45. MESOZOIC AND CENOZOIC SEDIMENTARY ENVIRONMENTS OF THE WESTERN NORTH ATLANTIC

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INTRODUCTION

Leg 44 completes a phase of exploration of the western North Atlantic Ocean. Integration of Leg 44 data with the results from earlier drilling (Legs 1, 2, 11, and 43) shows that the sedimentary units of Mesozoic age have great lateral continuity. Some of the Tertiary sequences are also widespread; some are restricted to sub-basins.

The data from Leg 44 extend and modify the eight lithologic units defined by Lancelot et al. (1972). We sampled six of Lancelot's major units; the other two are less extensive and are probably confined to the Cat Gap area near San Salvador Island. In addition to these six extensive formations, we discovered an extraordinary sequence of Miocene intraclastic chalk that is apparently confined to the Blake-Bahama Basin (Site 391; our unit 7a). (See also Site 391 report, this volume.) In the site reports we call these regional units "lithofacies" to distinguish them from the lithologic units recognized only at Site 391.

Drilling on the Blake Nose (Sites 389, 390, and 392) gave specific new information about the Cretaceous and lower Tertiary stratigraphy of the continental margin, which can now be correlated with the stratigraphy of the North Atlantic Basin.

Finally, the data from the COST (Continental Offshore Stratigraphic Test) well B-2 have recently been released (Smith et al., 1976). This well was drilled 4900 meters into the continental shelf off New Jersey and penetrated terrigenous clastic shelf sediments of Jurassic, Cretaceous, and Tertiary age. These contrast sharply with the Jurassic, Cretaceous, and Miocene shelf-derived carbonates in the Blake-Bahama Basin.

Figure 1 shows the locations of the various drill holes and the lines followed by the cross section of Figure 2. This section, which runs east from the Blake Plateau to the Bermuda Rise, then back northwest to the New Jersey shelf, shows the various sedimentary units of the western North Atlantic Basin. We recognize eight major units and two sub-units in the deep basin, three on the Blake Plateau, and six others on the New Jersey shelf. Our numbering system differs from that of Leg 11 because some of the units have been redefined. Our discussions will deal primarily with the units of the deep basin.

DESCRIPTION OF UNITS AND THEIR ENVIRONMENT

Unit 1 (Unsampled Facies)

Seismic records suggest the presence of a facies below our unit 2. We presume it to be of Jurassic age and of calcareous lithology, but its description must await further drilling.

Unit 2

Unit 2 is Kimmeridgian and Oxfordian (Late Jurassic) variegated red and green shaly limestones. It persists widely in the western North Atlantic Basin and has been sampled at Sites 105, 99, 100, and 391.

Lithologically, the unit consists of brick red, brownish green, and green calcareous claystone (33% carbonate) and clayey limestone (65% carbonate). The red colors coincide with the more clayey beds, which are locally fissile and laminated. They resemble the "ammonitico rosso" of the Mediterranean region. The red color is caused by hematite inclusions in minerals that are probably volcanogenic. They may have been derived from the then nearby mid-ocean ridge; but they are detrital, not precipitated from brines like the Red Sea deposits (Murdmaa, this volume).

Nannofossils are well preserved (Site 391), but foraminifers are rare and poorly preserved, except at Site 105 (Luterbacher, 1972). Ammonites, genus *Phylloceras,* were found in the red claystones at Site 391. Our interpretation of the depositional history of unit 2 is as follows. During Kimmeridgian-Oxfordian time the western North Atlantic Basin received mainly pelagic nannofossil ooze and clayey sediments deposited at bathyal depths but above the carbonate compensation depth. Slumping and turbidity currents were probably associated with small-scale intrabasinal relief — perhaps along tensional faults associated with the early stages of Atlantic opening.

The basin was narrow and therefore the limestones were close to the metalliferous source. The narrow basin also confined the distribution of turbidity current deposits from the American continent. Some of the presumed "pelagic" turbidites at Site 105 (Lancelot et al., 1972) may be basin sediments redeposited by flows from shallow carbonate

