Rise and demise of the Bahama–Grand Banks gigaplatform, northern margin of the Jurassic proto-Atlantic seaway

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ABSTRACT


An extinct, > 5000-km-long Jurassic carbonate platform and barrier reef system lies buried beneath the Atlantic continental shelf and slope of the United States. A revised stratigraphic framework, a series of regional isopach maps, and paleogeographic reconstructions are used to illustrate the 42-m.y. history of this Bahama–Grand Banks gigaplatform from its inception in Aalenian (?) (early Middle Jurassic) time to its demise and burial in Berriasian-Valanginian time (early Early Cretaceous). Aggradation–progradation rates for the gigaplatform are comparable to those of the familiar Capitan shelf margin (Permian), and are closely correlated with volumetric rates of siliciclastic sediment accumulation and depocenter migration. Siliciclastic encroachment behind the carbonate tracts appears to have been an important impetus for shelf-edge progradation. During the Early Cretaceous, sea-level changes combined with eutrophication (due to landward soil development and seaward upwelling) and the presence of cooler upwelled waters along the outer shelf appear to have decimated the carbonate producers from the Carolina Trough to the Grand Banks. This allowed advancing siliciclastic deltas to overrun the shelf edge despite a notable reduction in siliciclastic accumulation rates. However, upwelling did not extend southward to the Blake–Bahama megabank, so platform carbonate production proceeded there well into the Cretaceous. Subsequent stepwise carbonate abatement characterized the Blake Plateau Basin, whereas the Bahamas have maintained production to the present. The demise of carbonate production on the northern segments of the gigaplatform helped to escalate deep-water carbonate deposition in the Early Cretaceous, but the sudden augmentation of deep-water carbonate reservoirs in the Late Jurassic was triggered by other agents, such as global expansion of nannoplankton communities.

Introduction

In the early part of the Middle Jurassic (ca. 186 Ma) scattered clusters of small carbonate banks began to form along the North American margin of the proto-Atlantic seaway. The banks flourished and expanded for 42 m.y., culminating in a Late Jurassic carbonate gigaplatform (from the Greek "gigas", meaning "giant") that stretched > 5000 km from the Bahamas to the Grand Banks of Newfoundland (Fig. 1, Jansa, 1981, 1984) ("Great Mesozoic Carbonate Bank" of Meyer, 1989). Sheridan (1974), who was among the first to suspect its magnitude, used seismostratigraphy (e.g., Press and Beckman, 1954; Ewing et al., 1966; Sheridan et al., 1966, 1970; Sheridan and Drake, 1968; Emery and Uchupi, 1972), seafloor dredgings (Sheridan et al., 1969) and extrapolation of early drilling results from the Canadian margin (Laughton et al., 1972; McIver, 1972) to construct representative dip sections across the gigaplatform. By 1976, the U.S. Geological Survey had collected enough 24- and 48-channel, common-depth-point (CDP) seismic reflection profiles to show that a prominent buried "outer ridge" in the Georges Bank Basin, Baltimore Canyon Trough, and Carolina Trough (Fig. 2) probably represented a Late Jurassic–Early Cretaceous reef trend at the seaward edge of a prograded carbonate bank (Schlee et al., 1976; Grow et al., 1979). That same year, exploratory drilling in the Baltimore Canyon Trough and Georges Bank Basin confirmed the
Fig. 1. Comparison of Late Jurassic configuration of Bahama–Grand Banks gigaplatform with modern Great Barrier Reef of Australia. Great Barrier Reef rotated by 180° so equator is at bottom of page relative to both platforms. Carbonate tracts stippled.

presence of Jurassic shallow-water carbonate rocks (Smith et al., 1976; Scholle, 1977, 1980; Scholle and Wenkam, 1982; Amato and Simonis, 1979, 1980; Amato and Bebout, 1980; Libby-French, 1981, 1984; Poag, 1985). It was not until 1983, however, that the first of three boreholes penetrated the Upper Jurassic shelf edge in the Baltimore Canyon Trough (Fig. 3; Shell 372-1, 586-1, and 587-1), providing incontrovertible proof of a buried barrier reef in that basin (Edson, 1986a, b, 1987, 1988; Eliuk et al., 1986; Karlo, 1986; Meyer, 1986, 1989; Ringer and Patten, 1986; Erlich et al., 1988, 1990; Prather, 1988; Lawrence et al., 1990; Prather, 1991). A grid of seismic profiles across the continental shelf (Fig. 3) verifies the extent of the gigaplatform far beyond the Baltimore Canyon Trough (e.g., Emery and Uchupi, 1984; Uchupi and Shor, 1984; Schlee et al., 1988).

To the south, the platform rims the Carolina Trough and the Blake Plateau Basin (Sheridan et al., 1979; Dillon and Popenoe, 1988), then spreads across the Bahama Basin (Fig. 2) and into Cuba (Tator and Hatfield, 1975) and the eastern Gulf of Mexico (West Florida Platform, Salvador, 1987; Ball et al., 1988; Buffler, in press). Direct evidence of the ancient platform is also sparse in this southern area, but several exploratory wells and seafloor samplings have corroborated seismostratigraphic interpretations (Meyerhoff and Hatten, 1974; Tator and Hatfield, 1975; Benson et al., 1978a, b, c; Dillon et al., 1979, 1988; Freeman-
Fig. 3. Location of key multichannel seismic reflection profiles and boreholes used in this study. Modified from Grow et al. (1988).
To the north, the gigaplatform extends across the outer edge of the Georges Bank Basin onto the Canadian margin (continental shelf off Nova Scotia and Newfoundland), where another extensive seismic grid (tied to wells) records its presence (McIver, 1972; Jansa and Wade, 1975; Given, 1977; Eliuk, 1978, 1981, 1988; Jansa, 1981, 1984; Jansa and Wiedmann, 1982; Jansa et al., 1982, 1988b; Eliuk et al., 1986). Only two wells, however, have penetrated the shallow-water Jurassic reef facies on the Canadian margin (Shell Deroasco G-32 and Mobil-Texaco-PetroCanada Cohasset L-79; Pratt and Jansa, 1988). Two additional wells penetrated peri-reef debris (Shell-PetroCanada Penobscot L-30 and Chevron-PEX-Shell Acadia K-62). Recent drilling by the Ocean Drilling Program on the margin of Galicia Bank (off Spain, Boillot et al., 1988) has indicated that the gigaplatform may have extended even farther around the eastern end of the proto-Atlantic (Jansa et al., 1988). Coeval carbonate platforms stretched from the Grand Banks across the Galicia margin to the Lusitanian and Algarve basins of Portugal.

The purpose of this paper is to describe, illustrate, and interpret the geologic and seismic data concerning this carbonate gigaplatform as known along the U.S. segment of the proto-Atlantic seaway. I will attempt to discern its initiation, growth, and disappearance in the context of the regional depositional history of the margin; to examine its relationships to tectonic events, sea-level changes, paleoclimates and paleoceanographic regimes; and briefly to compare its development with coeval deposits on the Canadian and Gulf Coast margins.

Stratigraphy and correlation: strategy and problems

My general approach to correlation over this vast region has been to choose key wells (COST wells and selected exploratory wells) as lithostratigraphic and biostratigraphic standards by which to establish stratigraphic reference sections along dip-oriented seismic reflection profiles (Fig. 3; Poag, 1982b, 1985, 1987). Starting with reference sections in the Georges Bank Basin and Baltimore Canyon Trough, I have used seismostratigraphy (to identify depositional sequences; Mitchum et al., 1977a) and seismic facies analysis (to interpret lithofacies; Mitchum et al., 1977b) to extrapolate the stratigraphic and depositional framework through a margin-wide network of intersecting multichannel seismic reflection profiles (> 30,000 line-km) that covers the areas not yet (or only sparsely) drilled (e.g., Carolina Trough, Blake Plateau Basin, Bahama Basin; Fig. 3). The southern end of the seismic grid was tied to the stratigraphy of the Great Isaacs No. 1 well in the Bahama Basin (Fig. 3) and to Deep Sea Drilling Project Sites 390 (Blake Spur) and 391 (Blake Basin; Fig. 3). Seafloor samples from the Blake Escarpment (Dillon et al., 1988) provided further age constraints on the southern profiles. From these analyses, I defined 23 margin-wide depositional sequences (Poag and Sevon, 1989) which can be correlated and mapped from the Bahama Basin to the Georges Bank Basin. The stratigraphic correlations are highly interpretive in some areas however, especially in the deeper undrilled sections (older than Bajocian). Thus, other authors could be expected to define and correlate sequences somewhat differently (e.g., Lawrence et al., 1990). Indeed, as discussed later on, I have considerably revised some of my own previously published interpretations.

A host of authors (cited throughout the text) have analyzed various aspects of U.S. Atlantic margin stratigraphy, having relied mainly on seismic profiles. To date, however, only four principal groups of authors have offered detailed, stage-level, chronostratigraphic interpretations of the shelf-edge stratigraphy:

Figure 4 shows the contrasting correlations of these four groups of authors for two Shell wells that drilled and cored the shelf-edge carbonate section in the Baltimore Canyon Trough. The coarse lithostratigraphic and biostratigraphic correlations are similar, but in detail there are some significant contradictions, especially among the Minerals Management Service (MMS) correlations. It is especially notable that the MMS correlations (based on palynological interpretations of Cousminer, in Edson, 1986, 1987) show that the lower section of each well is older by 15–20 m.y. than any other group of researchers has indicated. I interpret this discrepancy to mean that older Jurassic palynomorphs have been reworked into the Upper Jurassic sections in this area.

The most contentious correlation problem encountered in the study area involves the Jurassic section in the Georges Bank Basin. Most authors who have studied this section (Amato and Simonis, 1980; Ascoli, 1982, 1983; Jansa and Wiedmann, 1982; Poag, 1982a, b; Schlee and Fritsch, 1982; Manspeizer, 1985; Schlee et al., 1985; Klitgord et al., 1988; Poag and Valentine, 1988; Schlee and Klitgord, 1988; several unpublished oil company reports) have interpreted the oldest non-evaporitic marine sediments above the basement to be of Early to Middle Jurassic age (e.g., COST G-1 well, ~2200 to ~4600 m; COST G-2 well ~3000 to ~6500 m; Fig. 5). In stark contrast is the interpretation made by Cousminer and his coauthors (Cousminer et al., 1984; Manspeizer and Cousminer, 1988; Cousminer and Steinkraus, 1988) and accepted in Manspeizer’s (1988) and Schlee et al.’s (1988) latest interpretations. The Cousminer group claimed that the lower 2200 m of the G-2 well (and thus equivalent sections throughout the other east coast basins) are of Triassic (Carnian–Norian) age. This disparate interpretation is based on Cousminer’s identification of rare, poorly preserved, Triassic palynomorphs in a single core (core 5 at 4434 m) in the COST G-2 well (Fig. 5). Another core (core 4), 400 m higher in the G-2 well, also contains Triassic palynomorphs (in greater abundance), but Cousminer contends that these have been reworked into Bajocian rocks (according to Davies (1985), however, these “Bajocian” rocks could be as young as Bathonian, which would agree with my correlations, as based on Ascoli’s (1982) biostratigraphy). Cousminer and Steinkraus (1988) also rejected, as “contamination”, the Middle Jurassic palynomorphs found by Fairchild and Gartner (1977) in a core at 5612 m in the COST G-2 well.

Placing the top of the Triassic at such a high stratigraphic position has untenable implications for the tectonic and depositional history of the Atlantic margin basins. Cousminer and colleagues used their interpretation of the biochronologic age of the rocks to argue that a “postrift unconformity” is present in the COST G-2 well either at 4051 m (Cousminer and Steinkraus, 1988) or at 4153 m (Manspeizer, 1988). They claimed that this unconformity is associated with an attenuated Liassic section, although they found no evidence of Liassic microfossils in the well (they cited only a personal communication to support the Liassic age). The stratigraphic position of the postrift

Fig. 4. Comparison of four different stratigraphic interpretations of two key wells drilled by Shell Offshore Inc. into Bahama–Grand Banks gigaplatform on the seaward margin of Baltimore Canyon Trough.
unconformity, however, is not dependent upon the age of the rocks above and below it. As generally defined (e.g., Falvey, 1974), the postrift unconformity is the surface that separates deposits formed during continental rifting (synrift deposits such as rift-basin fill) from deposits formed after seafloor spreading (drifting) had begun (postrift sediments). As such, the unconformity marks a profound change in structural and depositional style, which is manifest in two principal ways: (1) On seismic reflection profiles, synrift sediments typically show non-parallel (convergent), fan-like (wedge-shaped) reflection geometries (e.g., Montadert et al., 1979; Ladd and Sheridan, 1987; Hutchinson and Klitgord, 1988; Klitgord et al., 1988). These geometries result from the fact that the fault-bound margins of the rift basins subsided faster (collecting thicker sediment columns) than the non-faulted margins. This structural and depositional style contrasts markedly with that of the postrift deposits, which display principally horizontal (or gently warped), parallel reflection geometries, having accumulated on a more uniformly (thermotectonically) subsiding basin floor. The surface separating these two

Fig. 5. Comparison of four different stratigraphic interpretations of key COST (Continental Offshore Stratigraphic Test) wells drilled in Georges Bank Basin. C-N = Carnian-Norian.
contrasting structural and depositional regimes is easily discernible on many seismic sections as an angular unconformity (the postrift or "breakup unconformity"; Falvey, 1974). In addition, synrift and postrift deposits display distinctly different patterns of areal distribution. Synrift deposits typically occupy narrow, elongate, isolated basins (long axes parallel to subsequent spreading axis), and accumulate almost entirely upon continental or "transitional" crust. Postrift deposits, on the other hand, are more widespread (broader basins due to spreading seafloor and regional thermotectonic subsidence) and are well represented as deeper water deposits on the oceanic crust.

Along the U.S. Atlantic margin, synrift deposits can be clearly distinguished from postrift deposits by both their cross-sectional geometry and their areal distribution. Seismic sections (Figs. 6–10) and isopach maps (e.g., Figs. 11–13) show that most of the section in the COST G-2 well designated by Cousminer and Steinkraus (1988) and Manspeizer (1988) as "Liassic–Triassic" comprises unequivocal postrift deposits. It follows then, that if the "Liassic–Triassic" interval in the COST G-2 well is a postrift deposit, it can not also be Triassic in age, because all available onshore and offshore data indicate that seafloor spreading did not start until well into Jurassic time (see discussion below and references therein). Manspeizer himself (1985, 1988) has corroborated this, which is, of course, the reason that he, Cousminer, and Steinkraus placed the postrift unconformity so high in the COST G-2 well.

The Cousminer–Manspeizer–Steinkraus interpretation would place the postrift unconformity as much as 2600 m above where seismic sections and maps show it clearly to be in the Georges Bank Basin (and where it was drilled in both the G-1 and G-2 wells; e.g., Grow et al., 1988; Klitgord et al., 1988; Figs. 5 and 6). Correlation with equivalent rocks in the Baltimore Canyon Trough would place the Cousminer–Manspeizer–Steinkraus "postrift unconformity" 5500 m above its seismically determined position in the central part of the Baltimore Canyon Trough (e.g., Benson and Doyle, 1988; Klitgord et al., 1988; Lawrence et al., 1990; Fig. 7).

