A Comparison of Two Atlantic-type Continental Margins

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By JOHN S. SCHLEE

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Stratigraphy and structure of the continental margin of eastern North America and West Africa—their history as restricted rift basins and later as broad troughs

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A COMPARISON OF TWO ATLANTIC-TYPE CONTINENTAL MARGINS

By JOHN S. SCHLEE

ABSTRACT

The tectonic framework and deposits of the northwest African and eastern North American continental margins are similar; they reflect the complex interplay of differential subsidence, buildup of carbonate deposits, deposition of clastic sediments, and local tectonism. Early history was marked by block faulting or downwarping to form a series of basins at the margin edge in which continental clastic sediments were deposited. Where climatic and oceanographic conditions permitted, these beds were covered by evaporite deposits and shallow-water limestone. Off Liberia, volcanic rocks and clastic sediments dominate, whereas further northwest (Guinea-Bissau, Morocco), evaporite deposits and limestones are also in the section; a similar sequence of evaporite deposits and red beds of Late Triassic to Middle Jurassic age characterized the eastern Canadian margin. Salt forms diapirs, mainly off Canada and West Africa. The evaporite deposits are interbedded with or are overlain by limestone and dolomite that formed platforms and reefs adjacent to the newly formed Atlantic Ocean. The reef complexes are discontinuous features that appear to have acted as partial sediment dams during the Jurassic and Early Cretaceous as the North Atlantic Ocean widened. For some margins, these platforms and reefs have provided the foundation to which later physiographic features of the shelf and slope broadly conform. Fine-grained clastic sediments from ancient deltas overwhelmed the carbonate deposits during the Cretaceous to prograde the Atlantic margins seaward and build a gentle slope to the deep ocean. This slope was cut and steepened during the Tertiary and Quaternary.

The intersection of oceanic fracture zones with the continent can have different structural formats, depending on whether the margin has undergone divergent or transform movement. In areas where transform motion is dominant, fracture zones intersect areas marked by faulting, intrusion, and shallowly buried Precambrian rocks; narrow fault basins can be tucked in the shelf-slope areas between the intersection of these zones with the continent. On divergent margins, areas of present margin offset seem to be related to ancient continental zones of crustal offset and faulting, and the present offsets appear to be associated with zones of volcanism in the oceanic crust. These relations lend support to the idea that marked irregularities in the outline of the crustal break (leading to transform motion of crustal blocks) can lead to the formation of zones of weakness in the newly formed oceanic crust and then to the formation of seamounts and volcanic islands.

INTRODUCTION

In this paper, I examine the structure and stratigraphy of Atlantic-type continental margins (as described by Mitchell and Reading, 1969) along eastern North America and West Africa (fig. 1) to see the similarities and dissimilarities in patterns of continental-margin response to crustal separation. Also of interest are the possible ties between oceanic and continental structures and the different effects divergent and transform motion have had on the tectonic framework of the margin.

Since 1965, many offshore studies of West Africa and eastern North America (Beck and Lehner, 1974; Behrendt, Schlee, and Robb, 1974; Behrendt, Schlee, Robb, and Silverstein, 1974; Delany, 1971; Emery and others, 1975; Given, 1977; Institute of Petroleum and Geological Society of London, 1965; Jansa and Wade, 1975a, b; Lehner and de Ruiter, 1976, 1977; Mattick and others, 1974; Schlee and others, 1974, 1976; Sheridan, 1974a, b; Uchupi and others, 1976; Van der Linden and Wade, 1975) have revealed much about the margin structure and stratigraphy. Major summaries of the regional geology ashore (Dillon and Sougy, 1974; Fisher and others, 1970; Van Houten, 1977; Zen and others, 1968) in the two areas have aided in a comparison of the margins. Broad geophysical surveys of the eastern Atlantic (Emery and others, 1975; Uchupi and others, 1976) have added much new data on oceanic crustal structure there. Stratigraphic well data have been compiled for the eastern Canadian margin (Jansa and Wade, 1975a) and have been correlated to reflectors on multichannel seismic-reflection profiles (Given, 1977); such correlation is underway for the U.S. Atlantic margin (Smith and others, 1976; Scholle, 1977). Multichannel reflection profiles (Beck and Lehner, 1974; Lehner and de Ruiter, 1977; Schlee and others, 1976; Grow