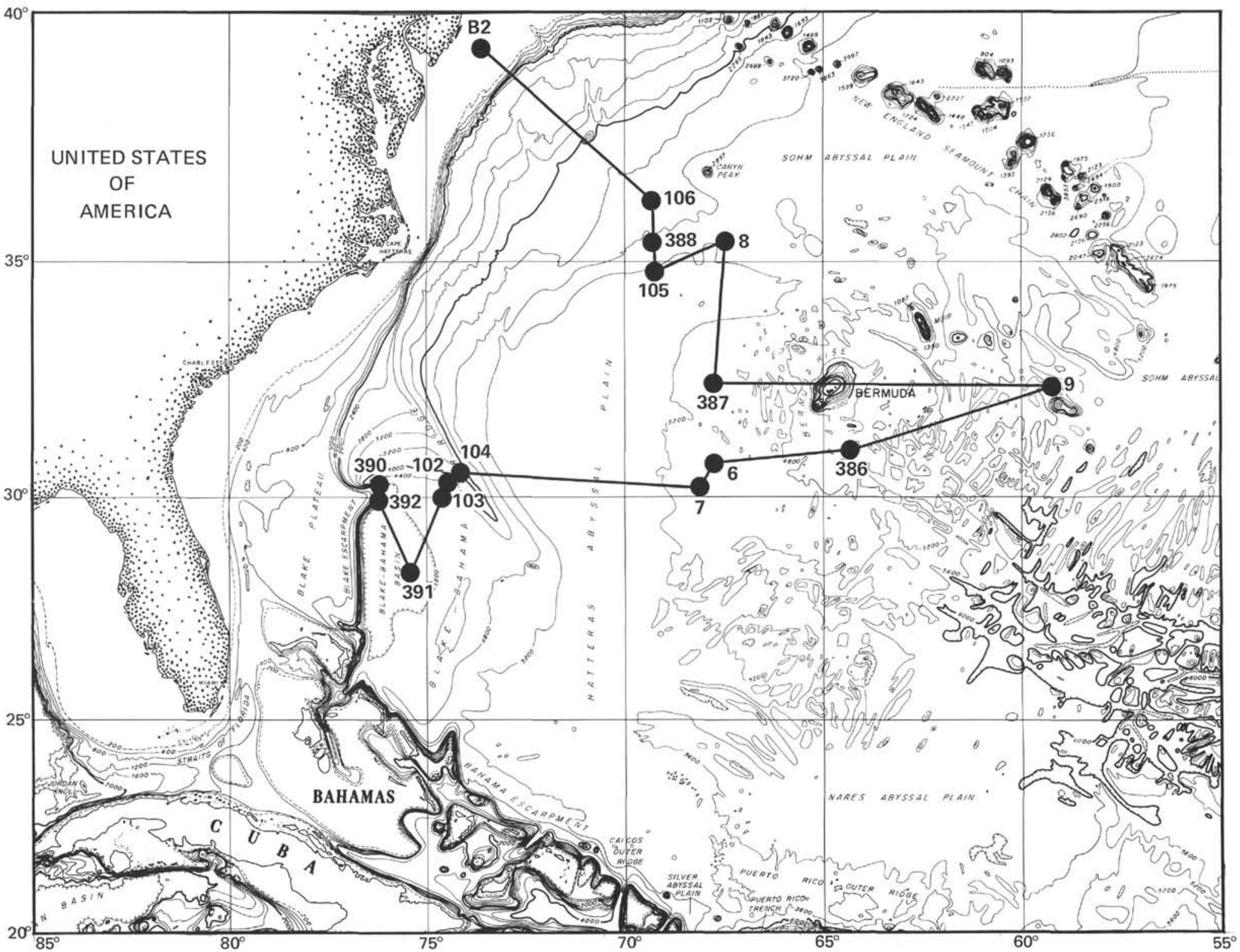


Figure 1. *Index map locating the drill holes used to construct the stratigraphic cross-section of the Western North Atlantic Basin. DSDP data is from Legs 1, 2, 11, 43, and 44, and the COST well B2 is shown.*