Seismic correlations along intersecting profiles from the COST G-1 to the COST G-2 wells in the Georges Bank Basin are straightforward and uninterrupted by structural complexities (essentially layer-cake geology, with thickening in the older section in a downflap direction, towards the G-2 well; Fig. 5). The stratigraphic interval that Ascoli (1982) interprets as Bajocian (on the basis of ostracodes) in the G-1 well (4407–4557 m) correlates with the bottom of the sequence I correlate as Bajocian–lower Bathonian. The top of my Bajocian–lower Bathonian sequence is, in turn, the top of the Triassic section according to Cousminer and Steinkraus (1988) and Manspeizer (1988). This age disparity (a difference of 35–40 m.y.) is reminiscent of the problem with Cousminer's "old" ages in the Baltimore Canyon Trough wells (Fig. 4, in column labeled Edson, 1986, 1987). After considering all the available data, it seems clear to me that reworking of older Triassic and Jurassic palynomorphs into younger Jurassic strata is much more pervasive in the east coast offshore basins than Cousminer and his colleagues have recognized. I therefore reject the Triassic interpretation proposed by Cousminer et al., and reaffirm my (and others') earlier conclusion that all the marine rocks below ~4000 m in the COST G-2 well (and equivalent sections in the other basins of the east coast) are most likely Early to Middle Jurassic deposits (but are probably limited to Aalenian and Bajocian–early Bathonian age; Poag, 1982a, b; Schlee et al., 1985; Manspeizer, 1985; Poag and Valentine, 1988; Klitgord et al., 1988).

In addition to these principal correlation problems, there are a number of minor correlation discrepancies of the type to be expected in a frontier exploration region where well data are sparse. The use of different fossil groups by different analysts, for example, causes variable placement of biozonal and chronostratigraphic boundaries; many of the benthic fossils used for correlation are facies-dependent, and may have different stratigraphic ranges in different paleoenvironmental settings. Other problems include the dependence on rotary cuttings for most samples (none of the sequence boundaries were encountered in cores), intense diagenesis of some carbonate sections, difficulty in obtaining correct seismic
Fig. 7. Shelf edge depth section along seismic line 25 across central part of Baltimore Canyon Trough. Above: General seismic features and magnetic profile (from Grow et al., 1988). ECMF = East Coast Magnetic Anomaly. Below: Geologic interpretation. Gigaplatform carbonate deposits stippled.
Fig. 8. Shelf-edge depth section along seismic line 28 across southern part of Baltimore Canyon Trough. *Above:* General seismic features and magnetic profile (from Grow et al., 1988). *ECMA* = East Coast Magnetic Anomaly. *Below:* Geologic interpretation. Giga-platform carbonate deposits stippled.
Fig. 9. Shelf-edge depth section along seismic line 32 across Carolina Trough. Above: General seismic features and magnetic profile (from Grow et al., 1988). ECMA = East Coast Magnetic Anomaly. Below: Geologic interpretation. Gigaplatform carbonate deposits stippled.
Fig. 11. Toarcian(?)–Aalenian isopachs. For full caption, see p. 78.
Fig. 12. Aalenian(?) isopachs. For full caption, see p. 78.
Fig. 13. Bajocian–lower Bathonian isopachs. For full caption, see p. 78.
velocities for depth conversion of seismic profiles, differences in seismic processing between different companies and institutions, poor resolution of thin stratigraphic intervals on multichannel seismic profiles, widespread stripping and reworking of sediments during sea-level falls, assumption of uniform depositional rates to extrapolate stratigraphic age, and great variability of depositional rates from place to place within a given basin.

These discrepancies can not be resolved using the data at hand. A much denser array of deeper wells in appropriate paleodepositional settings and with more complete coring is required to appreciably improve the correlations. Thus I rely heavily on modified versions (revisions herein) of the two standard reference sections I proposed for the Baltimore Canyon Trough (Poag, 1985, 1987) and the Georges Bank Basin (Poag, 1982b; Schlee et al., 1985) as the basis for the following stratigraphic interpretations.

**Sedimentary evolution of the gigaplatform**

Poag and Sevon (1989) have published a series of simplified isopach maps which show the postrift stratigraphic and depositional evolution of the Baltimore Canyon Trough region. These maps are used here in more complete form (although still simplified), along with additional ones for the Georges Bank Basin, Carolina Trough and Blake Plateau Basin in order to interpret the initiation, growth, acme and demise of the Bahama–Grand Banks gigaplatform (United States segment). A depth section across each trough and basin provides additional data for this discussion (Figs. 6–10). Outside the Georges Bank Basin, the oldest depositional sequences (pre-Bathonian) are interpreted entirely on the basis of seismostratigraphy and seismic facies analysis, because only in the Georges Bank Basin have wells penetrated deep enough to sample these sequences directly (e.g., COST G-2 well). As noted above, the early postrift stratigraphic succession described herein differs significantly from that presented in my earlier papers (Poag, 1982a, b, 1985, 1987), mainly because of constraints on the earliest reasonable age for initial postrift sediments, the release of industry data, and the availability of Ascoli's (1982, 1983) biostratigraphic revisions. The maximum possible age of the initial postrift sequence is still controversial, but most workers now agree that seafloor spreading (and postrift deposition) began at approximately 165–190 Ma (see Klitgord and Schouten, 1986). My current seismostratigraphic analysis, along with Ascoli's (1982, 1983) revised borehole data from the Georges Bank Basin, together with unpublished industry biostratigraphy, suggests that a 190–187 Ma date (late Toarcian–early Aalenian) is probably most realistic, a conclusion also reached by Jansa (1986) and Benson and Doyle (1988) (see also Lawrence et al., 1990). Furthermore, the Toarcian–Aalenian age agrees closely with a radiometric date of 183 ± 12 Ma (Jansa, 1986) for evaporites presumed to have precipitated in the Baltimore Canyon Trough during the transition from rifting to seafloor spreading. Nevertheless, because of continued uncertainty regarding the age of the stratigraphic unit underlying the dated Bajocian unit, I shall use a question mark when referring to this unit (= Aalenian(?)).
Transition from synrift to postrift deposition

Shallow-water carbonates were probably only a minor part of the initial postrift depositional sequence in the study area, if they were present at all. The transition from continental rifting to drifting along the U.S. Atlantic margin was initiated by a period of intense erosion [late Toarcian(?–early Aalenian(?)], which smoothed the irregular topography presumed to have developed around the Triassic and Early Jurassic rift basins. This erosion formed a distinctive angular unconformity across the rift basins (e.g., Hutchinson and Klitgord, 1988; Figs. 6–10). The transition was completed in the early Aalenian(?) when horizontally bedded evaporites (halite and anhydrite) accumulated in isolated, elongate depressions (Fig. 11). The early evaporite-filled depressions of the Georges Bank Basin formed five small depocenters or subbasins (~35–40 km maximum lateral dimension), which held 0.8–1.0 km (~0.2–0.3 s) of bedded evaporitic strata. Diapiric structures are rare in this basin, but one has been located in the northernmost subbasin, where it pierces ~6 km (3.3 s) of the overlying sedimentary section. In addition, several thickened salt swells appear to be present just above the postrift unconformity (Schlee and Fritsch, 1982; High, 1985).

The structurally high Long Island Platform separated the Georges Bank evaporite basin from the Baltimore Canyon Trough evaporite basin by a distance of ~330 km (Fig. 11). The evaporite basin in the Baltimore Canyon Trough covers ~15,000 km² (~300 x 50 km), contains at least 2–3 km (0.5–0.7 s) of bedded evaporites, and rims the landward edge of the East Coast Magnetic Anomaly (ECMA), which approximates the continent–ocean boundary (Klitgord et al., 1988; Fig. 7). The thickest depocenters surround the Schlee Dome (previously cited informally as the “Great Stone Dome”), an igneous intrusion near the northwestern edge of the evaporite depression (Fig. 2; Grow, 1980; Lippert, 1983; Poag, 1987; Grow et al., 1988; Jansa and Pe-Piper, 1988). A few prominent diapirs rise as much as 5–6 km into the overlying section, and halite was drilled on the flank of Schlee Dome (Houston Oil and Minerals 676 No.1 well; Fig. 3).

The Carolina Trough evaporite basin is separated from the Baltimore Canyon evaporites by a distance of ~300 km across the intervening Carolina Platform (Fig. 11). The Carolina Trough evaporite basin is similar in length and position (relative to the ECMA) to the Baltimore Canyon Trough evaporite basin, but it is much narrower (~20 km wide). The evaporite section of the Carolina Trough is also thinner (maximum ~1.6 km, 0.4 s), and forms many more diapiric structures. At least 26 diapirs, identified in the Carolina Trough from seismic profiles and sidescan sonographs of the seafloor have been interpreted as evaporite structures (Dillon et al., 1982). One additional evaporite sequence (~20 x 20 km) appears to have filled a small graben on the landward margin of the Carolina Trough off Cape Hatteras.

Equivalent evaporites are presumably present also in the Blake Plateau Basin (Dillon et al., 1982), but according to Klitgord and Schouten (1986) and Klitgord et al. (1988), rifting was still going on in the southern basins, so any Toarcian(?–Aalenian(?)) evaporites in this region would have been part of the synrift section. Early to Middle Jurassic(?)) evaporites have been drilled in the Bahama Basin (Tator and Hatfield, 1975), and a few Late Jurassic(?) domed features seen on seismic reflection profiles have been interpreted as salt structures (Ball et al., 1968; Sheridan et al., 1981). In general, however, evaporites in this region are difficult to identify on seismic profiles because of the thick (2–4 km) shallow-water carbonate section overlying them.

Initiation of shallow-water carbonate deposition:
Aalenian(?) sequence (~186–183 Ma)

The first major postrift sedimentary sequence deposited on the U.S. Atlantic margin probably accumulated during Aalenian time. The principal east coast basin (the largest, and with the thickest sediment column) was the Baltimore Canyon Trough, which at this time formed a broad, 45,000 km² depression (at 100 x 450 km, approximately three times larger than the preceding evaporite basin) off the coast of what now is New Jersey to North Carolina (Figs. 7, 8 and 12). Deposition rates in the Baltimore Canyon Trough (calculated from sediment volumes and using the Decade of
North America (DNAG) time scale; Palmer, 1983; Kent and Gradstein, 1986) were higher (~25,000 km$^3$/m.y.; Poag and Sevon, 1989) during this interval than at any other time prior to the Neogene. As a result, very thick depocenters developed on the middle and outer parts of a distinct, 100-km wide, continental shelf. The greatest thicknesses, however, reached ~5 km (1.6–2.2 s) along the continental slope off New Jersey. These depocenters appear to have been fed mainly by ancient equivalents of the Schuylkill and Delaware rivers bringing terrigenous sediments from the Central Appalachian Highlands (Poag and Sevon, 1989). Several thick siliciclastic lobes spread out over the incipient continental rise forming in the Sohm–Hatteras Trough (on oceanic crust) and lapped onto the western flank of the young mid-Atlantic spreading center. Seismic facies analysis suggests that the bulk of the Aalenian (?) sediments are siliciclastics. The presence of some high-amplitude reflections in the middle of the sequence, however, is possible evidence that a linear trend of four narrow (20 km × 70–80 km) carbonate tracts (oolite shoals?) formed on the middle-to-outer shelf during this time (Fig. 12) but did not reach the shelf edge. Lawrence et al. (1990) suggested that halite may be interbedded with the carbonate in these tracts. In the late depositional history of this sequence, carbonate may have formed a narrow, segmented platform (5–10 km wide) at the shelf edge in some locations (e.g., line 25), but it is difficult to substantiate the configuration and lithofacies of this deeply buried feature.

To the north, separated from the Baltimore Canyon Trough by the ~200-km-wide Long Island Platform, the Georges Bank Basin also received a sequence of probable Aalenian deposits as the first postrift accumulation (Fig. 12). The Aalenian (?) Georges Bank Basin was much smaller (100 × 180 km), however, than the coeval Baltimore Canyon Trough, and the sediment column was considerably thinner (0.8–1.0 km, 0.2–0.3 s). Carbonate deposits (known from drilling and seismic facies) appear to have composed about half the basin-fill, and were concentrated on the middle to outer shelf in the northern two-thirds of the basin. The carbonates constructed a broad (65 km wide), shallow-water, shelf platform (dolomites, lime-
**Development of southern "megabank": Bajocian–lower Bathonian sequence (~183–172 Ma)**

By the end of Bajocian–early Bathonian time, deposition in the U.S. Atlantic margin basins was nearly continuous for ~3000 km, from Georges Bank to the Bahamas (Fig. 13). The only depositional gap was a 50-60 km strip along the Long Island Platform. Carbonates were widespread in the Georges Bank and Blake Plateau basins, but were sparse in between, having been suppressed there by greater supplies of siliciclastic detritus.

The Georges Bank Basin had nearly doubled in area (~40–160 × 350 km), and most deposition still took place on the continental shelf, although a narrow continental slope and rise (18–20 km wide) had begun to develop. The seaward half of the shelf was occupied by a moderately broad (50–75 km) carbonate platform with a maximum thickness of ~1.5 km (0.7 s). The platform was bifurcated, however, by a siliciclastic wedge (fed by source terrains in the New England Appalachian highlands of Maine) that extended across the central part of the shelf and spread across the incipient continental rise (Fig. 13). The northern segment of the Bajocian–early Bathonian platform on Georges Bank is characterized by a series of isolated mounds, patch reefs?, and oolite shoals; six have been identified on seismic profiles, and five have been drilled (High, 1985; Mattick and Libby-French, 1988). One high-amplitude lenticular feature near the center of the basin turned out to be a bed of halite (drilled in the Exxon 955-1 well; Figs. 3 and 13). Along the outer edge of this northern platform is a low, raised rim, which has the configuration of a barrier reef (~110 km long; Figs. 7 and 13). Narrow, carbonate-rich, slope aprons (500–800 m (0.4–0.7 s) thick) developed just seaward of the platform edge. Siliciclastic debris that reached the Sohm–Hatteras Trough seaward of Georges Bank spread out as a bilobate submarine fan complex and filled in a series of basement troughs, whose long axes parallel that of the mid-Atlantic spreading center.

In the Baltimore Canyon Trough, the continental shelf was comparable in area (~100 × 450 km) to that of the Georges Bank Basin, but the Sohm–Hatteras Trough in this area had expanded to about 5–6 times (~150 km) the width of its Georges Bank counterpart (Fig. 13). Bajocian–lower Bathonian deposits in the Baltimore Canyon Trough appear to have been dominantly siliciclastics (seismic facies) derived from the central Appalachian Highlands and Adirondacks which built thick depocenters (1.5–2 km, 0.5–0.7 s) on the middle part of the continental shelf (Fig. 13). Siliciclastic detritus reached the shelf edge at many points along the outer margin of the trough and formed slope aprons as thick as 2 km (0.8 s).

The presence of high-amplitude, continuous seismic reflections along several profiles in the Baltimore Canyon Trough suggests that narrow carbonate platforms (100–115 km long, 15–25 km wide) developed at several places along the outer continental shelf and at the shelf edge (Fig. 13) (the thickness of the carbonate platforms was ~1.5–2 km (0.7–1.2 s); see also Lawrence et al., 1990). At three sites, small, mounded, carbonate buildups, or reefs, were constructed landward of the shelf edge during the latter part of Bajocian–early Bathonian time.

