheet 4). Lateral variation in the acoustic signature of Unit 4W east of long 69°00' W. suggests deposition of a sediment system of varying lithologies (sheet 4). Unit 4W pinches out to the east near the Bear Seamount saddle and onlaps R8 updip (sheet 8). The western margin of Unit 4W could not be determined due to poor resolution of the single-channel profiles.

Unit 4W is the oldest upper-rise unit to outcrop at the sea floor and is exposed at the distal reaches of Atlantis and Welker Canyons (sheet 9). The lower boundary of Unit 4W is reflector 4W (R4W) from long 71°00' to 69°00' W. where R4W downlaps onto R5W (sheets 4, 7), and reflector R5W east of long 69°00' W. (sheets 4, 7); Unit 4W onlaps R8 upslope (sheet 6). R4W marks the change from the chaotic internal reflectors of Unit 5W to the acoustically transparent nature of Unit 4W (sheet 4). R4W is a gently seaward-dipping horizon of low relief which onlaps R5W at the point where R4W changes dip to the southwest under Unit 5W. Both R4W and R5W onlap R8 upslope. Unit 4W onlaps R5W laterally (sheet 4) and updip (sheet 6).

Unit 4W varies in thickness to a greater extent than the underlying units in both dip and strike profiles. Anomalously thick sections of Unit 4W lie at the distal reaches of two submarine canyon systems, one downslope from Veatch Canyon and the other downslope from two unnamed canyons just east of Oceanographer Canyon (sheet 8). These submarine canyons may have been sediment sources for the eastern and western portions of Unit 4W, although the top of the unit is an erosional surface, which makes interpretation of the Unit 4W isopach tenuous.

Unit 3W

Unit 3W (U3W on seismic sections and maps) is a large body of strata inferred to be sheet drape. Unit 3W consists of wavy, parallel to subparallel, moderately continuous to discontinuous internal reflectors (sheets 4, 6). Unit 3W isopach values are variable (sheet 8), a probable function of current bathymetry as Unit 3W is exposed over much of the continental rise (sheet 9).

The western margin of Unit 3W lies at an outcrop location at long 70°30' W. and the eastern margin is located at the Bear Seamount saddle (sheet 8). The eastern margin of Unit 3W is defined by resolution difficulties of the upper and lower surfaces rather than a demonstrable pinchout of the unit. An uncorrelated unit lies to the east of Unit 3W northwest of Bear Seamount and possibly correlates with Unit 3W; however, resolution of the internal reflectors is obscured in this area by the arch in R8, precluding any tie of Unit 3W to the uncorrelated unit. Unit 3W pinches out upslope on R8 where the unit is overlain by Unit 2W (sheet 4). In the area where Unit 3W is exposed on the sea floor, selected dip profiles indicate that the upper portions of Unit 3W may grade into sediment that drapes the intercanyon areas of the continental slope (sheet 6). At these locations, truncation of the upper reflectors of Unit 3W is noticeable below a veneer of sediment, suggesting that downslope sedimentary processes are currently reworking Unit 3W in the intercanyon areas.

The lower boundary of Unit 3W is reflector 3W (R3W) (sheet 10), a seaward-dipping erosional surface that is characterized by basal onlap of internal reflectors of Unit 3W upslope and laterally, and by the truncation of upper internal reflectors of Unit 4W, particularly in topographic depressions in the upper surface of Unit 4W (sheets 4, 6). R3W crops out at several locations on the sea floor, exposing the underlying Unit 4W (sheet 10). West of the outcrop of R3W at long 70°30' W., an underlying uncorrelated unit is exposed (sheet 9), and probably correlates with Unit 4W, although resolution difficulties of R4W and R3W prevented a definite tie between the two units. R3W onlaps R8 upslope (sheet 6) and laterally to the east (sheet 4).

The sea floor forms the upper boundary of Unit 3W (sheet 4) except in the area between long 68°30' and 69°30' W., where R2W marks the upper boundary. Truncation of internal reflectors at the upper boundary of Unit 3W is evident, especially at the distal portions of submarine canyon axes, indicating that the morphology of the upper rise currently is being modified by erosional processes (sheet 4).

Unit 2W

Unit 2W (U2W on seismic sections and maps) is restricted to the area between long 68°30' W. and 69°30' W, and is inferred to be sheet drape that thins seaward (sheet 8). The unit consists of moderately continuous, subparallel to parallel reflectors (sheet 4). Unit 2W pinches out upslope on R8 (sheet 6) except where resolution difficulties did not allow a precise determination of the upslope boundaries of the unit.