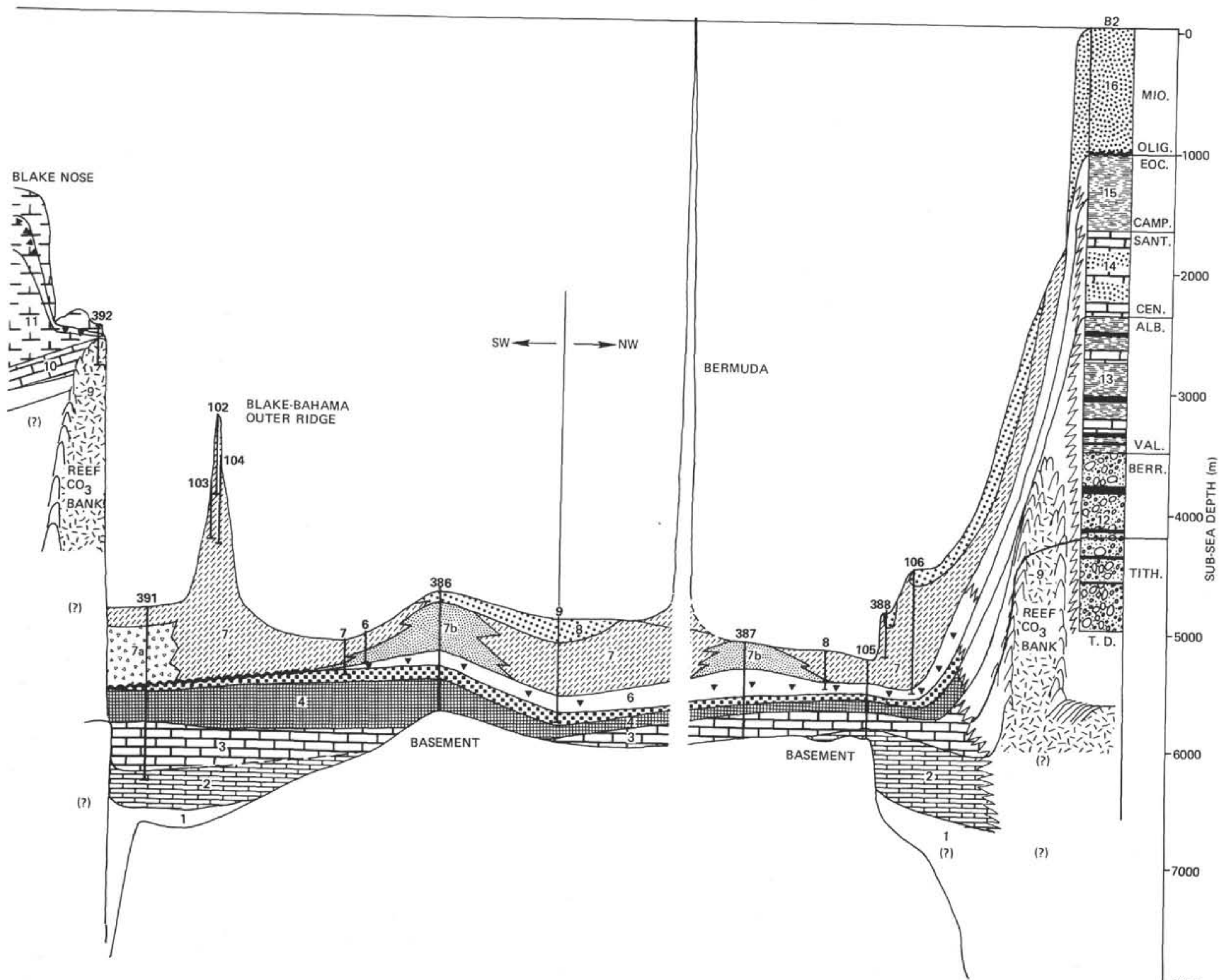


Figure 2. *Stratigraphic cross-section of the Western North Atlantic Basin based on DSDP and COST drilling data. See Table 1 for unit ages and lithologies.*

bank complexes which rimmed the margins of the nearly enclosed North Atlantic Basin. Schlee et al. (1976) report probable Upper Jurassic reef-bank masses along the edge of the New Jersey shelf (Figure 2) on the basis of seismic characteristics, and drilling off Nova Scotia along the edge of the present shelf has verified the existence of Upper Jurassic and lowermost Cretaceous carbonate banks (Jansa and Wade, 1975).

The question of why the North American continent did not shed more terrigenous detritus into the narrow, enclosed Kimmeridgian-Oxfordian basin and thus dilute the pelagic carbonate deposits remains unanswered. Indeed, this same question applies to Early Cretaceous sedimentation as well. Several hypotheses have been proposed. Schlee et al. (1976, p. 949) postulated that reefs on elevated blocks along the outer continental shelf acted as a partial barrier. More direct damming by structural relief has also been suggested (U.S. Geol. Survey, 1975, p. 32). This hypothesis requires a great volume of sediment to accumulate on the shelf during the Late Triassic Palisades disturbance. Uplift of a "shelf-edge ridge" along faults produced by the initial Atlantic rifting kept pace with deposition on the shelf. The barrier was effective until perhaps the Late Cretaceous. But this marginal basement ridge is purely speculative.

By Late Jurassic time, the Appalachians had probably long since been reduced to very low relief. The extensive fall zone surface ("peneplain") was developed soon after the relatively minor Triassic Palisades disturbance and before or during onset of Cretaceous coastal plain deposition. Downdip projection extends the fall zone surface beneath the Jurassic sediments. Upwarping and dissection of the fall zone surface to produce the present Appalachian relief began during the Cretaceous and has continued intermittently since. Westward drainage has apparently carried much of the eroded detritus to the Gulf of Mexico. Lack of relief in the North American hinterland perhaps explains the low influx of terrigenous sediments into the Atlantic Basin, particularly in the Late Jurassic.

Climate of the Atlantic region during Kimmeridgian-Oxfordian time is another possible factor responsible for low influx of terrigenous sediments. In an arid environment, runoff from Appalachian sources might have been low and influx of clastic sediments into the deep western North Atlantic Basin would have been small.

Whatever the cause, stratigraphic studies show that during Kimmeridgian-Oxfordian time carbonate deposits accumulated in the western North Atlantic within a basin shallower than the carbonate compensation depth. The pelagic limestones accumulating in this basin contained enough detrital iron to color most of the sediment reddish brown. A similar facies was drilled during Leg 41 at Site 367 (Lancelot, Seibold, et al., 1975) and, as has been noted, the comparable "ammonitico rosso" facies is well known (Bernoulli, 1972) in the Mediterranean region.

Unit 3

Unit 3 consists of Tithonian-Barremian white and gray interlayered pelagic limestone (Figure 2, Table 1). It has been sampled at DSDP Sites 99, 100, 101, 105, 387, and 391. Like unit 2, it wedges out eastward against basaltic basement and is not present at Site 386. It thickens westward toward the North American margin to 330 meters at Site 391 where four sub-units are recognized (Freeman and Enos, this volume). The upper sub-unit, 135 meters thick, consists of up to one-meter-thick light gray, sandy limestone, and calcarenite beds interlayered with thin beds of dark gray cross-laminated lime mudstone. Detrital quartz grains and schist fragments are common in the sandy limestone. Partial Bouma sequences evidence turbidity current transport. The second (from the top) sub-unit is 95 meters of thinly laminated, light gray to olive, or dark gray shaly calcisiltite, interbedded with bluish gray bioturbated calcilutite, black to dark gray calcareous claystone, and massive olive-gray calcilutite. The third sub-unit (40 m thick) is dominantly light bluish gray, bioturbated calcilutite with well-defined dark calcareous claystone layers and partings. The bottom sub-unit is about 70 meters thick and consists of white and greenish gray clayey limestone with minor partings of gray shale. Bioturbations are common.