The Bajocian–early Bathonian continental shelf narrowed southward from ~100–130 km in the Baltimore Canyon Trough to ~50–75 km in the Carolina Trough, where two siliciclastic depocenters dominated shelf deposition (Fig. 13)—one seaward of what is now Cape Lookout (~2 km (1.0 s) thick at the shelf edge), and the other south of Cape Fear (~1.8 km (0.7 s) thick). Elongate slope aprons fringed these shelf depocenters, and a narrow abyssal plain (10–40 × 300 km) developed in the Sohm–Hatteras Trough from Cape Fear to Cape Lookout.

Small carbonate platforms (10–20 × 60 km) appear to have developed at two places in the Carolina Trough during Bajocian–early Bathonian time, one off Cape Lookout and one off Cape Fear (Fig. 13). The maximum thickness of the platforms is ~1.8–2 km (0.6–1.1 s).

Farther south, in the Blake Plateau Basin, the physiography and lithofacies distribution appear to have been considerably different from that in
the northern basins. In particular, the continental shelf widened markedly to 350–450 km, and most of this huge shelf area (~160,000 km$^2$) appears to have received mainly carbonate deposition, forming a "megabank" (Fig. 13). Thus, the northern margin of the Blake Plateau Basin marked a significant physiographic, depositional and perhaps climatic boundary between carbonate-dominated and siliciclastic-dominated shelf regimes, which lasted for ~65 m.y. into Aiptian–Albian time (Benson et al., 1978a; Ladd and Sheridan, 1987; Austin et al., 1988a). In the southern part of the Blake Plateau Basin, a broad, relatively flat-topped, carbonate platform stretched essentially from the shoreline to the shelf edge. Subtle variations in thickness of the platform sediments (average 3–3.5 km, 0.8–0.9 s) appear to have been caused mainly by topographic relief on the underlying basement surface. A few small (2–5 km diameter) mounded buildups, or reefs, are scattered around the platform (twelve have been identified on seismic profiles; Fig. 13), and two larger (15 × 50 km and 3 × 20 km) shelf-edge reefs reached thicknesses of ~4 km (1.3 s). A large (90 × 150 km), elevated (karstic?) bank appears to have developed on the inner edge of the Blake Plateau Basin along the central part of the Florida peninsula (Shipley et al., 1978; Popenoe et al., 1984).

A single elongate swath (200 × 75 km) of siliciclastic sediments appears to have entered the northern part of the Blake Plateau Basin (Fig. 13) from a source in the southern Appalachian Highlands and the surrounding coastal plain. The maximum thickness of this siliciclastic wedge is near its termination on the middle of the continental shelf (~3.5 km, 1.1 s).

The original Bajocian–early Bathonian shelf edge appears to have formed a carbonate escarpment, which extended ~1000 km from the Blake Spur to the southern termination of the Bahama Platform (approximately at modern 25°N). Subsequently, however, the escarpment has retreated as much as 10–30 km from its original position between seismic profiles TD-5 and TD-2 (Figs. 10 and 14; Paull and Dillon, 1980; Sheridan, 1981; Freeman-Lynne et al., 1981; Dillon et al., 1985; Freeman-Lynne and Ryan, 1985). A thinned, narrow remnant of this shelf-edge retreat presently forms a flat-topped terrace, which is buried by Berriasian–Valanginian and younger abyssal deposits. If this stratigraphic relationship is correct, the terrace appears to have been formed during Jurassic time, rather than in the Tertiary, as asserted by Paull and Dillon (1980), or the Cretaceous, as interpreted by Sheridan (1981) and Sheridan et al. (1988). The Bajocian–lower Bathonian section is exposed along the face of the Blake Escarpment along seismic profile FC-1 and its vicinity (Fig. 14). Ladd and Sheridan (1987) have suggested that Middle Jurassic strata (perhaps including a Bajocian–lower Bathonian section) may be present farther south in the Bahama Basin beneath Andros Island and the southeastern side of Great Bahama Bank. Klitgord et al. (1988), however, believed that the oldest postrift sediments in the Bahama Basin are probably Oxfordian.

**Platform expansion in the northern basins: upper Bathonian–Callovian sequence (~172–163 Ma) and Oxfordian sequence (163–156 Ma)**

The history of carbonate platform development along the U.S. Atlantic margin following Bajo-
Fig. 15. Isopach map of upper Bathonian–Callovian sequence in Baltimore Canyon Trough region. Contours represent two-way travel time at 0.1 s intervals. Shelf and slope carbonate tracts stippled. Arrows indicate main routes of siliciclastic sediment supply. Diagonal shading indicates sequence missing or too thin to resolve on seismic lines. Position of depth section along seismic line 25 (Fig. 7 herein) indicated.
Fig. 16. Isopach map of Oxfordian sequence in Baltimore Canyon Trough region. Contours represent two-way travel time at 0.1 s intervals. Shelf and slope carbonate tracts stippled. Arrows indicate main routes of siliciclastic sediment supply. Diagonal shading indicate sequence missing or too thin to resolve on seismic lines. Position of depth section along seismic line 25 (Fig. 7 herein) indicated.
clay–lower Bathonian deposition is largely one of: (1) progressive seaward progradation of the shelf edge (interspersed with intervals of aggradation and regressive hiatuses), (2) expanded areal distribution of carbonates on the shelf, slope and upper continental rise, and (3) heightened shelf-edge relief. These changes are most notable in the northern basins, as typified by the Baltimore Canyon Trough, so for the sake of brevity, I shall confine description of the late Bathonian to Oxfordian sedimentary history to the record there.

Carbonate deposition in the Baltimore Canyon Trough accelerated during late Bathonian–Callovian time. The shelf-edge carbonate tract was now nearly continuous from the Bahamas to the Grand Banks, forming a > 5000-km-long gigaplatform. Continuous, high-amplitude reflections are present in an aggrading succession that comprises the lower half of this sequence along the outer part of the paleoshelf off New Jersey (Fig. 15). During deposition of the upper half of the sequence, the shelf edge prograded dramatically (~ 25 km) seaward of its early late Bathonian position (Fig. 7). The presence of numerous mound-ed seismic reflections suggests that an elevated reef system rimmed the shelf edge during the later part of the late Bathonian–Callovian interval [=Oxfordian (?) of Lawrence et al., 1990]. The upper carbonate strata of this sequence (= “Wilmington Platform” of Prather, 1988, and Schlager, 1989) have been drilled by some of the deeper wells in the Baltimore Canyon Trough (e.g., Tenneco 642-2 well; Bielak, 1986; Fig. 3). The maximum thickness of the gigaplatform near the shelf edge in this depositional sequence is ~ 4 km (1.8 s).

Landward of the gigaplatform, a series of four elliptical to subcrescentic, siliciclastic depocenters was present. These depocenters appear to have represented outer-shelf deltas, whose seaward advance was driven by a significant acceleration in siliciclastic accumulation rate (increase from 9000 to 14,000 km²/m.y.; Poag and Sevon, 1989). Siliciclastic sediment from these deltas appears to have transited the shelf edge mainly through four large submarine canyons (Fig. 15), and formed sediment ponds on the widening continental rise. Their distal margins onlapped the western flanks of the mid-Atlantic spreading center where they filled narrow troughs in the furrowed basement surface.

During Oxfordian time siliciclastic deposition decreased somewhat (from 14,000 to 11,000 km³/m.y.) in the Baltimore Canyon Trough, and encroached less rapidly on the benthic carbonate producers at the shelf edge. This slowed deposition was in part a consequence of diminished tectonic subsidence of the basin as sediment loading began to dominate subsidence on this passive continental margin (Watts and Steckler, 1979; Poag and Sevon, 1989). In addition, increased climatic aridity (Hallam, 1984; 1986) may have slowed delivery of terrigenous detritus to the basin.

Carbonate production appears to have developed a series of narrow, elongate depocenters that stretched nearly 400 km along the Oxfordian shelf edge from what now is Long Island to Virginia (Fig. 16). The principal carbonate depocenters were ~ 1.5 km (0.8–0.9 s) thick, and the gigaplatform reached widths of 20–25 km. The carbonate tract reached a total seaward progradation of ~ 50 km off New Jersey (Fig. 7). Landward of the gigaplatform a large mid-shelf delta complex built up off New Jersey, fed by the ancient Hudson, Delaware and Schuylkill rivers which drained the Adirondack and central Appalachian highlands (Fig. 16; Poag and Sevon, 1989). This delta was subsequently dissected into four small depocenters, from which terrigenous detritus moved over the shelf edge through pre-existing submarine canyons, eventually filling the canyons. Thick (~ 1 km, 0.7 s) slope aprons were again prominent, and several moderately large (50–75 km wide, 100–150 km long) submarine fan complexes spread into the Sohm–Hatteras Trough. The oldest clearly defined, very large [100 km wide, 0.4–1 km (0.3–0.7 s) thick] submarine fan complex yet discovered in the trough was constructed seaward of the south-

Fig. 17. Isopach map of Kimmeridgian–Tithonian sequence along U.S. Atlantic margin. Contours represent two-way travel time at 1 s intervals. Shelf and slope carbonate tracts stippled. Arrows indicate main route of siliciclastic sediment supply. Diagonal shading indicates sequence missing or too thin to resolve on seismic lines. Position of five depth sections (Figs. 6–10 herein) indicated.
Fig. 18. Shelf-edge stratigraphy and morphology along four seismic lines across Baltimore Canyon Trough segment of gigaplatform showing pinnacled barrier reef and overlying Berriasian-Valanginian siliciclastics. Seismic reflections traced for Kimmeridgian-Tithonian and Berriasian-Valanginian sequences; Kimmeridgian-Tithonian sequence stippled. Diagonal shading indicates Cretaceous and Cenozoic sedimentary rocks overlying studied section. Shell wells projected to lines 6 and 220. VE = vertical exaggeration. Uninterpreted version of line 6 can be seen in Grow et al. (1979).
Fig. 19. Shelf-edge of New England segment of gigaplatform. For full caption, see p.90.
ernmost submarine canyon, and stretched at least 350 km toward the mid-Atlantic spreading center (which was outside the mapped area by this time; Fig. 16). Abyssal sediments of the Oxfordian sequence have been sampled at DSDP Site 105 (100 km south of the southeastern corner of Fig. 16; Hollister et al., 1972), where they consist of mixed variegated calcareous claystones, marls, and clayey limestones. These characteristics are evidence of the long-distance transport of terrigenous sediment within the Sohm–Hatteras Trough.

**Maximum development of the gigaplatform:**

**Kimmeridgian–Tithonian sequence (~156–144 Ma)**

The acme of gigaplatform development and reef growth on the U.S. Atlantic margin spanned the late part of the Jurassic (Kimmeridgian and Tithonian time). Details of this acme in the Baltimore Canyon Trough region have been presented by Meyer (1989), who emphasized the stratigraphy, lithofacies and different stages of platform construction (see also Edson, 1986, 1987, 1988; Erlich et al., 1988, 1990; Prather, 1988, 1991; Lawrence et al., 1990). For the Georges Bank Basin more generalized treatments of Kimmeridgian and Tithonian stratigraphy and deposition have been presented by Ascoli (1982), Poag (1982a, b) and Schlee and Fritsch (1982).

The isopach map, seismic sections, and boreholes of the Baltimore Canyon Trough (Figs. 7 and 17) show that the lower part of the Kimmeridgian–Tithonian gigaplatform consists of shallow-water carbonates that continued to extend the shelf edge seaward along a ~1000-km-long segment from Massachusetts to Virginia. The carbonate rim had now prograded ~55 km onto the oceanic crust off New Jersey (maximum progradation; Fig. 7). The upper half of the Kimmeridgian–Tithonian sequence also consists of shallow-water carbonates at the shelf edge, but aggradational sedimentation dominated to produce a thick, elevated rim topped by a discontinuous, pinnacled, barrier reef system. The reef crest towered as much as 3 km above the floor of the Sohm–Hatteras Trough in some places, and as much as 150 m above the adjacent backreef shelf (Fig. 18). However, the gigaplatform was relatively narrow in this region, ranging from ~10 to ~30 km in width.

Landward of the gigaplatform were a series of siliciclastic deltas (Fig. 17). One large system of coalescing deltas, for example, extended 250 km from northern New Jersey to Maryland, and was more than 100 km across (dip direction). Separate delta lobes were fed by the ancient Hudson, Delaware, Susquehanna and Potomac rivers, carrying detritus from the northern part of the central Appalachian Highlands (Poag and Sevon, 1989). Siliciclastic accumulation rates had dropped from 11,000 to 6000 km³/m.y. by this time, however (Poag and Sevon, 1989), which slowed encroachment on the shelf-edge carbonate communities and allowed the platform to aggrade.

Along the Kimmeridgian–Tithonian continental slope, carbonate-rich aprons received detritus from the reef tract, and several small carbonate-enriched submarine fan complexes (25–50 × 100 km) formed on the upper continental rise (Fig. 17). The most prominent depositional features in the Sohm–Hatteras Trough, however, were four large siliciclastic submarine fan complexes, which derived their constituents mainly from the shelf delta systems. Distal sediments from these four fan complexes reached the lower continental rise 300–400 km from the shelf edge, having bypassed the shelf edge through prominent gaps in the barrier reef. Some of the...
Fig. 20. Revised stratigraphy of lower section drilled in COST GE-I well, in shoreward part of Blake Plateau Basin (= Southeast Georgia Embayment). Modified from Dillon and Popenoe (1988). Reinterpretation based on seismic extrapolation from Georges Bank Basin and Baltimore Canyon Trough wells, Great Isaac's well in Bahama Basin, and dive samples on outer end of line TD-3. Lowest definitive fossils identified in GE-I well [Aptian palynomorphs (R. Christopher and J. Bebout, in Poag and Hall, 1979)] came from cuttings sample at 2259 m.
deepest parts of the continental rise in this area, however, were still accumulating mainly carbonates, as shown by the presence of fine-grained pelagic limestones in the Kimmeridgian–Tithonian section at DSDP Site 105 (Hollister et al., 1972).

To the north of the Baltimore Canyon Trough, along the outer edge of the Long Island Platform and Georges Bank Basin, the shelf-edge reef system can also be identified on seismic profiles (Fig. 19), but it has not been directly sampled by drilling. The gigaplatform was significantly wider here (> 40 km), but the associated reef system was more segmented and discontinuous than off New Jersey; its general morphology, architecture and lithofacies, however, are similar (Fig. 17). Slope aprons (presumably carbonate-rich) were associated with the reef fronts in this area as well. Two broad gaps in the gigaplatform separated the Long Island and Georges Bank segments and appear to have allowed siliciclastic sediments to pass from outer-shelf delta systems onto the continental slope and rise. The resultant submarine fan complexes are not nearly as large or distinctive as those in the New Jersey region. Another siliciclastic shelf-delta system developed on the northern edge of the Georges Bank Basin during Kimmeridgian–Tithonian time, but its sediments appear not to have reached the Sohm-Hatteras Trough (Fig. 17). The seaward edge of the gigaplatform may have originally contained a more extensive reef tract, but its seaward edge has retreated as much as 10–30 km in the southern part of the Blake Plateau and Bahama basins (Fig. 17).