Reflector 2W (R2W) is the lower boundary of Unit 2W, a seaward-dipping surface of low relief which crops out at the western margin of the unit and in Hydrographer Canyon (sheet 10). R2W onlaps R8 upslope (sheet 6), although the updip termination of R2W was uncertain in some areas due to poor resolution. Basal onlap of Unit 2W internal reflectors onto R2W is evident updip (sheet 6) and laterally (sheet 4).

Internal reflectors of Unit 2W are truncated at the unit margins (sheet 4), indicating that the unit may have been more extensive over the continental rise during the time of deposition. Unit 2W is deeply incised at the distal reaches of Hydrographer Canyon (sheet 4) and crops out east of that location (sheet 9). Unit 2W thins drastically where it is exposed on the upper continental rise (east of long 69°00' W.; sheet 8), suggestive of the large amount of strata that has been eroded.

Unit 1W

Unit 1W (U1W on seismic sections and maps), the uppermost seismostratigraphic unit in the study area, is inferred to be sheet drape on the continental rise. Unit 1W consists of highly continuous, high-amplitude, parallel internal reflectors (sheet 4). Unit 1W thins both laterally and seaward (sheet 8). In certain areas, internal reflectors of Unit 1W lose their continuity and vary in amplitude at the lower boundary of the unit. Unit 1W onlaps R8 updip (sheet 6), although RV *Columbus Iselin* profile 10 (sheet 6) shows that the unit is erosionally truncated updip by a tributary to Hydrographer Canyon.

The lower boundary of Unit 1W is reflector 1W (R1W) (sheet 10), a seaward-dipping surface that represents an erosional interval. R1W is characterized by onlap of Unit 1W internal reflections and truncation of Unit 2W internal reflections, both along strike and updip (sheets 4, 6). The eastern and western margins of Unit 1W are sharply defined by the downslope continuation of the Hydrographer and Veatch Canyon systems, where R1W crops out (sheet 10). R1W and the internal reflectors of Unit 1W are truncated at these margins, suggesting that erosion (canyon downcutting) has defined the areal extent of Unit 1W. The upper boundary of Unit 1W is the present-day sea floor.

A subfacies of unit 1W that drapes the unit (<0.05 s two-way traveltime) within intercanyon areas truncates reflectors lying below the subfacies (sheet 4). This subfacies also drapes and truncates reflectors within other seismic facies units (Units 2W, 3W, and 4W) outcropping on the upper continental rise seaward of Georges Bank (sheet 4). Although canyons dissecting the Georges Bank margin are actively downcutting the upper-rise stratigraphy, intercanyon areas have experienced recent deposition of sediment. Parallel, high-amplitude reflections within the subfacies indicate turbidite activity that originates on the slope or outer shelf and carries sediment to the intercanyon areas.

Northeast Section

Unit 4E

Unit 4E (U4E on seismic sections and maps) is the lowermost seismostratigraphic unit in the study area northeast of Bear Seamount and is inferred to be a channel-fill deposit (sheet 11). The unit fills several negative relief features in R8 (sheet 4). The internal configuration of Unit 4E consists of wavy, subparallel reflectors of moderate continuity. Unit 4E pinches out upslope and laterally on R8.

Unit 3E

Unit 3E (U3E on seismic sections and maps) (sheet 11) is a widespread deposit inferred to be slope-front fill and consists of wavy, subparallel internal reflectors of moderate continuity. Localized zones that are acoustically transparent or that contain discontinuous, parallel reflectors are evident within Unit 3E seismic-reflection profiles (sheet 4). Unit 3E pinches out upslope on R8 (sheet 6).

Unit 3E probably correlates with the thin layer of strata directly overlying R8 northwest of Bear Seamount in the Lydonia Canyon area (sheet 9), but poor resolution of the seismic-reflection profiles prevents direct correlation. Unit 3E may continue northeast of Munson Canyon (sheet 4), but again, resolution is poor.

Unit 3E is bounded below by reflectors 3E (R3E) and R8 (Sheet 11). Both reflectors are characterized by basal onlap of Unit 3E internal reflectors both laterally and updip (sheets 4, 6). R3E is a localized seaward-dipping reflector that truncates the upper internal reflectors of Unit 4E.