Well-preserved nannofossils and calcitized radiolarians, are common in these Tithonian-Barremian sediments; ammonite aptychi occur in isolated layers. Foraminifers are rare and poorly preserved (etched in part). This suggests that unit 3 might have been deposited just above the CCD for the more resistant nannoplankton, and below the CCD for foraminifers and aragonitic ammonites. We infer therefore that these sediments were deposited in a deep bathyal environment.

The abundant burrows indicate that the bottom waters were generally well oxygenated and perhaps subjected to short periods of stagnation which produced the darker laminated layers. Cross-laminations in some beds of calcilutites suggest moderate currents. Slump structures (at Site 105) probably reflect intrabasinal relief, but the sandy turbidites at Site 391 contain quartz, schist fragments, and a few displaced oolites which clearly indicate that they are not "distal" turbidites (as defined by sedimentologists); they comprise complete Bouma sequences with sediments from the adjacent continental margin.

At Site 391 the terrigenous clastic contribution remained relatively small during Tithonian-Barremian time. This very small influx of clastic sediments is perhaps more enigmatic in view of the recent COST B2 well results from the New Jersey shelf (Figure 2, Table 1) (Smith et al., 1976). At the COST site, the Tithonian-Barremian was marked by rapid accumulations of thick variegated sandstone, shale, and coal (units 12 and 13) which were deposited in marginal or non-marine environments associated with a delta-like extension off New Jersey. The Appalachians apparently were providing considerable amounts of sediment during the Tithonian-Barremian and these clastics reached the middle-outer part of the present continental shelf. Perhaps the clastics were deposited in deltas or estuaries on the shelf and near the continental slope and the finer clastics were not redistributed by contour currents in the deep basin as they are today. In the eastern North Atlantic near the continental margin the distal portions of large clastic wedges of Early Cretaceous deltas were drilled at Site 370 (Lancelot, Seibold, et al., 1975).

Sites 390 and 392 show that a carbonate bank complex occupied the rim of the Blake escarpment at least as far north as the Blake Nose during the Early Cretaceous (lithofacies unit 9, Figure 2, Table 1). Unit 10, a mudbank limestone facies, appears to be contemporaneous with unit

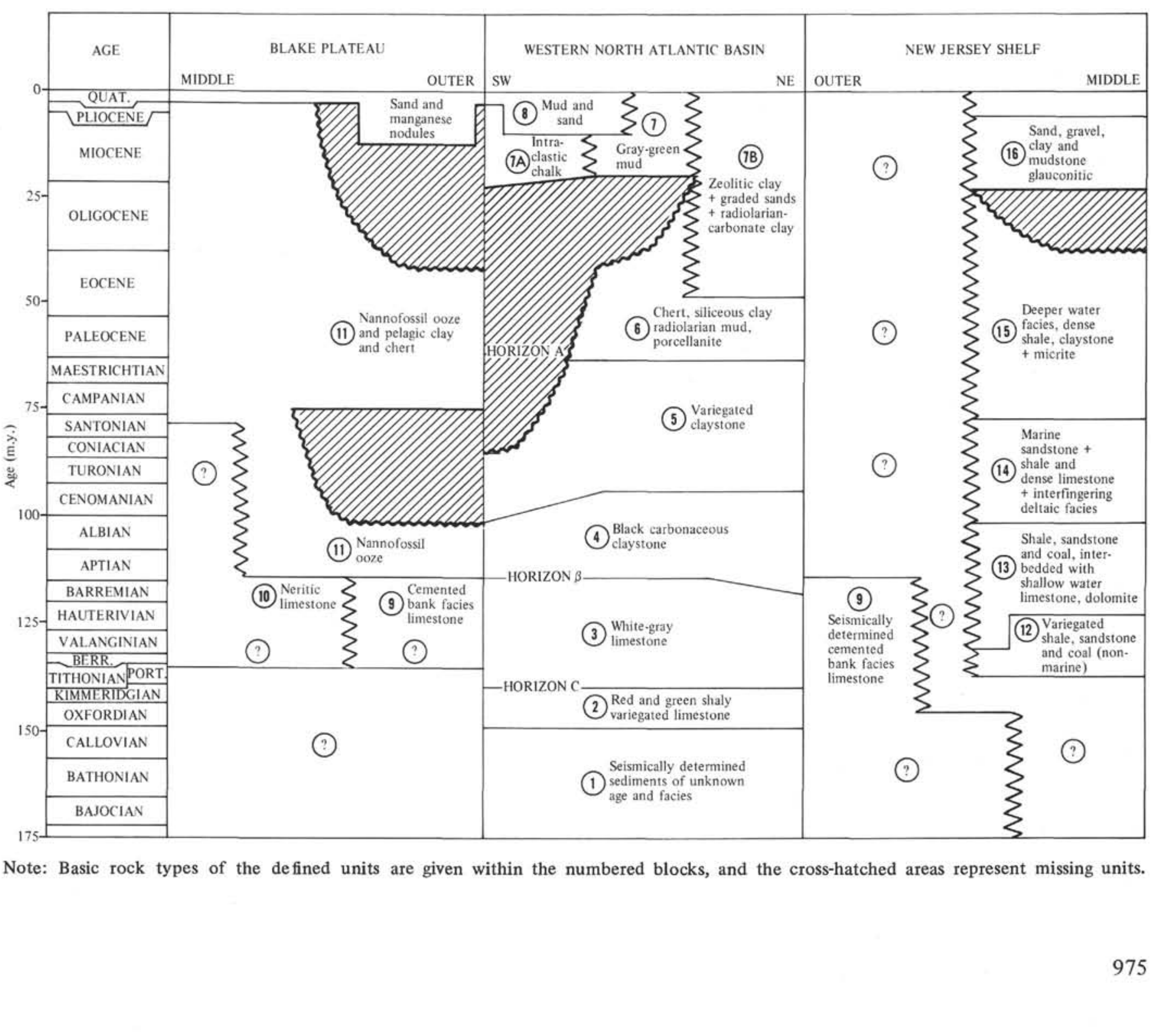
9. The limestone is apparently widespread as a seismically mappable unit under the western part of the Blake Plateau. The skelmoldic, oolite, and fenestral limestone sub-units of unit 9 were all deposited within a few meters of sea level. These rocks have undergone fresh-water diagenesis (cementation and solution) during at least one regression which produced a massive, crystalline, in some cases cavernous, rim limestone (Enos and Freeman, this volume). Because of analogous acoustic characteristics, Schlee et al. (1976) infer a "reefal ridge" or carbonate bank on the outer continental shelf off New Jersey (Table 1, Figure 2). The age of this reef is also Early Cretaceous on the basis of seismic correlation from the B2 COST well. Thus reef-bank damming may have prevented terrigenous sediments from reaching the deep basins in Tithonian-Barremian time.