Extension of the gigaplatform and shelf-edge reef system into the Scotian Basin has been described by several authors (Jansa and Wade, 1975; Eliuk, 1978, 1981, 1988; Jansa, 1981; Eliuk et al., 1986; Jansa et al., 1988a). The general structural, stratigraphic and lithofacies relationships are similar to those along the U.S. margin. Jansa et al. (1988a) have suggested that the gigaplatform did not end at the Grand Banks. A segment of Kimmeridgian–Tithonian platform cored at ODP Site 639 on the Galicia Bank margin (Bouillot et al., 1988) was interpreted by Jansa et al. (1988a) as a connector between the Grand Banks platform and that of the Lusitanian and Algarve basins, which rimmed the eastern end of the proto-Atlantic seaway during the Late Jurassic.

South of the Baltimore Canyon Trough a distinctly different stratigraphic and depositional history is recorded by the Kimmeridgian–Tithonian sequence. As in the Bajocian–early Bathonian interval, and in all subsequent sequences, the most obvious difference is the greater expanse of the carbonate platform, which widened progressively southward until it occupied the entire continental shelf of the Blake Plateau and Bahama basins (Fig. 17). In fact, in Kimmeridgian–Tithonian time, an enormous carbonate megabank formed the southern part of the gigaplatform, extending ~900 km from the the Bahama Basin to the South Florida Basin (Gulf of Mexico) (Tator and Hatfield, 1975; Sheridan et al., 1981, Applegate et al., 1982; Ball et al., 1988). No accompanying barrier reef system has been documented south of Virginia, but two large individual reefs appear to have occupied the Blake Nose, and two additional isolated reef complexes appear to have been built on the gigaplatform off Florida (Fig. 17). The seaward edge of the gigaplatform may have originally contained a more extensive reef tract, but its seaward edge has retreated as much as 10–30 km in the southern part of the Blake Plateau and Bahama basins (Fig. 14; see mention in the discussion of Bajocian–lower Bathonian deposits; Paull and Dillon, 1980; Freeman-Lynde et al., 1981; Freeman-Lynde and Ryan, 1985). This erosion appears to have exposed the Kimmeridgian–Tithonian section (and older Jurassic sections) at the seafloor along the face of the Blake and Bahama escarpments. The remaining major carbonate depocenter in this region is near the middle of the megabank, rather than at its edge.

Carbonate accumulation on the megabank was interrupted, however, by a large siliciclastic depocenter that extended from southern Georgia to within 50–100 km of the shelf edge (Fig. 17). This depocenter appears to have formed from coalescent...
Fig. 22. Shelf-edge stratigraphy and morphology along four seismic lines across Baltimore Canyon Trough segment of gigaplatform showing Berriasian–Valanginian siliciclastic deltas burying gigaplatform. Seismic reflections traced for Kimmeridgian–Tithonian and Berriasian–Valanginian sequences; Kimmeridgian–Tithonian sequence stippled. Diagonal shading indicates Cretaceous and Cenozoic sedimentary rocks overlying studied section. $V_E =$ vertical exaggeration. Uninterpreted versions of lines 2 and 10 can be seen in Grow et al. (1979).
Fig. 23. Shelf-edge stratigraphy and morphology along four seismic lines across Long Island Platform segment of giga-platform showing "empty bucket" lagoon behind reef and variable degrees of burial or exposure (drowning unconformity) of forereef slope. Seismic reflections traced for Kimmeridgian-Tithonian and Berriasian-Valanginian sequences; Kimmeridgian-Tithonian sequence stippled. Diagonal shading indicates Cretaceous and Cenozoic sedimentary rocks overlying studied section. Pattern at bottom of lines 23 and 16 represents basement. $VE =$ vertical exaggeration. Uninterpreted version of line 9 can be seen in Grow et al. (1979).
ing delta complexes fed by three river systems, which derived terrigenous detritus from the southern Appalachian Highlands. The updip margin of this delta system has been drilled by exploratory wells and by the COST GE-1 stratigraphic test on the inner part of the continental shelf (Fig. 3; Scholle, 1979). The inferred Kimmeridgian–Tithonian sediments sampled there (age estimated herein by seismostratigraphic extrapolation) are coarse, unfossiliferous (presumably non-marine) sands and associated terrigenous facies (Fig. 20).

The fabric of the isopach patterns on the continental slope and rise is also different seaward of the Blake Plateau and Bahama basins compared to along the northern basins. Elongate pods of sediment rim the southern shelf edge and the Blake Escarpment, and probably consist primarily of debris eroded from the gigaplatform. No distinctive fan-like bodies of sediment appear to extend across the continental rise in this southern region, but one thick pod on the upper part of the rise north of the Blake Spur (Fig. 17) [700 km (0.7 s) thick] and another south of the Blake Spur [500 m (0.5 s) thick] appear to have intermittently received siliciclastic deposits from the large shelf-delta complex. At DSDP Site 534 (Fig. 3) in the Blake–Bahama Basin for example, the lower part of a Kimmeridgian–Tithonian section comprises 90 m of red calcareous claystones and marly limestones (50–80% siliciclastics) interspersed with greenish-gray claystone and marl, black carbonaceous clay, and turbidites of light gray and pink micritic, bioclastic and oolitic limestone (Ogg et al., 1983). Similar lithologies were encountered ~28 km to the west, at DSDP Site 391, which is intersected by the seaward end of seismic profile TD-3 (Figs. 3 and 14; Benson et al., 1978b).

**Demise of the gigaplatform: Berriasian–Valanginian sequence (~144–131 Ma)**

The widespread deposition of shallow-water carbonate sediment along the outer margin of the Carolina Trough, Carolina Platform, Baltimore Canyon Trough, Long Island Platform and Georges Bank Basin essentially ended at the close of Jurassic time. In isolated patches, shallow-water carbonate production continued into the Early Cretaceous (e.g., Ryan et al., 1978; Erlich et al., 1988, 1990; Meyer, 1989), but most of the earliest Cretaceous carbonate appears to have been of deep-water pelagic origin (Meyer, 1989; Erlich et al., 1990). The same was true along the Scotian Shelf (Eliuk, 1988; Eliuk and Levesque, 1988; Jansa et al., 1988b), but to the south, in the Blake Plateau Basin, shallow-water carbonates persisted across the broad megabank into at least Barremian time, and in much of the Bahama Basin they have persisted to the present (Benson et al., 1978b, c; Schlager and Ginsburg, 1981; Ladd and Sheridan, 1987; Dillon and Popeneoe, 1988; Dillon et al., 1988).

Poag et al. (1990) have described the Berriasian–Valanginian depositional regime of the Baltimore Canyon Trough area, where three large shelf-edge delta systems built out from sources in the central Appalachian Highlands and Adirondacks (Fig. 21). Relict (and/or still growing) elevated reef structures prevented access to the Sohm–Hatteras Trough by these shelf-edge delta systems, except where deposition was rapid enough to bury them (Fig. 22). At these points, large volumes of siliciclastic sediment reached the continental slope and rise in the form of extensive, thick, slope aprons and submarine fan complexes. The most notable submarine fan complex of the Berriasian–Valanginian sequence is the Ocean City Fan, which extends ~500 km from the shelf edge to DSDP Site 603 (Fig. 3), where terrigenous turbidites constitute the distal elements of the system (Sarti and Von Rad, 1987; Holmes et al., 1987).

Along the seaward edge of the Long Island Platform, Berriasian–Valanginian sediments fill elongate depressions (scour channels?, “empty bucket” lagoons?) parallel to and landward of the Kimmeridgian–Tithonian reefs (Fig. 23). These Berriasian–Valanginian strata lap onto the crests of the reefs, but generally are missing on the forereef slopes (=drowning unconformity of Schlager, 1989). The upper part of this broad seafloor exposure of the Kimmeridgian–Tithonian gigaplatform may never have been covered with Berriasian–Valanginian sediment because of its steep slope. Lower down, however, subsequent erosion may have removed some of the siliciclastic cover from the escarpment face. On the outer shelf
Fig. 24. Shelf-edge stratigraphy and morphology along four seismic lines across Georges Bank Basin segment of gigaplatform showing complete burial of gigaplatform by Berriasian–Valanginian siliciclastic sediments. Seismic reflections traced for Kimmeridgian–Tithonian and Berriasian–Valanginian sequences; Kimmeridgian–Tithonian sequence stippled. Diagonal shading indicates Cretaceous and Cenozoic sedimentary rocks overlying studied section. Pattern at bottom of lines 8 and 211 represents basement. VE = vertical exaggeration.
seaward of Cape Cod, an area where the Kimmeridgian–Tithonian reef system was never (or was only weakly) developed (Fig. 24), the Berriasian–Valanginian siliciclastics formed a broad delta complex (Fig. 21), which supplied terrigenous detritus to the Sohm–Hatteras Trough. At least two primary and one secondary distributary routes are indicated by the isopach contour pattern. A multilobed submarine fan complex formed in this region, but extended only a relatively short distance (50–100 km) across the upper continental rise. Along the northern margin of the Georges Bank Basin, the Berriasian–Valanginian siliciclastics also failed to cover the upper parts of the gigaplatform escarpment. The presence of several small, coeval, submarine fan complexes attests, however, to sporadic spilling of siliciclastic detritus into the Sohm–Hatteras Trough in this area. Similar relationships have been described for the Scotian Basin (Jansa and Wade, 1975; Given, 1977; Eliuk, 1978, 1988; Eliuk and Levesque, 1988).

South of the Baltimore Canyon Trough, in the vicinity of what now is Cape Hatteras, another major Berriasian–Valanginian siliciclastic depocenter was formed by a shelf-edge delta complex (Fig. 21). Sediments from this complex also buried the Kimmeridgian–Tithonian gigaplatform, and spilled into the Sohm–Hatteras Trough (Fig. 25). The thickest part of the siliciclastic prism (800 km, 0.7 s) occupied the continental slope and rise, and from it, a broad (100–150 km wide) submarine fan complex distributed siliciclastic sediments at least 500 km basinward. This fan is the most southerly Berriasian–Valanginian fan complex presently known in the Sohm–Hatteras Trough.

Moving southward, there is a 500-km stretch from Cape Hatteras to southern Georgia in which the prograding Berriasian–Valanginian siliciclastic blanket did not cover the steep upper slope of the Kimmeridgian–Tithonian gigaplatform. In fact, strata even older than Kimmeridgian–Tithonian appear to have been exposed along this escarpment at that time (Fig. 26). I infer, however, from truncated reflections at the seaward edge of the Berriasian–Valanginian sequence, that its sediments originally covered at least part of this escarpment, and have subsequently been eroded. About 150 km north of the Blake Spur, a Berriasian–Valanginian carbonate tract developed on the outer shelf (profile FC-7, Fig. 27), and a series of mounded, somewhat chaotic reflectors suggests that a small reef developed in the upper part of the sequence. Further landward, a mid-shelf carbonate tract (as determined from seismic facies analysis) is separated from the shelf-edge tract by a 30-km-wide swath of siliciclastic sediments. This swath joins a major siliciclastic shelf-edge depocenter, which abuts the northern margin of the Blake Spur (Fig. 21). Sediments of this depocenter buried the Kimmeridgian–Tithonian gigaplatform escarpment under at least 1 km of terrigenous detritus. Seismic profile FC-8, which crosses this terrigenous deposit (Fig. 27), probably shows the original (pre-erosion) configuration of the siliciclastic prism as it draped the gigaplatform. This depocenter appears to have formed at the confluence of two major distributary systems, which originated in the southern Appalachian Highlands. Siliciclastics from this depocenter entered the Sohm–Hatteras Trough and filled a basement depression along the northern flank of the Blake Spur. From there, the sediments entered a narrow channel between the Blake Escarpment and a basement high about 30 km to the east (Fig. 21).

A series of elongate slope aprons skirted the gigaplatform from Cape Hatteras to the Blake Spur, from the thickest of which (~ 1 km, > 1.1 s) a sediment lobe extended southward, wrapped around the seaward margin of an elongate basement high, and then turned westward again to parallel the Blake Escarpment. This contour-following isopach pattern suggests that abyssal bottom currents redistributed sediments into contourite drifts along the base of the Blake Escarpment in Berriasian–Valanginian time. Such an interpretation was broached by Tucholke and Mountain (1979), but was refuted by Freeman and Enos (1978) and Robertson and Bliefnick (1983) after analyzing the sedimentologic properties of cores taken in the Blake Basin.

Farther southward, on the Blake Spur, the shelf carbonate tract was ~ 180 km wide (Fig. 21). Seismic line TD-5 indicates that strata prograded across the spur from its landward edge, where a prominent, elongate, mounded reef structure forms part of what I correlate as the Berriasian–Valangin-
Fig. 25. Shelf-edge stratigraphy and morphology along three seismic lines across southern Baltimore Canyon Trough segment of gigaplatform showing lack of prominent reefs and burial of gigaplatform under Berriasian-Valanginian siliciclastics. Seismic reflections traced for Kimmeridgian-Tithonian and Berriasian-Valanginian sequences; Kimmeridgian-Tithonian sequence stippled. Diagonal shading indicates Cretaceous and Cenozoic sedimentary rocks overlying studied section. \(VE\) = vertical exaggeration.
ian sequence (Fig. 28). Benson et al. (1978c) interpreted this Blake Spur reef to be of Barremian age, based on correlations with their interpretation of the stratigraphy at DSDP Sites 390 and 392. Dillon et al. (1985, 1988), on the other hand, used the same DSDP data together with outcrop samples from the face of the Blake Escarpment to infer an Aptian–Albian age for a coeval reef crossed by line TD-4. I infer that the main reefs formed during Berriasian–Valanginian time, but that their crests were reoccupied by reef organisms in Aptian–Albian time. From this reef, the sedimentary section thins gradually along line TD-5 to the nose of the Blake Spur, where it thickens again slightly. This thickening suggests that another Berriasian–Valanginian reef originally occupied the nose, but subsequently has been planed off, perhaps during a ~vel fall at the end of Valanginian time. The Berriasian–Valanginian section is now exposed at the seafloor along the Blake Escarpment, and a sample of Valanginian–Hauterivian age was collected from a depth of 3390 m below sea level, where seismic profile TD-5 crosses the nose of the escarpment (Fig. 28; Dillon et al., 1988). In addition to the escarpment sample, the DSDP drilled Sites 390 and 392 on Blake Nose (Benson et al., 1978a, c). Hole 390, which is located on seismic profile TD-5, penetrated a well-dated Barremian–Aptian section (age based on foraminifera and nannofossils), but in the underlying 35-m section only disaggregated fragments of shallow-water limestone were recovered, the fossil constituents of which yielded no age-diagnostic forms. This 35-m section corresponds to the upper two-thirds of the Berriasian–Valanginian section as I have correlated it on profile TD-5 (Figs. 14 and 28).

At Site 392, about 25 km due south of Site 390 (still on the Blake Nose), a Barremian section of nannofossil ooze and reddish brown, ooidal limestone was penetrated, which unconformably overlies a 260-m section of shallow-water limestones (fenestral, oolitic, and skelmoldic) containing no dateable fossils (Fig. 28). Freeman and Enos (1978) interpreted this succession of limestones to represent a single regressive depositional sequence, but Benson et al. (1978c) suggested, on the basis of evidence for freshwater diagenesis, that one or more emergent intervals could be represented in the succession. Poor core recovery (~3% of the cored interval) in the limestone section precludes direct identification of possible sequence boundaries within the succession. However, judging from its much greater thickness and lithologic variability relative to the equivalent section at Site 390, I suggest that only the upper ~113 m of fenestral limestone correlates with the section I assign to the Berriasian–Valanginian. The lower ~176-m succession of skelmoldic to oolitic limestone may well represent the top of the Kimmeridgian–Tithonian gigaplatform.