Unit 2E

Unit 2E (U2E on seismic sections and maps) (sheet 11) lies unconformably above Unit 3E and is inferred to be slope-front fill transitional to sheet drape away from the continental slope. Unit 2E strata are exposed over portions of the continental rise south of Georges Bank (sheet 9). The unit consists of moderately continuous, wavy, subparallel internal reflectors (sheets 4, 6). Unit 2E pinches out upslope on R8; the lateral boundaries of the unit are uncertain due to a loss of resolution of the upper and lower boundaries in along-strike profiles.

The lower boundary of Unit 2E is reflector 2E (R2E), a seaward-dipping surface of low relief (sheet 11), characterized by basal onlap of Unit 2E internal reflectors and localized truncation of Unit 3E's upper internal reflectors (sheet 4). Small, localized channel structures, defined by R2E, cut into the underlying Unit 3E. Of particular interest is a buried channel that lies below R8 in this area, which may represent the pre-R8 position of Powell Canyon (sheet 4). R2E outcrops in Powell and Munson Canyons (sheet 11), and onlaps R8 upslope (sheet 6).

Loss of resolution of R2E due to poor acoustic returns northeast of Munson Canyon, and of the upper boundary of Unit 2E (reflector 1E (R1E)) southwest of Powell Canyon prevented the determination of the lateral boundaries of Unit 2E. Most of the uncorrelated unit west of Powell Canyon probably correlates with Unit 2E, but a loss in resolution of the upper boundary of Unit 2E (R1E) prevents a direct tie.

Unit 1E

Unit 1E (U1E on seismic sections and maps) is the uppermost seismostratigraphic unit of the continental rise in the northeast section of the study area (sheet 11). Unit 1E is inferred to be sheet drape and portions of it are exposed over most of the continental rise in this area (sheet 9). Unit 1E has been eroded and it is uncertain as to how much of the section is missing. The configuration of Unit 1E internal reflectors consists of highly continuous, parallel reflectors (sheet 4).

The lower boundary of Unit 1E is reflector 1E (R1E) (sheet 11), a seaward-dipping surface of moderate relief that onlaps R8 updip, and outcrops downdip (sheet 6). R1E is characterized by localized truncation of the upper internal relectors of Unit 2E, but it generally marks a concordant change from the moderately continuous reflectors of Unit 2E to the highly continuous reflectors of Unit 1E (sheet 4). Basal onlap of Unit 1E internal reflectors onto R1E are evident updip (sheet 6). The westernmost margin of the unit could not be determined due to loss of resolution of R1E, although much of the uncorrelated seismic facies east of Powell Canyon (sheets 4, 9) probably correlate with Unit 1E.

The isopach values of Unit 1E are a function of its upper boundary, the sea floor. Portions of the unit have been removed due to downcutting of a series of canyon systems between Munson and Nygren Canyons (sheet 4). An alternate interpretation by O'Leary (1986) suggests that a portion of this area represents a major lower slope slide. Truncation of the upper internal reflectors of Unit 1E, particularly at the junction of the unit with canyon axes, demonstrates that Unit 1E has been considerably eroded.

DISCUSSION

Interpretation of high-resolution seismic-reflection profiles indicates that the upper 1.0-s interval of the upper continental-rise sequence southeast of Georges Bank formed as a result of cyclic erosional-depositional processes similar to what has been noted by other authors studying the Georges Bank upper-rise stratigraphy (Uchupi and others, 1977; Uchupi and Austin, 1979; Valentine, 1981; Poag, 1982a,b; Schlee and others, 1985). Laterally extensive acoustic unconformities, displaying angular relations to reflectors above and below the unconformable surfaces, are well developed throughout the section. The seismostratigraphic units defined by these unconformities represent onlapping sequences of slope-front and basin fill with differing internal configurations and localized areas of chaotic fill. Thus, the origin of the post-middle Miocene-rise sedimentary wedge is interpreted to be a result of processes related to the deposition of submarine fan systems (similar to the findings of Sangree and Widmier, 1977).

A widespread unconformity, reflector R8, forms the base of the upper-rise sedimentary wedge. The correlation of R8 with a reflector identified on deep-penetration, low-resolution, multichannel seismic-reflection profiles (Valentine, 1981; Poag, 1982b; Mountain and Tucholke, 1985; Schlee and others, 1985) gives us an age estimate for R8 of middle to late Miocene. Oligocene or lower age strata that lie stratigraphically below R8 are exposed in submarine canyon axes along the lower slope (Stetson, 1949; Gibson and others, 1968; Ryan and others, 1978; Valentine and others, 1980), and thus do not invalidate a middle to late Miocene(?) age estimate of R8. The age of R8 is at best a rough estimate because of a lack of borehole control. The best estimate we can give in this study, based on lithologic data, is that R8 is post middle Oligocene(?). Extrapolation of R8 upslope to the continental-shelf strata was tenuous and prevented correlation of R8 to previously interpreted shelf stratigraphy and borehole control from the COST G-1 and G-2 wells (Klitgord and others, 1982; Poag, 1982a, b; Schlee and Fritsch, 1983).