Unit 4

Unit 4 of Barremian/Aptian-Cenomanian consists of black to dark green carbonaceous clay and shale. This facies has been sampled at DSDP Sites 101, 105, 386, 387, and 391. The unit is thickest in the west and wedges out eastward against younger basaltic basement on the eastern part of the Bermuda Rise. The sediments are mostly silty clay, with an average of about 65 per cent clay. The clay is mostly mica (40%) and montmorillonite (10% to 25%), with chlorite and kaolinite comprising less than 2 per cent. Minor amounts of carbonates, quartz, feldspar, and pyrite occur in this lithofacies. The $CaCO_3$ content is generally less than 2 per cent, although some samples contain up to 25 per cent. Organic material is quite variable; it ranges from 0.1 to 4.8 per cent, with one extreme value of 14.8 per cent from Site 105. Geochemical analyses indicate that the bulk of the organic material was derived from detrital terrigenous plant debris washed into the basin from the adjacent continents (Dow, this volume). In general, this dark shale facies grades downward into the Tithonian-Barremian white and gray limestone (unit 3). The whole unit is comparatively poor in fossils.

The depositional environment that produced this thick interval of black carbonaceous shale must have been one of widespread reducing conditions. Euxinic stagnation extended across most of the western North Atlantic Basin, and this same, or a similar carbonaceous facies was deposited in the eastern North Atlantic at about the same time (Lancelot, Seibold, et al., 1975). Similar sediments are found in other ocean basins and some marginal seas (Schlanger and Jen-

TABLE 1
Stratigraphic Relationships of Western North Atlantic



Note: Basic rock types of the defined units are given within the numbered blocks, and the cross-hatched areas represent missing units.

kyns, 1976). Various authors (Schlanger and Jenkyns, 1976; Fischer and Arthur, 1977) have speculated that a uniform global climate led to reduced circulation of cold, oxygenated, bottom waters and increased production of organic carbon. The reduced circulation superimposed on widespread Cretaceous transgressions would have produced an expanded oxygen-minimum layer that resulted in deposition of carbon-rich sediments at intermediate depths. This global effect may have been accentuated in the Atlantic because spreading had not yet opened connections to the Arctic Basin and through the South Atlantic to the other ocean basins.

The scarcity of calcareous foraminifer fossils at Site 391 and the etching of the nannofossils suggest that deposition was at or below the CCD. A sparse fauna of Cretaceous foraminifers was recovered near the top of this unit at Site 391 and radiolarian debris was reported from Leg 11 (Site 105). Thus, during the middle part of the Cretaceous carbonaceous clay was apparently deposited below the carbonate compensation depth in a stagnant basin in which the terrigenous components (mineral and organic) were not diluted by carbonates.

During the Aptian-Cenomanian, the western North Atlantic Basin was part of a nearly enclosed seaway. The North Atlantic continental land masses were intact and the incipient South Atlantic was just emerging as a narrow seaway. The mid-oceanic ridge further restricted bottom circulation. Clastic debris from the North American continent, shed off the rising and eroding Appalachian Mountains, formed deltaic swamps on the New Jersey shelf (unit 13 and part of 14, B2 COST well, Table 1). Apparently, the climate over the North American continent allowed abundant plant growth. The coals in Aptian-Cenomanian beds on the New Jersey shelf (unit 13, Figure 2, Table 1) also attest to high plant productivity.