Beginning at the Blake Spur, the seaward edge of the Berriasian–Valanginian megabank (along with older strata) has been eroded landward by about 2–5 km from its estimated original position (Figs. 10, 14 and 29; Paull and Dillon, 1980; Freeman-Lynde and Ryan, 1985). Reefs may have occupied this missing segment of the platform during Berriasian–Valanginian time, as Benson et al. (1978c) suggested, on the basis of sediments drilled at DSDP Site 392. If so, however, it is likely that they were eroded during the interval of reef setback.

From the Blake Spur southward, a continuous shallow-water carbonate tract covered the outer third of the continental shelf in Berriasian–Valanginian time (Fig. 21). The next large Berriasian–Valanginian reef is crossed by seismic profile TD-4 (Fig. 3), ~20 km from the present shelf edge (Figs. 10 and 21). Berriasian–Valanginian strata prograded slowly across the remaining segment of the megabank and appear to have been sharply truncated at the seafloor along the upper part of

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Fig. 26. Shelf-edge stratigraphy and morphology along four seismic lines across Carolina Trough and Carolina Platform segments of gigaplatform showing lack of, or moderate development of, reefs and exposure of steep platform edge (drowning unconformity) at end of Berriasian–Valanginian deposition. Seismic reflections traced for Kimmeridgian–Tithonian and Berriasian–Valanginian sequences: Kimmeridgian–Tithonian sequence stippled. Diagonal shading indicates Cretaceous and Cenozoic sedimentary rocks overlying studied section. Pattern at bottom of lines 6 and 30 represents basement. E*∗E=vertical exaggeration. Uninterpreted versions of lines TD-6 and USGS-POD can be seen in Dillon et al. (1982) and Grow et al. (1979) respectively.
Fig. 27. Shelf-edge stratigraphy and morphology along two seismic lines across southern Carolina Trough (FC-8) and northern Blake Plateau Basin (FC-7) segments of megaplatform. Seismic reflections traced for Kimmeridgian-Tithonian and Berriasian-Valanginian sequences; Kimmeridgian-Tithonian sequence stippled. Diagonal shading indicates Cretaceous and Cenozoic sedimentary rocks overlying studied section. \( V.E \) = vertical exaggeration. Note striking differences in reef development, height of forereef escarpment, and degree of platform burial. Vertical exaggeration nearly twice that of the previous shelf-edge sections.
Fig. 28. Shelf-edge stratigraphy and morphology along line TD-5 across Blake Spur (Blake Plateau Basin) segment of gigaplatform showing large, well-defined reef in Berriasian–Valanginian section. Seismic reflections traced for Kimmeridgian–Tithonian, Berriasian–Valanginian, Barremian, and Aptian–Albian sequences; Kimmeridgian–Tithonian sequence stippled. Diagonal shading indicates Cretaceous and Cenozoic sedimentary rocks overlying studied section. VE = vertical exaggeration. Uninterpreted version of line TD-5 can be seen in Dillon et al. (1985).
the Blake Escarpment. Here again, a segment of the Berriasian–Valanginian platform edge, ~2.5 km wide, appears to have been removed by erosion.

Two sediment samples taken from the face of the Blake Escarpment along line TD-4 yielded "approximate" Barremian? nannofossil dates (Dillon et al., 1988) for the section I have correlated as Berriasian–Valanginian (Fig. 10). Landward of the outer-shelf carbonate province crossed by seismic profile TD-4, a broad (~200 km) tongue of siliciclastic sediments divided the megabank into an inner-shelf and outer-shelf segment (Fig. 21).

Seismic profiles along this part of the inner shelf show an abrupt, buried, seaward-facing escarpment, which has been interpreted by Shipley et al. (1978) and Popenoe et al. (1984) to be a carbonate reef or bank. Its chaotic seismic signature is much like the sections in the Bahama Basin that Ladd and Sheridan (1987) interpreted as diagnostically altered, karstic, limestone terrain. The upper surface of this reefal? mass is onlapped by the edge of the broad siliciclastic tongue that originates from distributaries in southern Georgia to form a mid-shelf depocenter approximately 700 m (0.6 s) thick (Fig. 21). Several deep boreholes, including the COST GE-1 stratigraphic test, have penetrated this segment of the siliciclastic wedge (Fig. 20; Scholle, 1979; Dillon and Popenoe, 1988). The wedge is, however, unfossiliferous in this updip position, so its Berriasian–Valanginian age cannot be confirmed by paleontology. The beds in the COST GE-1 well, which immediately overlie the section I correlate as Berriasian–Valanginian, contain Aptian palynomorphs (Poag and Hall, 1979).

Along the base of the Blake Escarpment, Berriasian–Valanginian strata (in this region and southward) fill an elongate basement depression and lap seaward onto the flank of a broad basement plateau (where the section thins significantly). Presumably, these strata include primarily carbonate sediments eroded from the escarpment and swept off the outer edge of the megabank.

Seismic line TD-3 crosses a series of prominent down-to-the-basin normal faults near the Blake Escarpment (Fig. 14). These faults displace the surface of the ancient shelf several hundred meters downward toward the Sohm–Hatteras Trough. The main fault trace appears to intersect the seafloor and the upthrown block forms the seaward face of a prominent cliff at the present shelf break. Three sediment samples taken from the escarpment along seismic profile TD-3 have yielded nannofossils of Hauterivian–Valanginian age (Dillon et al., 1988) in the section I correlate as Berriasian–Valanginian (3300–3500 m below sea level).

DSDP Hole 391C was drilled on seismic profile TD-3 in the Sohm–Hatteras Trough (Fig. 3; Blake–Bahama Basin of some authors; Benson et al., 1978b). Cores recovered from the section I correlate as Berriasian–Valanginian contain lower Berriasian–upper Valanginian shale and calcilutite (~1100–1260 m below the seafloor). These sediments were interpreted by Benson et al. (1978b) to represent a mixture of distal siliciclastic turbidites (cross-laminated mudstones), coarse oolitic calcareous turbidites derived from the nearby shelf (Blake Plateau), and laminated nannofossil (pe-
logic) limestones. At nearby Site 543 (26 km northeast) the Berriasian-Valanginian section comprises mainly lime mudstones, marly limestones, black claystones and calcilutites (Sheridan et al., 1983). Intercalated sandy turbidites contain ooids and neritic fossils derived from the Blake Plateau.

Seismic profile FC-1 crosses another Berriasian-Valanginian reef at the shelf break (Fig. 14). The top of the reef has been eroded to an unusually flat, level surface about 10 km across. The escarpment edge is not significantly faulted at this crossing.

The southernmost seismic profile used for this study is profile TD-2 (Fig. 14). Where profile TD-2 crosses the Blake Escarpment, the Berriasian-Valanginian section has been truncated and pinches out on (onlaps) the underlying flat, eroded surface of the Kimmeridgian-Tithonian gigaplatform ~4 km from the present shelf break (not shown on Fig. 14). Here, as at the profile TD-3 crossing, the outer part of the megabank has been faulted downward into the Sohm-Hatteras Trough, but here the faulting is much more pervasive, as shown by a series of en echelon blocks, which have dropped down to the southeast. Total vertical displacement is of the order of 1400–3000 m. A small prism of Berriasian-Valanginian strata appears to partly fill a narrow depression between the base of the escarpment and a broad basement high (Blake Spur Ridge; Fig. 21). Berriasian-Valanginian strata onlap the basement high, but along profile TD-2 do not cross it. South of Little Bahama Bank the Berriasian-Valanginian section has been drilled in the Great Isaacs well (Tator and Hatfield, 1975; Sheridan et al., 1981; Schlager et al., 1988), in several wells in southern Florida (Applegate et al., 1982), and in wells on the West Florida Platform (Ball et al., 1988). All these wells penetrated shallow-water carbonate and evaporite lithologies in the Berriasian-Valanginian interval.

Gigaplatform growth patterns and shelf-edge configuration

Figures 14, 18, 19, and 22–27 show that the growth patterns, cross-sectional geometry and surficial morphology of the Bahama-Grand Banks gigaplatform have varied considerably within a broad continuum of rates, facies, styles, stages and shapes, as Jansa (1981, 1984), Eliuk (1978, 1981), Emery and Uchupi (1984), Schlee et al. (1988) and Meyer (1989) have expressly pointed out.

In the most recent comprehensive analysis, Meyer (1989) recognized a “genetically” oriented system of platform-margin categorization based on three successive depositional “stages”, which he applied to the Kimmeridgian-Berriasian section of the Baltimore Canyon Trough:

Stage I (Progradation): A period of rapid seaward platform growth. Carbonate-production potential is presumed to have been sufficient only for platform aggradation, but the carbonate tract prograded because rapid siliciclastic deposition helped to fill the adjacent accommodation space in the Sohm-Hatteras Trough. Stage I ended with a relative sea-level fall and subaerial exposure of the gigaplatform.

Stage II (Aggradation): The supply of siliciclastic detritus to the Sohm-Hatteras Trough dwindled. Accelerated relative sea-level rise was matched by accelerated carbonate production to produce a relatively stationary barrier reef, topped by a series of pinnacles. Stage II ended with another fall in relative sea level and subaerial exposure of the gigaplatform.

Stage III (Drowning): Rapid and large relative sea-level rise drowned the neritic carbonate producers, and deposited a thin veneer of largely pelagic carbonates. Sediments of Stage III are normally too thin to be distinguished on seismic profiles.

In an exemplary study of the Permian Capitan shelf margin (Delaware Basin) Garber et al. (1989) recognized a progradation-aggradation succession similar to Meyer’s Stages I and II. They also concluded that siliciclastic basin-fill, along with sea-level change and emplacement of allochthonous carbonate debris onto the basin margin, was a major mechanism for shelf-edge progradation.
I agree in general with Meyer's interpretation of a tripartite Late Jurassic–Early Cretaceous platform evolution in the Baltimore Canyon Trough, although we disagree on the details of timing, the lateral continuity of carbonate deposition, and the relative importance of forcing mechanisms for progradation. I, for example, would place most of the prograding Kimmeridgian strata (Stage I; shown in Meyer's fig. 3A, B) in the Oxfordian sequence, more like what he shows for the Scotian Basin (Meyer's fig. 14). Furthermore, the depositional variability along strike may have been greater and more persistent through Stage II (aggradation) than implied by Meyer (e.g., his fig. 13). As a case in point, Fig. 17 shows four large passages through the carbonate tract (20–30 km wide), where siliciclastic deposition appears to have stifled carbonate production throughout most of Kimmeridgian–Tithonian time.

The lateral variation of gigaplatform growth is even more striking when viewed on a margin-wide scale (Bahamas to Georges Bank). For example, progradation was most pronounced in the central part of the Baltimore Canyon Trough and tapered off toward the bounding structural platforms (Fig. 30; see also Emery and Uchupi, 1984). A similar, but more irregular progradation took place in the Georges Bank Basin. Selected depth-converted cross sections (Figs. 6–10) indicate that each basin or trough had its own individual growth history. From Aalenian(?) to early Bathonian time, the shelf edge prograded slowly (70°–900 m/m.y.) in the Baltimore Canyon Trough (Fig. 31). At the same time, the shelf edge retreated slightly in the Georges Bank Basin (−700 m/m.y.) and the Carolina Trough (−180 m/m.y.), but aggraded in the Blake Plateau Basin. In the late Bathonian–Callovian interval, rapid progradation (800–2800 m/m.y.) was the rule for the entire margin north of the Blake Plateau Basin (where a retreat of −800 m/m.y. took place). This seaward thrust continued through the Oxfordian (200–3000 m/m.y.), except in the southern Baltimore Canyon Trough (line 28), where a slight retreat (−300 m/m.y.) appears to have begun (and aggradation again dominated the Blake Plateau Basin). Through the Kimmeridgian and late Tithonian slight progradation (400 m/m.y.) took place in the central part of the Baltimore Canyon Trough, but in the other northern basins the shelf edge retreated (−200–300 m/m.y.).

It is instructive to compare the growth rates of the Bahama–Grand Banks gigaplatform with those of the Capitan shelf margin calculated by Garber et al. (1989). Table 1 shows that the gigaplatform and its pre-Callovian predecessors aggraded at rates of ~50–400 m/m.y., which are comparable to a range of 95–430 m/m.y. for the entire Guadalupian sequence of the Delaware Basin. Maximum Capitan rates of 335–430 m/m.y. at the shelf margin match Bajocian–early Bathonian rates in the Blake Plateau Basin and late Bathonian–Callovian rates in both the Blake Plateau Basin and central Baltimore Canyon Trough.

Progradation rates of the gigaplatform range from 200 to 3000 m/m.y., which are similar to the minimum rates (1900–3200 m/m.y.) on the distal extremities of the Capitan margin. At its maximum along the northern margin, however, the Capitan
margin prograded 2.5 times as fast as the maximum gigaplatform rate (7600 vs 3000 m/m.y.). Retreat of the gigaplatform varied from −182 to −833 m/m.y.

Growth differential (horizontal versus vertical) for the Bahama–Grand Banks gigaplatform ranged from 1:1 to 17:1 (Table 1), which is considerably less than that of the Capitan margin (25:1–30:1). It is curious that the growth differential of 3:1 in the central Baltimore Canyon Trough during Kimmeridgian–Tithonian time was matched by an identical retreat differential in the other northern basins.

When Meyer (1989) compared the Baltimore Canyon Trough's Late Jurassic evolution with that of the coeval Scotian Basin, he found that these two segments of the gigaplatform also had distinctly divergent growth histories. Whereas rapid platform progradation took place throughout much of the Baltimore Canyon Trough, aggradation dominated most of the Scotian Basin. Meyer ascribed this divergent growth history to the greater rate of siliciclastic basin filling that took place seaward of the Baltimore Canyon Trough.

My data suggest, however, that siliciclastic encroachment from the landward side of the platform may have been equally as important (or sometimes more important) than siliciclastic basin filling on its seaward side (see also Erlich et al., 1990). This conclusion is supported by Fig. 30, which shows that the locus of maximum progradation was along line 25, in alignment with the locus of maximum siliciclastic encroachment (Figs. 7 and 17).

The record of volumetric siliciclastic accumulation rates for the Baltimore Canyon Trough (Fig. 31A; Poag and Sevon, 1989) provides further evidence that Meyer's and Garber et al.'s basin-fill hypothesis needs modification. During Aalenian (?) time, unusually high accumulation rates (25,000 km³/m.y.), associated with rapid thermotectonic subsidence (Watts and Steckler, 1979), restricted carbonate production to a few scattered tracts, and shelf-edge progradation was minimal.
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C.W. POAG
(Fig. 12). A significant reduction in Bajocian–early Bathonian siliciclastic deposition (9000 km³/m.y.) allowed carbonate-producing communities to flourish widely, which significantly expanded the shelf-edge platforms. An increase to moderate siliciclastic accumulation rates in the late Bathonian–Callovian and Oxfordian (11,000–14,000 km³/m.y.) caused the carbonate communities to migrate rapidly seaward, consequently accelerating shelf-edge progradation. Siliciclastic accumulation rates fell to 6000 km³/m.y. in the Kimmeridgian–Tithonian, reducing the rate of encroachment toward the shelf-edge carbonate tract, and the gigaplatform either aggraded or retreated. Note also that the gigaplatform was significantly wider (expanded landward) in the Georges Bank and Blake Plateau basins (Figs. 6–10), where the supply of siliciclastic shelf sediments (and encroachment on the carbonate tract) was least. Meyer (1989), in contrast, believed that siliciclastic accumulation rates increased during this interval, having used the common “dip-stick” method of rate calculation based on the thickness of the sediment column in selected wells. But as Poag and Sevon (1989) showed (and the data herein confirm), a few local dip-stick measurements are by no means adequate for measuring regional sedimentation rates in the highly variable 1,000,000 km² covered by the Baltimore Canyon Trough–Hatteras Basin depositional regime.