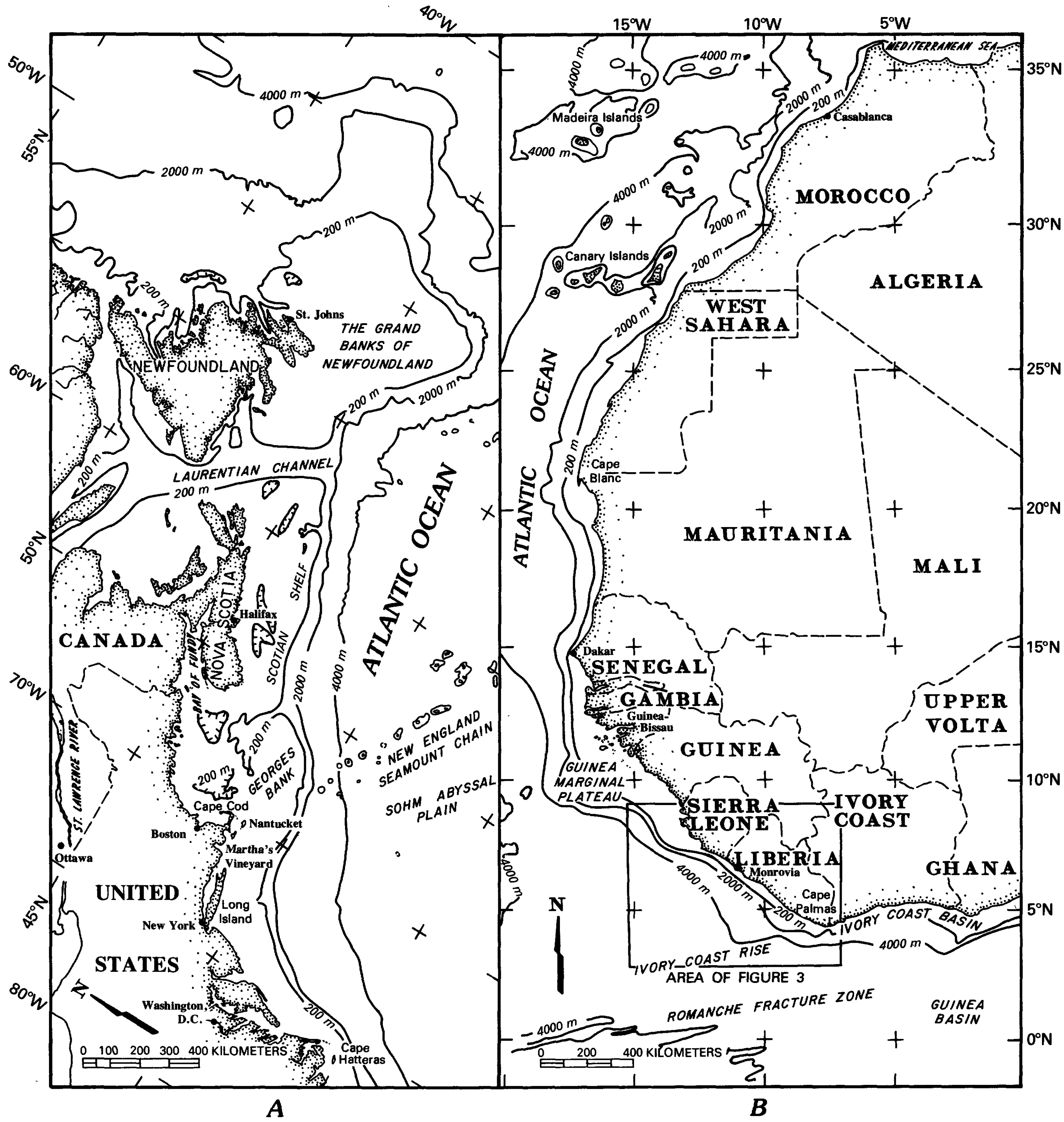

FIGURE 1.—Index maps showing geography and continental margin bathymetry. *A*, Eastern North America. *B*, West Africa. Base modified from Uchupi (1971).

and others, 1979) have allowed much to be inferred about deep structures beneath the shelves off West Africa and off the Eastern United States. In addition, refraction surveys (Grow and Sheridan, 1976; Keen and others, 1975), magnetic studies (Behrendt and Klitgord, 1976; Emery and others, 1970; Haworth, 1975; Klitgord and others, 1976; Taylor and others, 1968), and gravity data (Grow and others, 1975) have contributed to the picture of crustal-margin configuration.