Detritus from this plant material eventually washed into the deep basin to form the carbonaceous black shale of unit 4. The uppermost coal deposit at the B2 COST well occurs in Albian sediment (unit 13) which suggests the waning and disappearance of the warm, humid environment during the Albian. On the New Jersey shelf the next younger Cenomanian to Santonian (unit 14, Figure 2, Table 1) consists of marine sandstone and shale and shallow-water limestone which interfingers with deltaic sand. This reflects a large-scale marine transgression and a decrease in the influx of terrigenous sediments off the eroding Appalachians. The deposition of the carbonaceous black shale (unit 4) ended in the deep basin at about the same time which suggests that changes in source area, as well as in worldwide circulation and climatic patterns, influenced their accumulation.

Although some workers have suggested that unit 4 might be an important potential source bed for petroleum, Site 391 samples proved too immature to have produced significant hydrocarbons (Dow, this volume) and that yields from geochemical processing are low. Increased depths of burial under the continental rise, however, should produce higher pressure and temperature conditions which are more conducive to petroleum generation. And a higher yield facies might be found closer to the North American continent beneath the, as yet unsampled, rise.

The sedimentary deposits on the Blake Plateau during Aptian-Albian time consisted of nannofossil ooze (unit 11) (Figure 2, Table 1). The Campanian/Albian unconformity represents a long depositional hiatus and is overlain by more nannofossil ooze. The presence of Aptian/Albian nannofossil ooze implies a rather normal oceanic environment on the Blake Plateau while the deeper basin was euxinic and stagnant. If so, there was a strong vertical gradient in the western North Atlantic. Normal circulation and oxygenation extended to intermediate depths of no more than 2000 meters; water at greater depths was stagnant.

Some time after the Albian but before the Campanian, strong submarine currents scoured the Blake Nose. They created an angular unconformity amid a generally condensed nannofossil ooze section. This observation is inconsistent with models which show the worldwide oxygen-minimum zone invading the continental shelves during the Aptian-Cenomanian (Schlanger and Jenkyns, 1976; Fischer and Arthur, 1977). The strong deep current on the Blake Nose, however, could not be attributed to shallow surface currents such as the Gulf Stream. Alternatively, it may have resulted from changes in North Atlantic circulation attending the deep opening of the Labrador Sea rifts in the north. Colder northern waters would have entered the Atlantic through these new rifts, to form deep contour-following currents.

Unit 5

Unit 5 is of Upper Cretaceous (Turonian?-Maestrichtian) age and consists of thin, variegated claystone (Figure 2, Table 1). The claystone consists of yellow, brown, orange, purple, green, and red montmorillonite, mica, and kaolinite. At Site 105 this facies is enriched in heavy metals (Mn, Zn, Pb, Cr, Ni, and V) and yields sphalerite, pyrite, siderite, goethite, hematite, iron, montmorillonite, clinoptilolite, and phillipsite.

Unit 5 generally lacks fossils, but a few calcareous nannofossils were found which indicate its Turonian-Maestrichtian age. This relatively thin unit (40 to 100 m thick) is extremely condensed because of either very low sedimentation rates (0.35-0.14 cm/thousand years if the entire post-Cenomanian Cretaceous is represented) or unrecognized hiatuses.

This variegated claystone has been sampled at DSDP Sites 7, 9, 105, 386, 387, and 391. The discovery of this facies at Site 391 revealed that its lateral extent is far greater than previously recognized (mainly near the Bermuda Rise).

This unit contrasts markedly with the carbonaceous claystone facies of unit 4, and includes a great change in the depositional environment. Reducing conditions were succeeded by generally oxidizing conditions. The paucity of calcareous fossils implies that unit 5 was deposited below the carbonate compensation depth, but this does not explain the general paucity of radiolarians and other siliceous fossils. Pyritized radiolarians are common in Hole 391, Core 70. Because some of the variegated clays are metalliferous, some workers have suggested that these deposits were akin to those of the Red Sea brines. An alternative source of metal-rich volcanic brines in the western North Atlantic was the Kelvin Seamount, a region volcanically active during this time (Tucholke, Vogt, et al., 1975). However, Site 391 was near neither the spreading center nor the Kelvin Seamount. Also, inorganic geochemistry studies show that the iron in these sediments is mainly detrital, rather than brine precipitates (Murdmaa et al., this volume). Although an increase in detrital iron could reflect increased activity from other volcanic sources, the causes of metal enrichment must be found elsewhere.

The very slow deposition rate of these sediments suggests that submarine diagenesis and oxidation may have removed much of the calcareous and siliceous fossil material. Also, strong ocean-bottom currents may have periodically swept the deep basin clean of sediments.

As noted above, the Campanian/Albian unconformity on the Blake Nose and the very fossiliferous Campanian/Maestrichtian nannofossil ooze (unit 11) of the Blake Plateau (Figure 2, Table 1) show that strong ocean bottom circulation and normal oxygenated conditions existed at least along the Atlantic Margin. If an opening of the Atlantic on the north to deep colder waters produced the Blake Nose currents, then strong currents probably swept the deep basin at this time.

The marine limestone of unit 14 on the New Jersey Shelf shows that a Cenomanian through Santonian transgression, followed by Campanian-Maestrichtian deepening of the shelf, occurred as a result of continued subsidence and sediment starvation. This deepening produced the dense, deep-water shale deposits of the lower part of unit 15 (Figure 2, Table 1). Thus we infer from the B2 COST well data that the influx of terrigenous clastic detritus into the western North Atlantic shelf was insufficient to keep pace with subsidence. The low sediment supply from the Appalachians during the Turonian-Maestrichtian resulted in the very low sedimentation rate in the deep basin as well.