O'Leary (1988) placed the late Oligocene A^u horizon of Mountain and Tucholke (1985) within his Layered Rise Unit (the continental-rise sedimentary wedge; fig. 1). By comparing the stratigraphic relations of unconformities recognized by Schlee and others (1985) with the high-resolution seismic-reflection profiles interpreted in this study, in addition to seismostratigraphic ties along USGS MCS Line 13 (K. Klitgord, oral commun.), A^u clearly lies stratigraphically below the continental-rise sedimentary wedge; below R8. The earlier age limit for the upper continental-rise section (above R8) is thus interpreted to be post-late Oligocene, later than the Eocene age proposed by O'Leary (1988).

The processes responsible for the formation of R8 also are speculative. The truncation of internal reflectors in seismostratigraphic units lying below R8 were identified at locations along the slope, indicating that the surface represents an erosional interval. Downdip away from the slope-rise transition, R8 becomes conformable with underlying reflectors in dip profiles with sufficient resolution, indicating either a nondepositional or erosional interval. In many profiles, however, resolution below the unconformable surface was insufficient to demonstrate angular or conformable relationships of reflectors at the upper margins of underlying sequences. R8 is a laterally extensive surface onto which all overlying units onlap, indicating that the formation of the surface probably was tied to a major erosional event. Poag (1987) described an unconformity that severely eroded the slope area in the middle Miocene offshore New Jersey sediments as being the upper-rise equivalent to horizon Merlin, a deep-sea middle Miocene erosional interval caused by a relatively brief period of intensified bottom-current flow (Mountain and Tucholke, 1985). Truncation of underlying reflectors along the slope by R8, location of R8 above horizon A^u, and onlap of all overlying reflectors seaward of Georges Bank, as well as ties along MCS lines that intersect the DSDP Leg 95 area, demonstrate that R8 is the upper rise equivalent of horizon Merlin.

Following the erosional hiatus that formed R8, downslope transport of sediment began building the post-middle Miocene continental-rise sedimentary wedge, resulting in a series of overlapping submarine-fan systems. This agrees with O'Leary's (1988) interpretation that the continental-rise sedimentary wedge was derived, at least partially, from various point sources along the slope. Whether the rise units also were derived (or modified) from laterally distal sources is uncertain.

Increased thickness of several of the seismostratigraphic units downslope from the axes of present-day submarine canyon systems indicates that these canyons may have been active in the late Tertiary and provided a conduit for the mass transport of sediment from the outer continental shelf and upper slope to the upper rise. Unit 4W shows appreciable thickening at the distal reaches of Veatch and Oceanographer Canyons (sheet 8). The isopach map of Unit 5W (sheet 5) shows increased sediment thickness directly downslope from the Atlantis, Alvin, and Nantucket Canyon systems. We interpret Unit 5W to be a series of overlapping submarine-fan systems in agreement with O'Leary's (1988) interpretation of his equivalent to Unit 5W (Lentil, fig. 1).

The variation in acoustic characteristics in each of the mapped seismostratigraphic units (acoustically transparent areas that grade into areas of well-laminated parallel and (or) chaotic internal reflectors) suggests either that distinct depositional environments existed during deposition or that different source areas may have contributed sediment within a single seismostratigraphic sequence. For example, Unit 6W extends over a large area of the upper continental rise (sheet 5) and grades laterally from an area of evenly laminated, parallel internal reflectors west of Hydrographer Canyon (which suggests turbidity current deposition) to an area of subparallel to chaotic returns east of Hydrographer Canyon (which indicate another type of sedimentary deposit, possibly a debris-flow deposit following the definition given in Middleton and Hampton, 1976). Each of the seismostratigraphic unit boundaries, in turn, exhibits unconformable relations that grade laterally or updip to conformable boundaries, indicating that deposition and erosion played an integral part in the development of these acoustic boundaries. Poag (1987) suggests that sequence boundaries on the upper rise are primarily the result of downslope sediment transport due to sediment gravity flow. The boundary that separates Unit 1W from Unit 2W (R1W) exhibits this relationship particularly well (sheet 4). The upper internal reflectors of Unit 2W are truncated by R1W in certain areas above which onlap of the basal internal reflectors of Unit 2W is common, particularly in the topographic depressions in R1W. However, the boundary relations of Units 1W and 2W are conformable in adjacent areas (sheet 4). Thus, a complex interplay of mass-movement processes (Schlee and others, 1985; O'Leary, 1988) probably were responsible for the formation, distribution, and seismostratigraphic-unit boundary relations on the upper rise.