The bathymetric migration of principal Jurassic siliciclastic depocenters in the Baltimore Canyon Trough region (Fig. 31B; Poag and Sevon, 1989) also bears on the growth history and processes of this segment of the gigaplatform. During Aalenian(?), Bajocian–early Bathonian, and late Bathonian–Callovian time, for example, principal siliciclastic depocenters were located on the continental shelf (Fig. 31B), where maximum encroachment rates could be maintained on shelf-edge carbonate tracts. During the Oxfordian to Tithonian interval, however, large volumes of siliciclastics began to bypass the shelf to form bathyal and abyssal depocenters (Meyer reported a succession exactly the reverse of this). This bypassing may have further reduced siliciclastic encroachment on shelf-edge carbonate communities.

Thus Meyer’s (1989) and Garber et al.’s (1989) hypothesis that siliciclastic basin filling can enhance the progradation of carbonate platforms is only weakly supported by the diverse relationships highlighted herein. Along the U.S. margin it appears, rather, that siliciclastic encroachment was often equally or more important. The divergent basin histories described above show, however [and so do many modern and additional fossil examples (e.g., Doyle and Roberts, 1988)], that contiguous siliciclastic deposition was but one of several interactive bio-physico-chemical agents that created, maintained, and terminated the gigaplatform.

**Paleogeography, paleoceanography and paleoclimate**

In order to fully appreciate the development of the Bahama–Grand Banks gigaplatform it is important to understand its relationships with regional paleogeography, paleoceanographic conditions, and prevailing paleoclimate. A number of authors, including Manspeizer (1981, 1982), Hay et al. (1982), Parrish and Curtis (1982), Parrish et al. (1982), Emery and Uchupi (1984), Hallam (1984, 1986), Jansa (1986), Roth (1986, 1989), Tucholke and McCoy (1986), Barron (1987) and Schlee et al. (1988), have analyzed and recon-
structured the Jurassic and Early Cretaceous paleogeography, paleoceanography and paleoclimate of the proto-Atlantic seaway. In the most recent comprehensive interpretations (Jansa, 1986; Tucholke and McCoy, 1986), shallow-marine waters from the Tethys Sea entered the developing Pangean rift zone between North America and Africa from two northeastern gateways during Late Triassic time (Norian). Evaporites, the chief sedimentary deposits of the Triassic and Early Jurassic, precipitated in what was essentially a single intracratonic basin, which extended as far southwest as the southern end of the Baltimore Canyon Trough. My interpretation (Fig. 32) is more like that of Holser et al. (1988) in that: (1) along the U.S. margin, in late Toarcian(?)-early Aalenian(?) time, three discrete evaporite basins were separated by structurally high platforms upon which no seismically detectable sediment accumulated, and (2) evaporite deposition reached the Carolina Trough, which at that time appears to have been the most southwestern depocenter of the proto-Atlantic seaway. Coeval evaporites may also have accumulated farther south beyond the seaway, however, in the Blake Plateau rift basin.

According to most modern plate reconstructions this long, narrow seaway (50–200 × 4300 km) lay in a low-latitude (10–20°N) position (Sclater et al., 1977; Smith and Briden, 1977; Firstbrook et al., 1979; Scotese et al., 1981; Emery and Uchupi, 1984; Zeigler et al., 1984; Manspeizer, 1985; Kliting and Schouten, 1986; Jansa, 1986). Its sinuous long axis was oriented approximately east–west from a Tethys gateway (Biscay Seaway of Jansa, 1986) to the Long Island Platform, at which point the axis turned gently to the southwest (Fig. 32, Long Island Bend). A second gateway from Tethys (Gibraltar–Rif Seaway of Jansa, 1986) channeled surface currents northwestward to the Grand Banks.

Parrish et al. (1982) used the global distribution of coal and evaporites, which reflects the balance between precipitation and evaporation, to predict the relative amount of rainfall on Pangea. For the proto-Atlantic seaway, the model predicts low rainfall in the Triassic and moderately low rainfall.
throughout the Jurassic and Early Cretaceous. The Blake Plateau and Bahama basins would have become increasingly wetter (moderately high rainfall), however, near the Jurassic–Cretaceous transition.

By the end of Aalenian(?) time, seafloor spreading had split the nascent proto-Atlantic seaway into a northern (Sohm–Hatteras) and southern (Madeira–Gambia) deep-water trough, each bounded landward by shelf basins and separated from each other by a mid-ocean (mid-seaway) ridge, or spreading center (Fig. 33; Jansa, 1986; Klitgord and Schouten, 1986; Tucholke and McCoy, 1986). The cessation (or diminution) of evaporite deposition and the beginning of benthic carbonate deposition on the continental shelves during the Aalenian(?) attest to improved circulation at shallow and mid-water depths as far west as the Georges Bank Basin. Carbonate production was still sparse farther down the seaway, however, and restricted surface-water circulation may still have characterized the margin from Baltimore Canyon Trough to the Carolina Trough, which was closed to communication with the Pacific or the yet to be formed Gulf of Mexico, although some shallow Aalenian(?) marine waters may have invaded the still-active rifts of the Blake Plateau Basin (Phair and Buffler, 1983; Salvador, 1987; Schlager et al., 1984; Buffler, in press).

No Aalenian deep-sea sediments have been recovered from the Sohm–Hatteras Trough, but DSDP Site 547 (Fig. 33), near the Tethys end of the Madeira–Gambia Trough, appears to provide some evidence of Aalenian bathyal circulation. Jansa et al. (1984) described a poorly recovered succession of mainly pale yellowish-brown and pale red micrite nodules encompassed in a pale yellowish-brown, burrowed, calcareous claystone matrix (cores 547-14, 15 and 16). Most of the nodular clasts are displaced biomicrites composed mainly of radiolarian casts, together with ostracodes, foraminifera and Globochaete. These characteristics prompted these authors to infer deposition in oxygenated bottom waters at outer neritic or upper bathyal depths. One prominent black shale interval was interpreted as evidence of occasional periods of relative stagnation, probably associated with an oxygen-minimum layer. The distribution of Aalenian(?) deposits in the Georges Bank region is evidence that maximum water

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![Fig. 33. Paleogeographic reconstruction of proto-Atlantic seaway at end of Aalenian(?) deposition, after seafloor spreading had begun. Spreading axis indicated by segmented line. Carbonate tracts shown. Arrows indicate dominant flow directions of surface currents. Dashed lines indicate present outline of continents. Scale approximate. Adapted from Jansa (1986) and Tucholke and McCoy (1986).]
depths there were probably bathyal, as only a restricted (~20 km wide) continental slope existed, and apparently no continental rise had yet formed (Fig. 12). Beyond this narrow passageway, however, just southwest of the Long Island Bend, an incipient continental rise and abyssal plain appear to have been present where the Sohm–Hatteras Trough widened to ~80–170 km in front of the Baltimore Canyon Trough. The abyssal trough narrowed again to ~10–15 km along the Carolina Platform, only to widen again (40–90 km) seaward of the Carolina Trough (Fig. 12). The Sohm–Hatteras Trough terminated in a cul-de-sac, approximately seaward of what is now Cape Fear, North Carolina. Here the trough was closed on three sides by elevated seafloor topography (Carolina Trough, Blake Plateau Basin, mid-seaway spreading center), which may have prevented deep-water connections with the Madeira–Gambia Trough. Under such conditions, as Jansa (1986) suggested, a Mediterranean type of stratified circulation probably developed in the Sohm–Hatteras Trough. Warm, clear, wind-driven Tethyan surface water would have entered the eastern end of the trough, flowed ~3000 km through the narrow seaway within a relatively arid climatic regime, and descended as it became more saline and denser near the cul-de-sac. The return flow must have been relatively stagnant and sluggish as it passed through narrow, circuitous passageways back to Tethys.

Bajocian–early Bathonian time saw significant changes in the paleogeography and paleoceanoographic conditions along the U.S. margin of the proto-Atlantic. Seafloor spreading had widened the seaway for ~15 m.y., and by the middle of Bathonian time the Sohm–Hatteras Trough (from shoreline to sedimented flank of the spreading center) was on average ~300–400 km wide (Fig. 34; the seaway would have been more than twice as wide). Increased benthic carbonate production created wider, more extensive outer-shelf platforms in the Georges Bank Basin. The Blake Plateau and Bahama basins in particular underwent a vast expansion of carbonate production, which resulted in construction of a 450 x 600-km megabank (Fig. 13). These developments indicate that warm, clear, well-circulated surface waters were reaching the southern terminus of the seaway. Carbonate production was more limited in the Baltimore Canyon and Carolina troughs, because large volumes of siliciclastic sediments (Fig. 31A; Poag and Sevon, 1989) still suppressed benthic carbonate communities.

The best evidence of deep-water circulation for Bajocian–early Bathonian time comes again from DSDP Site 547 (Fig. 34). There, an upward change to reddish brown, sandy, limestone breccias and conglomerates (lithologic subunit VIA3 of Jansa et al., 1984), topped by a series of bioturbated, fossiliferous, pelagic wackestones, indicates good abyssal ventilation and bottom circulation near the widened Tethys gateway. Bottom-water circulation in the Bahama cul-de-sac, however, was probably much poorer than at Site 547, because of the great distance from Tethys and because of the still quite narrow dimensions (no more than 50–100 km wide in places seaward of the Carolina Trough and Blake Plateau Basin) and circuitous axis of the Sohm–Hatteras Trough (Fig. 13). The trough may also have been shallower here than at Site 547; the present relief between the Bajocian–lower Bathonian sequence seaward of the Blake Escarpment and its neritic equivalent on the escarpment is 1500 m (Fig. 10), which indicates a similar paleodepth in Bajocian–early Bathonian time.

The slow northward migration and counterclockwise rotation of the North American plate had not appreciably changed the low-latitude position (~5°–22°N) of the U.S. marginal basins by the end of Bajocian–early Bathonian time, as reflected in the continued presence of thick carbonate deposits. No significant alterations in the paleoclimate during this time interval are indicated by the global geologic record or by theoretical models.

By the end of late Bathonian–Callovian deposition the proto-Atlantic seaway had widened to as much as 1000–1200 km, and was probably connected with the Gulf of Mexico (Fig. 35; Scott, 1984; Taylor et al., 1984; Westermann, 1984) and to the Pacific Ocean ("Hispanic Corridor" of Smith, 1983; "Americas Seaway" of Jansa, 1986; Tucholke and McCoy, 1986; see Salvador, 1987, however, for a countervailing opinion). Benthic carbonate production continued to proliferate, and lateral expansion of the shelf-edge tracts created
Fig. 34. Paleogeographic reconstruction of proto-Atlantic seaway at end of Bajocian-early Bathonian deposition. Spreading axis indicated by segmented line. Carbonate tracts stippled. Arrows indicate dominant flow direction of surface currents. Dashed lines indicate present outline of continents. Scale approximate. Adapted from Jansa (1986) and Tucholke and McCoy (1986).

Fig. 35. Paleogeographic reconstruction of proto-Atlantic seaway at end of late Bathonian-Callovian deposition. Spreading axis indicated by segmented line (axis has jumped to east and extended south and west into Gulf of Mexico (vast evaporite beds there in Callovian)). Carbonate tracts stippled. Plain arrows indicate dominant flow direction of surface currents; broken arrow indicates possible deep-water outflow to Tethys Sea. Dashed lines indicate present outline of continents. Scale approximate. Adapted from Jansa (1986) and Tucholke and McCoy (1986).
the Bahama–Grand Banks gigaplatform. Moreover, there is evidence that the Blake–Bahama megabank had expanded into the southeastern Gulf of Mexico (Schlager et al., 1984; Buifler, in press). In addition, sandy, shaley limestones of the Tepexic Formation in Mexico (Cantu Chapa, 1971; Scott, 1984; Taylor et al., 1984) provide evidence of a Pacific connection (Jansa, 1986). Callovian sediments are the oldest to have been recovered from the abyssal Sohm–Hatteras Trough (Blake–Bahama Basin). Sheridan et al. (1983), Ogg et al. (1983), and Robertson and Ogg (1986) reported a succession of dusky red, calcareous, silty marls overlain by alternations of non-calcareous claystones, marly limestones, black shales, thin radiolarites, silts and sands near the base of the Blake Escarpment at DSDP Site 534 (Figs. 3, 17 and 35). These authors estimated that the paleodepth at the time of deposition was approximately 3000 m; this estimate is corroborated by the present ∼2800 m of vertical relief between the abyssal Callovian section and its inferred neritic equivalent exposed along the Blake Escarpment (Fig. 10). Seismic facies and sedimentologic analyses suggested to Ogg et al. (1983) and Robertson and Ogg (1986) that the basal Callovian claystones may represent contourites, formed by sluggish bottom currents. Tyson (1984), on the other hand, favored redeposition by slumps, debris flows and turbidity currents. The dark colors, extensive pyritization, relative abundance of marine and terrestrial organic matter, and the presence of phosphate concretions and glauconite in the claystones and shales, suggest periodic oxygen deficiency at, or just below, the seafloor, possibly in local hollows. This conclusion is supported by the lack of nearly all fossils except radiolarians and fish skeletal debris, although bioturbation (Chondrites) is evident in some gray to green claystones. Green-gray limestones, which represent calciturbidites, become numerous in the upper part of the Callovian succession. Ogg et al. (1983) and Robertson and Ogg (1986) concluded that abyssal circulation near Site 543 was mainly an intra-seaway system, and that exchange of bottom waters with Tethys and the Pacific was minimal because of shallow sill depths. Although the southern abyssal portion of the narrow (50–100 km) proto-Atlantic seaway appears still to have been a virtual cul-de-sac, surface circulation was evidently sufficient to allow nektonic Tethyan ammonite populations to reach Cuba, the Gulf Coast and Mexico (Scott, 1984; Taylor et al., 1984; Westermann, 1984; Jansa, 1986).

The presence of broad, carbonate-rich shelves in the Blake Plateau and Bahama basins indicates continued vigorous circulation of warm, clear, surface waters in the southern reaches of the proto-Atlantic. In contrast, partly coeval precipitation of vast evaporite beds in the Gulf of Mexico (Louann Salt) indicates restricted marine circulation there. The eroded terrace (cut into the inferred Bajocian–lower Bathonian sequence; Figs. 10 and 14) along the buried base of the Blake Escarpment may be an indication, however, of important changes in shallow-water circulation of the southwestern Sohm–Hatteras Trough during the late Bathonian–Callovian interval. This is the time when the mid-Atlantic spreading center jumped eastward and propagated southward, skirted the Blake–Bahama megabank, and connected through fracture zones to a nascent Gulf of Mexico and/or Caribbean spreading center (Fig. 35; Anderson and Schmidt, 1983; Klitgord and Schouten, 1986). This rearrangement created a narrow passageway between the North American and African plates along the Blake–Bahama megabank. Presumably, surface currents accelerated by this bottleneck could have eroded the outer margin of the megabank and pushed the carbonate production zone as much as 30 km landward, producing the terrace (Figs. 14 and 29). This situation may have been sustained until the seaway became appreciably wider in Berriasian–Valanginian time. Meanwhile, an upper Bathonian to Tithonian succession could still accumulate in deeper parts of the Blake–Bahama Basin (e.g., DSDP Site 534). By the early Berriasian the passageway had widened enough to reduce current flow significantly, and deposition resumed on the Bajocian–early Bathonian terrace. However, the bounding escarpment was now so steep and high (∼2 km) that the resulting basinal accommodation space could not be filled, thus preventing shelf-edge progradation.