Thus, the stratigraphy of the Atlantic Margin, the New Jersey terrigenous clastic shelf, and the carbonate Blake Plateau reveals that during the Late Cretaceous the major environmental change in the western North Atlantic was a decreasing supply of terrigenous minerals and organic detritus, and an increase in oxygenation and bottom circulation.

Unit 6

Unit 6 of Paleocene-Eocene age is a suite of siliceous sediments and chert (Figure 2, Table 1). Unit 6 is found at DSDP Sites 7, 8, 9, 10, 376, and 387 where it has been extensively cored. Although not sampled there, this unit probably extends to Sites 105 and 106 where slow drilling rates and correlation to seismic reflector horizon *A* suggests the presence of Eocene chert.

On the basis of drilling and seismic data, unit 6 is missing (eroded) to the southwest, and a significant hiatus exists between the Miocene and Cretaceous sediments. Hydrocarbon maturation profiles indicate that black shales of unit 4 were buried beneath as much as 800 meters of sediment, which was eroded before overlying Miocene sediments were deposited (Dow, this volume). Thus, cherty, siliceous Paleocene-Eocene sediments may have covered the entire western North Atlantic Basin and been subsequently eroded in the southwest by strong submarine currents.

Chert, although a characteristic of unit 6, comprises a rather small percentage of the total sediment. Other lithologies are siliceous claystone, radiolarian mud, radiolarian ooze, porcellanite, and some zeolitic clay, silty mudstone, and nannofossil claystone. The common element is high silica content. The characteristic color is grayish green, but various shades of yellow-brown and olive also occur. Although radiolarians and diatoms are the most abundant fossils, calcareous nannofossils and pelagic foraminifers are also present.

Oligocene sediments are missing over most of the western North Atlantic Basin; and we cannot be certain that deposition of siliceous sediments continued into the Oligocene. On the Bermuda Rise, however, a continuous sequence of Eocene through Oligocene radiolarian-rich carbonate clay, zeolitic clay, and graded sands (Figure 2, Table 1) suggests that Eocene environments persisted through the Oligocene.

Biogenic silica predominates over biogenic carbonate in the lower Tertiary sediments of the deep western North Atlantic Basin. This may reflect increased oceanic circulation, upwelling, and perhaps colder temperatures during that time (Fischer and Arthur, 1977). (Colder temperatures would have raised the carbonate compensation depth.) But, although less abundant than siliceous sediments, the carbonate sediments are not totally lacking. Hence variation in CCD cannot be the only factor governing the lithologic change.

Note that even on the Blake Plateau, which was above the CCD, radiolarian ooze and chert accumulated over a widespread area during the early Tertiary (Figure 2, Table 1). Within the nannofossil ooze of unit 11, interbeds of hard chert were recovered near the Eocene/Paleocene boundary. Interbeds of radiolarian ooze occur in the Blake Plateau calcareous ooze, and dissolution of the radiolarians apparently contributed to formation of the cherts, as it did in the deep western North Atlantic. Thus, the chert and siliceous sediments of the Paleocene-Eocene are truly widespread both laterally and vertically, and reflect a unique depositional environment over the entire western Atlantic Ocean. Biogenic production of silica was probably a more important factor in the depositional environment than variation of the CCD.

The lack of terrigenous clastic sediments from the adjacent North American continent is also a characteristic of the Paleocene-Eocene sedimentary environment. In the B2 COST well on the New Jersey shelf (Figure 2, Table 1), the Paleocene through Oligocene sediments are dense deep-water (bathyal) shale, claystone, and micrite of unit 15. Radiolarians are abundant in the Eocene claystone. Apparently so little clastic sediment reached the shelf that subsidence exceeded sediment accumulation and the water deepened to bathyal depths. The reduced clastic contribution into the Atlantic Basin during Paleocene-Oligocene time prevented dilution of biogenic oozes and cherts.

Unit 7

Unit 7, of Miocene-Pliocene age, is largely gray-green hemipelagic mud (Figure 2, Table 1). It was encountered at DSDP Sites 6, 7, 8, 9, 101, 102, 103, 104, 105, 106, 388, and 391. The hemipelagic mud forms the North American continental rise, which Ewing and Hollister (1972) postulate was constructed by the mud-wave and current-drift deposition.

Texturally this unit is silty clay and clay (average 70% clay) with a few thin laminae of silt or silty sand. Quartz comprises 20 to 35 per cent of the bulk samples; mica is dominant in the fine fraction and ranges from 30 to 40 per cent. As percentage of mica decreases in older samples, kaolinite increases from 5 per cent to 20 per cent. The carbonate content is generally less than 10 per cent, although the samples of this unit from the Blake Outer Ridge (Site 102, 103, 104) were relatively rich in carbonate (20%). Organic carbon contents of the gray-green mud average 0.25 per cent to 0.5 per cent, but some values of more than 1.0 per cent are found (Dow, this volume).

Calcareous nannofossils are abundant throughout; foraminifers are common only in samples from the continental rise above the CCD. The few foraminifers found in the abyssal plain show effects of dissolution. Siliceous fossils, both radiolarians and diatoms, are common on the Blake Outer Ridge, but rare elsewhere.