Deposition of the upper continental-rise sedimentary wedge above R8 occurred in two distinct basin areas that are separated by a structural high underlying R8 northwest of Bear Seamount (sheet 4). The thin sedimentary sequence above R8 across the Bear Seamount saddle may be a result of either erosion or nondeposition of sediment. Swift (1986) suggests that abyssal current erosion and (or) nondeposition of sediment near the axis of the New England Seamount chain may have been accentuated in the post-A^u section on the middle to lower continental rise. If this is also true for the upper rise, deposition on the upper rise may have been further complicated by downslope erosional-depositional processes acting on the upper rise. The rise wedge is much thinner northeast of this saddle (<0.5 s) in comparison to the section southwest of the saddle (up to 0.9 s thick), suggesting that (1) sediment influx in the northeast section was relatively lower, (2) the northeast section is equivalent to the upper seismostratigraphic units of the southwest section, making R8 time transgressive to the northeast, or (3) higher erosional activity occurred in the northeast during the development of that part of the rise. The acoustic nature of seismic facies and unconformities southwest and northeast of the Bear Seamount saddle area differ with respect to each other; therefore, no direct comparisons can be made between units in the two areas regarding timing of deposition of unit 1E versus 1W, and so on. The above suggests that seismostratigraphic relations within the two areas are the result of different post-R8 depositional environments; however, based on the ties with USGS MCS lines, the post-R8 stratigraphic sections in both areas represent the same time interval, indicating that an interplay of varying sedimentation supply, rates, depositional environments, and erosional activity resulted in two distinct post-R8 seismostratigraphic sequences.

High-resolution seismic-reflection profiles indicate that the upper continental rise seaward of Georges Bank is presently undergoing a period of erosion or nondeposition. Submarine canyons cut the lower-slope and upper-rise seismostratigraphic units, controlling the outcrop pattern and distribution of exposed seismic facies on the upper rise (sheet 9). Canyon downcutting produced truncated internal reflectors at canyon walls in the upper rise units, in addition to truncating R8 along the lower slope (sheets 3, 4, 6). A distinct lack of deep-seated fault traces in the high-resolution seismic-reflection profiles suggests that erosional activity, as opposed to structural control, has been the primary agent responsible for the present-day morphology of the lower slope and upper rise. An exception to this lack of structural control on the present-day morphology is what is interpreted to be the localized diapirism of Unit 5W (sheets 4, 6). This proposed diapirism has disrupted overlying reflectors R4W and R3W and may affect the surface morphology (Unit 3W).

SUMMARY

1. Ten laterally extensive acoustic unconformities were identified and mapped within the upper 1.0-s interval on the lower continental slope and upper continental rise southeast of Georges Bank. Identification of these unconformities within the upper rise sedimentary wedge allowed delineation of 11 seismostratigraphic units.

2. One unconformable surface, R8, forms the base of the onlapping rise sedimentary wedge, and is interpreted to represent a middle Miocene erosional interval (Merlin) which affected the lower slope and upper rise southeast of Georges Bank

3. The rise sediment wedge was formed as a result of cyclic depositional-erosional processes operating on the lower slope and upper rise.

4. The deposition of a single seismostratigraphic unit was a function of varying depositional environments, and possibly varying source area. Deposition of the upper rise units was a product of mass-movement processes.

5. A thickening of several seismostratigraphic units at the distal reaches of existing canyon systems suggests that these same

canyons may have been in place in the late Tertiary, and were conduits for sediment gravity flows to the upper rise area.

6. The surface morphology of the upper rise off Georges Bank is interpreted to be a product of erosional activity, indicated by truncated reflectors at the margins of seismic sequences outcropping on the upper rise, particularly at the distal reaches of existing canyon systems.

7. A structural high below R8 in the area northwest of Bear Seamount divides the upper rise into two separate depositional basins. The thinning of the seismostratigraphic units, inability to correlate seismic facies between the two basins, and general lack of resolution of the internal reflectors across this saddle inhibited correlation of the units within the two basins. The relative timing of deposition within the two basins therefore remains in question.

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