Jansa (1986) cited an explosive expansion of radiolarian populations during Bathonian–Callov-
ian time as an indication of unhindered circulation between Tethys, the proto-Atlantic and the Pacific, but this radiolarian distribution reflects only circulation of surface to mid-depth water masses, where most of these planktonic organisms lived. Jansa (1986) also suspected that the radiolarian blooms were triggered by changing circulation patterns, which created coastal upwelling zones, including stretches along the seaward margins of the Carolina Trough and Blake Plateau Basin. It is unlikely, however, that significant upwelling took place at these locations, for the heightened nutrification would probably have depleted the carbonate-producing communities that built the gigaplatform (Hallock and Schlager, 1986; Hallock, 1988; Hallock et al., 1988).

Oxfordian time brought further improvement in shallow-water circulation in the proto-Atlantic seaway, manifest by sustained aggradation of the gigaplatform in the Blake Plateau and Bahama basins, and by continued progradation in the Georges Bank Basin, Carolina Trough, and parts of the Baltimore Canyon Trough (Figs. 6–10 and 31A). A dramatically improved Gulf of Mexico connection led to extensive platform and reef building there as well (Smackover Formation; Baria et al., 1982; Scott, 1984; Jansa, 1986; Salvador, 1987; Buffler, in press).

Jansa (1986) envisaged a northern (clockwise) and southern (counterclockwise) gyre in the surface-current systems of the Oxfordian proto-Atlantic, although a dominant southwesterly flow was still maintained from Tethys to the Gulf of Mexico and Pacific. Abyssal circulation in the southern part of the seaway was still rather restricted however. Abyssal depths of ~3000 m were maintained along the Blake–Bahama Escarpment (Fig. 10) near DSDP Site 534 (Fig. 3), where in situ Oxfordian sediments are black, horizontally bedded, non-bioturbated, sparsely fossiliferous claystones. These characteristics suggest that bottom waters were poorly oxygenated and sluggish (Ogg et al., 1983). Interbeds include redeposited reddish and greenish claystones, representing distal turbidites (probably from the nearby slope of the Carolina Trough), and greenish-gray, marly, pelmicritic limestone turbidites derived from the adjacent Blake Plateau platform. Chondrites burrows in the upper portions of some claystone turbidites, however, indicate intermittent oxygenation of this site. A similar environment, ~1000 km farther northeast at DSDP Site 105 (Fig. 3), is indicated by the presence of greenish-gray marly limestone and marl containing a variety of bioclasts and peloid grains, reflecting carbonate turbidites (Hollister et al., 1974; Ogg et al., 1983).

Five hundred kilometers to the southeast, however, at DSDP Site 100 (Fig. 3), Oxfordian abyssal sediments are mainly greenish-gray pelagic limestones containing numerous burrows and some current bedding, perhaps reflecting a greater distance from terrigenous sources and more oxygenated bottom waters.

By the end of Jurassic time the proto-Atlantic seaway had widened to ~1500–2000 km, and developed broad, relatively deep connections with Tethys, the Gulf of Mexico and the Pacific (Fig. 36). A relatively wide abyssal plain was present in both the Sohm–Hatteras and Madeira–Gambia troughs, and submarine fan complexes were actively filling them (Fig. 17; Poag and Sevon, 1989). Unencumbered connections with Tethys and the Pacific further improved general circulation systems at all depths. On the shelves, reduced siliciclastic input (Fig. 31A; Poag and Sevon, 1989) and the acme of benthic carbonate production broadened and thickened the gigaplatform and built a spectacular pinnacled barrier along the Baltimore Canyon Trough (Figs. 7 and 18). Although the North American plate continued its northward trek and counterclockwise rotation, the Bahama–Grand Banks gigaplatform still lay between ~5 and 28°N, and the depositional record reflects optimal environmental conditions for the benthic carbonate producers.

Abyssal environments bordering the gigaplatform also underwent a significant upgrading and progressive carbonate enrichment. At DSDP Site 534 (Figs. 3, 17 and 36), for example, the Kimmeridgian–Tithonian succession began with grayish-red, calcareous (nannofossiliferous) claystones, graded upward into pale red marly nannofossil limestones, and culminated with white, nearly pure, nannofossil limestones. Similar Kimmeridgian–Tithonian successions have been cored at DSDP Sites 99, 100, 105 and 391 (Figs. 3, 17 and 36;
Hollister et al., 1972; Jansa et al., 1979; Ogg et al., 1983; Jansa, 1986). Such lithofacies reflect well-oxygenated bottom waters, a depressed carbonate compensation depth, a significant increase in calcareous plankton production (Hallam, 1975; Roth 1986, 1989), and reduced siliciclastic input. There is little sedimentary evidence of bottom currents, however, and benthic organisms other than foraminifera and ostracodes are rare in these sediments. Radiolarians, dinoflagellates, calpionellids, Saccocoma (a planktonic crinoid) and small pelagic mollusks are common, but nannoplankton are dominant among the planktonic fossils, and moderately abundant ammonites represent the nekton.

Ogg et al. (1983) and Jansa (1986) made special note of this abyssal carbonate injection, which lasted through much of the Early Cretaceous. Jansa (1986) and Roth (1986, 1989) speculated that such a carbonate spike might result from a shift of carbonate production from the continental shelves to the pelagic realm during the Late Jurassic (the “Keunen Event” of Roth, 1986). Jansa described a gradual displacement of North Atlantic shelf carbonates by siliciclastic encroachment beginning in the Late Jurassic to Early Cretaceous. Jansa’s timing of the neritic-to-pelagic carbonate shift, however, does not fit the sequence of events along the U.S. margin. On this margin, coincident with the abyssal carbonate injection, carbonate platforms and shelf-edge reefs reached maximum development and siliciclastic encroachment declined (Figs. 6–10 and 31A). The shelf carbonate production was not shut down until Berriasian–Valanginian time. Thus, repositioning the carbonate “factories” in deeper waters may have reinforced abyssal carbonate saturation during the Early Cretaceous, but some other mechanism must have initiated it in the Late Jurassic. One possible mechanism is the reduction of siliciclastic sediment supply during Kimmeridgian–Tithonian time (Fig. 31A), possibly associated with increased continental aridity (Hallam, 1986), which would have reduced the noncarbonate component of abyssal sediments. A second, probably more important mechanism is the “Keunen Event”, a major pulse
of coccolith carbonate production that took place in the Late Jurassic (Roth, 1986, 1989).

By the end of the first major Early Cretaceous depositional episode (Berriasian–Valanginian) benthic carbonate production along the Bahama–Grand Banks gigaplatform had essentially ceased as far southwest as the Carolina Trough (Figs. 6–10, 21 and 37). Meanwhile, light-colored pelagic carbonates were accumulating at numerous sites (DSDP Sites 99, 100, 105, 391 and 543) in the Sohm–Hatteras Trough, except near major sources of terrigenous detritus (e.g., DSDP Site 603). Marine connections with Tethys, the Gulf of Mexico and the Pacific continued to broaden (Jansa, 1986), and the Tethys gateway may have deepened to 3000 m (Tucholke and McCoy, 1986), and comparable depths characterized the southern part of the Sohm–Hatteras Trough (Fig. 10). The Parrish and Curtis (1982) atmospheric circulation model indicates that westward equatorial flow was maintained over the proto-Atlantic seaway, and Jansa (1986) and Tucholke and McCoy (1986) suggested that a clockwise North Atlantic surface-water gyre may have developed, accompanied by the initiation of proto-Gulf Stream circulation along the eastern U.S. margin.

Tucholke and Mountain (1979) and Tucholke and McCoy (1986) suggested that the lensoid shape of the Early Cretaceous deposits in the Blake–Bahama Basin (Fig. 21) might be due to intensified bottom currents that impinged upon the Blake–Bahama Escarpment. Freeman and Enos (1978) and Robertson and Bliefnick (1983) argued, in contrast, that ubiquitous fine laminations seen in marly Berriasian–Valanginian nannofossil chalks at DSDP Sites 543 and 391 (Figs. 3, 21 and 37) are not current-derived, lacking ripples, cross-bedding, scours, and other current-associated sedimentary structures. Neither are the seismic reflections in this interval hummocky, as in typical contourite drifts.

An Early Cretaceous decline in neritic carbonate production was felt widely in the proto-Atlantic and Tethys region, extending from the Carolina

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**Fig. 37.** Paleogeographic reconstruction of proto-Atlantic seaway at end of Berriasian–Valanginian deposition following demise of Bahama–Grand Banks gigaplatform. Spreading axis indicated by segmented line. Carbonate tracts stippled. Plain arrows indicate dominant flow direction of surface currents; broken arrows indicate possible flow direction of deep-water circulation. Dashed lines indicate present outline of continents. Scale approximate. Numbered dots represent DSDP core sites. Note upwelling along east-west trending segment of North American shelf edge (Carolina Trough to Grand Banks), but not along north-south trending segment (Blake Plateau and Bahama Basins). Adapted from Parrish and Curtis (1982), Jansa (1986) and Tucholke and McCoy (1986).
Trough to North Africa and into the southern USSR and the Arabian peninsula (Jansa and Wiedmann, 1982; Hallam, 1984). Jansa and Wiedmann attributed this decline to siliciclastic replacement due to Cimmerian tectonism (uplift of siliciclastic source terrains). Hallam, on the other hand, suggested that it was caused by a dramatic increase in continental runoff as a more humid Early Cretaceous climate replaced the generally arid Late Jurassic climate. Hallam cited as evidence the widespread disappearance of evaporites, reintroduction of kaolinite after a period of absence, and abundance of siderite in "Wealden" clays.

Causes of demise of Jurassic shallow-water platforms

Why, after surviving for 42 m.y. the vicissitudes of environmental stress associated with the birth of a new ocean basin (shifting sediment supply, sea-level rise and fall, altered current patterns, changing subsidence rates, plate migration) did the gigaplatform languish at the end of the Jurassic? Sheridan (1976), writing before the stratigraphy of U.S. Atlantic shelf basins was constrained by drilling, was the first to suggest an answer to this question. He projected poorly dated stratigraphy from a few coastal wells in New Jersey ~20-50 km downdip to a series of offshore seismic reflection lines. From these jump correlations he deduced that a massive bank had built up on the New Jersey continental shelf during Barremian-Aptian time. This bank-building episode was followed by construction of a smaller reef-bank complex, which endured from Albian to Santonian-Campanian time. Believing that a similar stratigraphic succession was represented in the Blake Plateau Basin, Sheridan concluded that the biphasic bank-to-reef development and its subsequent termination were coeval in both basins. Unfortunately, none of Sheridan's offshore profiles actually crossed any wells, and as a result, his reef stratigraphy was ~64 m.y. too young.

To explain the termination of the "Barremian-Aptian" bank, Sheridan called on a regression brought about by a major change in seafloor spreading and a tilting of the basins to the west. He suggested, furthermore, that significant environmental changes related to deep-sea anoxia might have impeded recovery of the benthic carbonate producers. He envisaged a similar scenario for the demise of the "Albian-Santonian" reef-bank (reduction of seafloor spreading, opening of the Labrador Sea, increased cold bottom currents, end of abyssal anoxia). Of course, with the inaccurate stratigraphy, these specific events are irrelevant to the actual history of the gigaplatform, but the inferred "one-two punch" of relative sea-level change accompanied by prolonged environmental disturbance was probably correct.

More recently, Jansa (1981, and repeated in 1984) presented a synthesis of the Mesozoic carbonate platforms of eastern North America as known before the shelf-edge reef was drilled in the Baltimore Canyon Trough. Jansa reported an apparent north-to-south stratigraphic progression (Grand Banks to the Bahamas) in the termination of carbonate production. This progression, he inferred, was due to northward movement of the North American plate into climatic zones increasingly hostile to benthic carbonate producers (Fig. 38). From this interpretation he derived a maximum rate of plate migration (~1.5 cm/yr), which was similar to rates derived from paths of polar wander (Irwing, 1979), although he used the present latitudes of the basins rather than their paleolatitudes. Almost simultaneously, Schlager (1981) reached the same conclusion regarding North American plate migration, although he recognized an overprint of amphi-Atlantic platform-drowning events near the end of the Jurassic. Several subsequent authors (e.g., Schlee et al., 1988) have perpetuated Jansa’s idea.

It now seems certain, however, that the global carbonate-production zone remained between the latitudes of 5 and 35° throughout Mesozoic and Cenozoic time (Zeigler et al., 1984), and that the Bahama-Grand Banks gigaplatform did not move out of this zone until the Late Cretaceous. Zeigler et al. (1984) noted furthermore, that this carbonate-production zone did not expand appreciably into higher latitudes during the warmest parts of the Cretaceous as would be expected in a climate-controlled (temperature-sensitive) system. These authors suggested that instead, reduced light refraction (in the upper water column) at higher
Fig. 38. Chart showing chronological cessation of shallow-water carbonate production along Bahama–Grand Banks gigaplatform. Scales at top show present latitudes (above) and end-of-Jurassic paleolatitudes (below). Dotted line represents early concept (Jansa, 1981) of carbonate cessation progressing diachronously from northern Grand Banks to Bahamas. Solid line shows revised cessation curve based on current information. Early part of revised curve is identical to Jansa’s curve, but later part shows nearly simultaneous Late Jurassic–Early Cretaceous cessation along U.S. margin as far south as Carolina Trough. Note stepwise cessation in Blake Plateau Basin (Blake Spur) and northern Bahama Basin. Shallow-water carbonate tract reoccupied shelf in northern Bahamas during late Paleogene (Oligocene). Deposition in southern Bahama Basin was never seriously interrupted.

Latitudes (which would have been relatively constant through post-Paleozoic time), must have limited photosynthesis among the carbonate producing community. In contrast, Hay et al. (1988), using a different paleogeographic reconstruction, concluded that carbonate production did expand appreciably northward in the middle part of the Cretaceous in response to a more equable climate.

Regardless of the paleogeographic contradictions, Jansa’s (1981) curve for cessation of carbonate production (Fig. 38), is stratigraphically out of date. As Eliuk and Levesque (1988) have pointed out, we now are confident that the Late Jurassic–Early Cretaceous termination of benthic carbonate production was nearly synchronous from the Grand Banks to the southern Carolina Trough (through 15° of present latitude, but only 9° of Late Jurassic paleolatitude). By contrast, the termination of benthic carbonate production in the Blake Plateau and Bahama basins has been step-like. At the edge of the Blake Escarpment, for example, a temporary step-back in reef construction took place in the Berriasian–Valanginian interval (line TD-5, Fig. 28), and a permanent drowning event took place at the end of Barremian time (e.g., DSDP Sites 390 and 392). In the northern part of the Bahama Basin (Great Isaacs well and ODP Site 627; Figs. 3 and 21), on the other hand, the shallow-water platform was not drowned until Cenomanian time; moreover, benthic production of carbonate resumed there in the Oligocene, and continued to the present. In still other Bahaman areas (e.g., Cay Sal, Andros and Long Island wells; Meyerhoff and Hatten, 1974; Schlager et al., 1988; Figs. 3 and 21) benthic carbonates constitute the entire Mesozoic–Cenozoic section. Thus a revised carbonate-cessation curve for the North American margin (Fig. 38) would refute Jansa’s correlation with plate motion.