Horizontal lamination occurs locally as distinct pavements of foraminifers and zones of burrowing. Gas expansion structures and expansion-induced porosity are also common. Interparticle porosities range between 45 and 80 per cent. At greater depths the gray-green mud is more indurated.

Generally unit 7 was derived from terrigenous sources and deposited rapidly along the continental rise by contour currents. Only rapid deposition (2-3 cm/1000 yr at Sites 388, 102, 103, and 104, and 20 cm/1000 yr in mid-Miocene; Ewing and Hollister, 1972) would preserve the foraminifers and nannofossils below the CCD. Ewing and Hollister (1972) described deposition of the mud by contour currents in detail on the basis of DSDP drilling on the Blake Outer Ridge. The mineral content indicates that bottom currents transported the mud great distances along the continental rise from a source on the North American continent.

Sub-Unit 7a

A unique intraclastic chalk forms a distinctive Miocene sub-facies in the Blake-Bahama Basin (sub-unit 7a) (Figure 2, Table 1). The chalk is massive and occurs in thick intervals interbedded with gray-green hemipelagic mud that appears to have been deposited throughout the Miocene. Seismic records (Sheridan et al., this volume) show that the intraclastic chalk is confined to the Blake-Bahama Basin where gravity flows ponded it behind the Blake Outer Ridge (Ewing and Hollister, 1972).

The matrix of the chalk is transported nannofossil debris; the intraclasts are mainly dark greenish gray or blue-gray radiolarian-rich mudstones. White limestone lithoclasts containing shallow-water foraminifers occur in a few layers. The radiolarian-rich mudstone intraclasts are identical in lithology and age to the hemipelagic mud interbedded with the intraclastic chalk. The mud apparently was the indigenous sediment of the Miocene Blake-Bahama Abyssal Plain which was disrupted and incorporated into the intraclastic chalk. Other lithologies interbedded with the chalk are white structureless, carbonate silt (97% $CaCO_3$), and thin graded beds of claystone intraclasts with erosional basal contacts and partial Bouma sequences.

This Miocene chalk sub-facies was formed by debris flows and turbidity currents from the shallower Blake Plateau. As this sediment flowed down the canyons and channels of the Blake escarpment (such as Great Abaco Canyon) and the Bahamas, the consolidated shallow-water Eocene to Cretaceous limestones cropping out along the canyons were swept up and incorporated into the debris and eventually deposited as a chaotic slurry in the deep basin. This viscous slurry eventually consolidated into the intraclastic chalk.

Sub-Unit 7b

Farther east, on the Bermuda Rise at Sites 386 and 387, a pelagic zeolitic clay predominates (sub-unit 7b). It is interlayered with siliceous mud and graded beds of quartz, silt, carbonate sand, biogenic silica sand, and heavy minerals. The volcanic Bermuda pedestal was evidently the main source area for sediments at these sites. The sites were isolated from terrigenous clastic sediments of the continental rise by great distance and high elevation.

The marked change in sedimentary environment of the deep western North Atlantic Basin between deposition of the Paleocene-Eocene siliceous biogenic oozes and the terrigenous clastic hemipelagic mud and intraclastic chalk reflect fundamental geologic changes. The appearance of the hemipelagic mud following a long period of erosion and/or nondeposition during the Oligocene suggests the onset of contour currents as an active depositional agent in the western Atlantic. The construction of the Blake Outer Ridge is a good example of their supposed action (Ewing and Hollister, 1972).

A new supply of terrigenous sediment may have been an even more important factor than currents. As mentioned above, the Paleocene-Oligocene was a time of low sediment supply to the western Atlantic continental shelves. Following nondeposition or erosion on the New Jersey shelf during the Oligocene, coarse sands and gravels interbedded with mudstones were deposited in a shoaling environment during the Miocene (unit 16; Figure 2, Table 1). As the shelf shoaled and prograded the western North Atlantic received finer grained components of the terrigenous debris deposited to form unit 7. The Appalachians may have been uplifted again in the Miocene.

The intraclastic chalk of the Blake-Bahama Basin was apparently derived by submarine processes from the Blake Plateau. Seismic activity along impinging fracture zones, possibly related to tectonism in Cuba, could have caused recurring liquefaction of the soft nannofossil oozes on the plateau.

Unit 8

Unit 8, of Pleistocene-Holocene age, consists of quartz, sand, and silt, interbedded with hemipelagic mud or nannofossil ooze (Figure 2, Table 1). At Site 106 these sand beds are turbiditic and commonly graded; they form a large part of the continental rise prism. The sand fraction comprises up to 70 per cent of the sediment. Quartz, feldspar, mica, and chlorite are the major terrigenous components; montmorillonite predominates in the clay fraction. The carbonate content ranges from 2 per cent to 39 per cent, averaging 15 per cent, and foraminifers and calcareous nannofossils are widely distributed.

The Pleistocene glacial expansions and the resulting rapid drops of sea level exposed the shelves adjacent to the basin. Turbidity currents formed in response to the greater relief and carried the unconsolidated shelf sands onto the continental rise and the abyssal plains. Abundant terrigenous material was available from the glacially eroded continent. Deposition by turbidity currents has probably declined since the Pleistocene, and many areas of the western North Atlantic Basin now receive little sediment other than hemipelagic mud.

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