Furthermore, if the paleogeographic reconstruction used here (Fig. 37) is correct, we see that Berriasian–Valanginian shallow-water carbonates accumulated in the Gulf of Mexico at latitudes higher than the Baltimore Canyon Trough to Grand Banks region. Also, we know that shallow-water carbonate production returned to the northern Atlantic basins periodically (although on a smaller scale) during the Cretaceous (Scholle and Wen kam, 1982; Eliuk and Levesque, 1988) and Cenozoic (Ward and Strickland, 1985).

Recent investigators of the Bahama–Grand Banks gigaplatform (Eliuk and Levesque, 1988; Meyer, 1989; Poag and Sevon, 1989; Erlich et al., 1990) agree that the most likely explanation for the sudden abatement of benthic carbonate production is platform drowning. Schlager (1981) eloquently argued that long-term eustatic rise alone is not sufficient to drown a healthy carbonate platform. But a rapid eustatic or tectonic pulse...
probably could do so, especially if accompanied by other environmental disturbances, such as "inimical bank water".

Several authors have amplified such a reef-drowning scenario (Hallock and Schlager, 1986; Scott, 1988; Macintyre, 1989), which begins with a sea-level fall that exposes the continental shelf to subaerial weathering and soil formation. Carbonate-producing benthic communities that occupied the shelf edge migrate downward to compatible habitats on the upper slope. This activity is followed by a rapid sea-level rise, which floods the shelf and erodes the nutrient-rich soil to form a turbid, hypernutrient water column. The turbidity and excessive nutrients prevent the displaced reef organisms from repopulating the shelf edge, until they are submerged below the critical depth from which they can catch up with rising sea level. Stratigraphic and petrologic evidence indicates that such events could have repressed Late Jurassic carbonate production on the Bahama–Grand Banks gigaplatform. Seismostratigraphic analysis shows that a widespread erosional unconformity separates the Kimmeridgian–Tithonian carbonates from the Berriasian–Valanginian siliciclastics in the northern basins. Evidence of freshwater diagenesis in limestone cores from the upper part of the Baltimore Canyon reef tract (Eliuk et al., 1986; Meyer, 1986, 1989; G. Edson, pers. commun., 1988) indicates that the reef was emergent, or nearly so. (This is less well recorded on the Canadian margin, however; Eliuk et al., 1986; Pratt and Jansa, 1988.) Furthermore, the reef communities (sampled in cores) were dominated by corals, algae and stromatoporoids (Eliuk et al., 1986; Karlo, 1986; Pratt and Jansa, 1988; Meyer, 1989; G. Edson, pers. commun., 1988), all of which are zooxanthellate organisms that rely on photosynthesis for their life processes. These organisms are particularly susceptible to the lethal effects of turbid, hypernutrient waters. Meyer (1989) and Erlich et al. (1990) argued convincingly that a marine flooding event, characterized by markedly reduced deposition, deep-water shelf faunas, and "empty-bucket" morphology (raised rim and deep lagoon typical of platforms forced to keep up with a rapid elevation of sea level), finally ended the ~42-m.y. history of Jurassic platform building in the Baltimore Canyon Trough region. But surely, marine flooding must have inundated the gigaplatform repeatedly during those 42 million years (e.g., Haq et al., 1987). What was special about the terminal Jurassic event?

The coincidence of widespread drowning (including both marine flooding and siliciclastic smothering) of Atlantic carbonate platforms (on both North American and African margins) and a marked turnover of terrestrial plant taxa (Delevoryas, 1970) at or near the Jurassic–Cretaceous transition is evidence that these events were controlled by globally effective agents. A eustatic fall in the early Berriasian may have started the sequence of platform exposure and drowning, but this would hardly have affected the terrestrial ecosystems so significantly. Jansa and Wiedmann (1982) and Hiscott et al. (1990) cited widespread tectonism (uplift, intraplate stress) in the circum-Tethys region, although according to Hallam (1984) the carbonate to siliciclastic switch occurred in many sections devoid of independent evidence of tectonism. Hallam (1984) suggested that the continental botanic changes are partial evidence of a significant paleoclimatic shift (increased humidity) in the Early Cretaceous. He further suggested (and Zeigler et al., 1987, concurred) that the humidity increase may have been tied to a critical threshold of minimum oceanic size, which the proto-Atlantic seaway may have crossed in Berriasian–Valanginian time.

The question remains, however, why such events did not terminate the Blake Plateau and Bahama segments of the gigaplatform. The qualitative models of paleoatmospheric circulation proposed by Parrish and Curtis (1982) may provide part of the answer. Their model predicts that coastal upwelling (which can elevate trophic resources (nutrients and organic matter) in surface waters, and thereby suppress reef and platform growth; Zeigler et al., 1984; Hallock and Schlager, 1986; Hallock et al., 1988) was initiated from the Grand Banks to the Carolina Trough (but not farther southward) at the end of the Jurassic. Certainly, significant paleoceanographic changes of some kind are indicated by the burst of nanoplankton abundance and diversity that marked the late Tithonian invasion by these organisms of the oceanic realm (Roth,
Upwelling could well have provided the nutrient sources necessary to escalate nanoplankton production, while simultaneously decimating the platform builders. At the same time, upwelling may have lowered the surface-water temperature along the platform margin to levels unacceptable for extensive carbonate production. Cold polar temperatures in the Early Cretaceous, for which evidence is growing (Rich et al., 1988; Ginsburg and Beaudoin, 1990; M.A. Arthur, pers. commun., 1990), may have produced a cold, deep-Atlantic water mass, which could be tapped by upwelling.

Another piece of the puzzle may involve the proximity of siliciclastic sediment sources. Even though the delivery of siliciclastics to the Baltimore Canyon Trough actually declined in the Early Cretaceous (Fig. 31A; Poag and Sevon, 1989), the narrower northern shelves still provided a shorter route to the shelf-edge carbonate tracts than the broad shelves of the Blake Plateau and Bahama basins. So perhaps the combination of rapid shelf flooding, and intensified surface-water nutrification and cooling (brought about by relative sea-level rise and upwelling), accompanied by an injection of terrigenous organic matter (associated with siliciclastic encroachment), provided the particularly detrimental environment necessary to selectively decimate the northern carbonate tracts.

**Conclusions**

The principal results derived from this study are enumerated below and in Table 2.

1. A revised Jurassic-Lower Cretaceous stratigraphic and depositional framework demonstrates that six thick postrift depositional sequences [Aalenian(?), Bajocian-lower Bathonian, upper Bathonian-Callovian, Oxfordian, Kimmeridgian-Tithonian, and Berriasian-Valanginian] can be mapped from the Georges Bank Basin to the Blake Plateau Basin. All six sequences have been drilled in the Georges Bank Basin, but most are extrapolated by seismostratigraphy into undrilled portions of the southern basins. There is no convincing evidence of thick Triassic deposits in the sequences drilled on Georges Bank. Postrift deposition in this northern half of the proto-Atlantic seaway (Sohm–Hatteras Trough) and its marginal basins began prior to Bajocian time, probably in the early Aalenian (~187 Ma).

2. Siliciclastic deposition dominated throughout this region during the early stages of seafloor spreading [Aalenian(?)] and Bajocian–early Bathonian time], but small carbonate tracts developed early on the continental shelves and persistently expanded throughout the Jurassic. Although each basin experienced a somewhat different history of carbonate production and platform development, a rapid seaward progradation of the carbonate tracts generally characterized late Bathonian–Callovian or Oxfordian deposition. The impetus for such rapid progradation has been attributed to a combination of high carbonate-production potential (which produced large amounts of reef-slope debris) and rapid filling of the contiguous basin margin with siliciclastic sediments (which, together, reduced accommodation space). Both these mechanisms were undoubtedly important along the U.S. Atlantic margin, but the temporal migration of siliciclastic depocenters in the Baltimore Canyon Trough was out of phase with that predicted by the basin-filling hypothesis. This suggests to me that siliciclastic encroachment from the landward side, which forced the carbonate tract to grow seaward, may have been equally important as a cause of rapid progradation (or more important in some cases) as siliciclastic basin filling.

3. The period of rapid progradation was followed by an interval of prolonged aggradation (Kimmeridgian--Tithonian), during which peak carbonate production created a >5000-km-long gigaplatform and pinnacled barrier reef system. Maximum aggradation (~300–400 m/m.y.) and progradation (~2000–3000 m/m.y.) rates for the Bahama–Grand Banks gigaplatform are comparable to those of the well-studied Permian Capitan shelf margin, but maximum growth differential (horizontal versus vertical growth = 17:1) of the gigaplatform was approximately half that of the Capitan margin.

4. North of the Blake Plateau Basin, carbonate-producing neritic communities of the gigaplatform were decimated during Early Cretaceous time (Berriasian–Valanginian) by a successive fall and rise of sea level, presumably accompanied by eutrophication due to soil-derived nutrients and organic
<table>
<thead>
<tr>
<th>Depositional sequence</th>
<th>Shelf-edge deposition</th>
<th>Paleogeography</th>
<th>Paleoeceanography</th>
<th>Paleoclimate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aalenian (?)</td>
<td>Evaporites disappear; siliciclastics dominate; main depocenters on shelf; carbonate tracts small, scattered.</td>
<td>Trough long, narrow (2750 x 50–150 km); closed at southern end; lat. = 10°–20°N.</td>
<td>Good surface circulation down to Georges Bank; poor farther south; deep waters sluggish, locally stagnant.</td>
<td>Tropical; moderately arid; easterly winds dominant year round.</td>
</tr>
<tr>
<td>Bajocian–lower Bathonian</td>
<td>Siliciclastics dominate; main depocenters on shelf; small carbonate tracts expand; southern megabank develops.</td>
<td>Trough widens (100–250 km); still closed at southern end; Blake Plateau rift inundated; lat. = 5°–22°N.</td>
<td>Good surface circulation throughout; deep circulation poor; local stagnation.</td>
<td>Tropical; moderate rainfall; easterly winds dominant year round.</td>
</tr>
<tr>
<td>Upper Bathonian–Carnian</td>
<td>Significant expansion and progradation of northern carbonate tracts to form gigaplatform; main siliciclastic depocenters begin shift off shelf.</td>
<td>Trough widens (400 km); spreading axis jumps east, extends south, forms narrow strait between megabank and Africa; links to Gulf of Mexico and Pacific; lat. = 5°–22°N.</td>
<td>Good surface and mid-depth circulation connected to Gulf of Mexico and Pacific; Tethys ammonites migrate through; radiolarian populations expand; deep circulation still poor, with local stagnation.</td>
<td>Tropical; moderate rainfall; easterly winds dominant year round.</td>
</tr>
<tr>
<td>Kimmeridgian–Tithonian</td>
<td>Acme of carbonate production; pinnacled barrier reef develops; megabank expands; siliciclastic supply decreases; main depocenters off shelf.</td>
<td>Trough widens (600 km); still narrow strait along southern margin of megabank; lat. = 5°–28°N.</td>
<td>Good surface circulation throughout; improved deep circulation; depressed CCD; deep-water carbonate injection, nannoplankton expansion, and upwelling initiated near end of Tithonian; North Atlantic Gyre and proto-Gulf Stream develop?</td>
<td>Tropical; increased aridity; easterly winds dominant in winter, westerly influence in summer; high-pressure cell over eastern end of seaway.</td>
</tr>
<tr>
<td>Berriasian–Valanginian</td>
<td>Amphi-Atlantic platform drowning; siliciclastic burial north of Blake Plateau; siliciclastic supply still low; main depocenters off shelf; megabank expands.</td>
<td>Trough widens (&gt;1000 km); lat. = 5°–29°N.</td>
<td>Upwelling north of Blake Plateau dominates shelf carbonate producers and continues nannoplankton expansion; deep-water carbonate injection continues except near terrigenous sources.</td>
<td>Tropical; increased humidity and rainfall; taxonomic turnover among terrestrial plant communities; easterly winds in winter, westerlies in summer; high-pressure cell over eastern seaway; seaway becomes major moisture source.</td>
</tr>
</tbody>
</table>
matter entrained in shallow waters shoreward of the reef tract, combined with upwelling of cool, nutrient-rich waters seaward of the tract. Although siliciclastic accumulation rates were low at this time, the northward termination of carbonate production allowed the dying shelf-edge platform in that region to be extensively buried by terrigenous sediments. A pronounced drowning unconformity was developed, however, where the forereef slope was too steep to retain a siliciclastic cover.

(5) A switch from dominantly carbonate to siliciclastic deposition on continental margins at the end of the Jurassic was widespread around the proto-Atlantic seaway and Tethys region, and has been attributed mainly to Cimmerian tectonism (greater source-to-basin relief) and increased climatic humidity and rainfall (accelerated delivery of terrigenous detritus to offshore basins). Neither of these mechanisms, however, appears to have applied to the U.S. margin, where siliciclastic accumulation rates remained low during the Late Jurassic carbonate abatement. The cessation of carbonate production appears to have been sufficient in itself to allow siliciclastics to begin filling the vast backreef and forereef accommodation space.

(6) The terminal Jurassic cessation of shallow-water platform growth has been attributed by some authors to northward migration of the North American plate margin into a climatic regime unsuitable for voluminous carbonate production. A revised cessation curve shows, however, that carbonate production ceased almost simultaneously from Georges Bank to the Carolina Trough. Furthermore, the paleolatitude of the northern proto-Atlantic seaway never exceeded the limits of the tropical carbonate-productivity zone. Early Cretaceous strata deposited at equivalent paleolatitudes in the Gulf of Mexico, for example, were dominantly shallow-water carbonates.

(7) Contrasting opinions explain the formation of a >400-km-long terrace that rims the gigaplatform along the base of the Blake Escarpment. I offer an additional alternative by suggesting that the terrace was created in late Bathonian–Callovian time, when the mid-seaway spreading axis jumped eastward to open a narrow strait between the Blake Plateau segment of the gigaplatform and the African margin. I infer that this bottleneck sufficiently accelerated surface currents to push the carbonate tract 10–30 km to the west, while at the same time eroding the top of the Bajocian–early Bathonian platform.

(8) A significant Late Jurassic shift in carbonate production from the surrounding shelf margins into deep waters of the proto-Atlantic seaway (as well as the Tethys and Pacific oceans) has been widely recognized for many years. Some authors have suggested that this shift may have resulted from the demise of shelf-dwelling carbonate communities. The record of carbonate production in the U.S. marginal basins, however, disputes this correlation, because shallow-water carbonate production peaked in concert with the deep-water carbonate injection. Presumably, the abatement of shelf carbonate production did eventually enrich the deep oceanic carbonate reservoir, but the initial basal injection seems to be more reasonably attributable to an expansion of calcareous nanoplankton populations combined with a general reduction in siliciclastic sediment supply (perhaps related to increased climatic aridity).

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