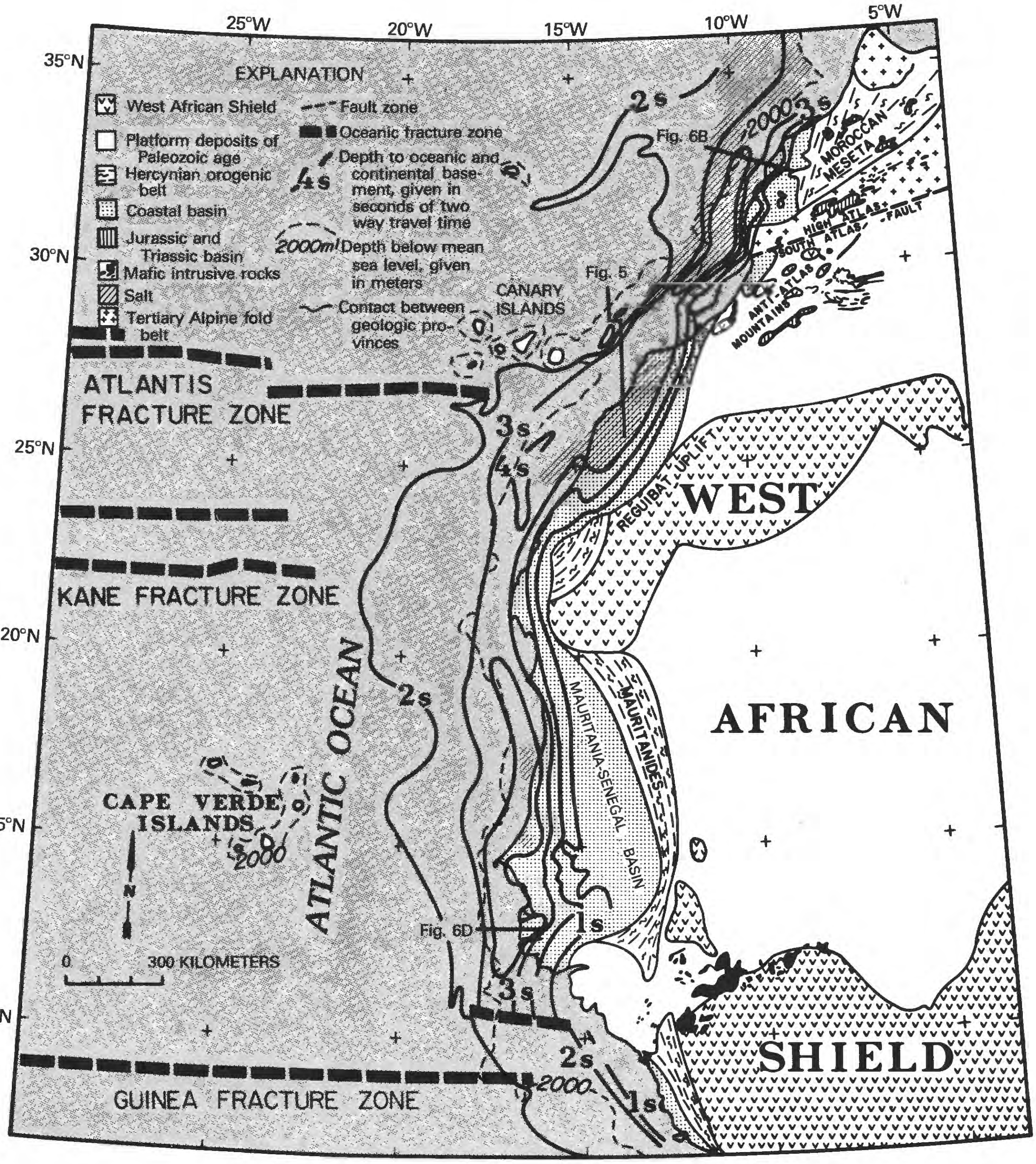

FIGURE 2.—Generalized geologic map of West Africa north of Liberia showing major structural framework. Compiled from the Association of African Geological Surveys and United Nations Educational, Scientific, and Cultural Organization (1968), and Uchupi and others (1976, figs. 3 and 35). Locations of African sections (figures 5 and 6*B* and *D*) are indicated here.

ACKNOWLEDGMENTS

Many of my colleagues have contributed to this paper through their comments and discussions with me: W. P. Dillon, K. D. Klitgord, J. A. Grow, and J. C. Behrendt of the U.S. Geological Survey; Elazar Uchupi and K. O. Emery of the Woods Hole Oceanographic Institution; and L. H. King of the Bedford Institute of Oceanography, Dartmouth, Nova Scotia. David A. Ross of the Woods Hole Oceanographic Institution and James E. Case and William P. Dillon of the U.S. Geological Survey read the paper and helped it to attain its final form.

Kevin King and Michael Roy prepared the illustrations.

WEST AFRICA

STRUCTURAL ELEMENTS OF THE REGION

The major structural elements of West Africa (figs. 2 and 3) are the West African Shield, the Mauritanides, and the coastal basins that border the Mauritanides or West African Shield. Major structural features transverse to the margin are the Alpine fold belt of Morocco (fig. 2), a zone of intrusions associated with the Canary Islands, and faults through the Guinea marginal plateau (fig. 1*B*). The West African Shield consists of Precambrian metamorphic rocks and granite, and it extends from the Ghana-Ivory Coast-Liberia area north to the Anti-Atlas Mountains of Morocco (Dillon and Sougy, 1974) and westward to near the coast in a few places, although it is covered in some areas by platform deposits of Paleozoic age (fig. 2). The main outline of the West African Shield had achieved its present size and shape by 1,000 m.y. (million years) ago. Subsequent epeirogenic movements have warped it to create the Reguibat uplift of northwest Africa, and the Anti-Atlas Mountains of Morocco and Algeria. Adjacent to these uplifts, the shield is covered by varying thicknesses of marine platform deposits of late Precambrian and Paleozoic age in several broad basins (Dillon and Sougy, 1974; Association of African Geological Surveys and United Nations Educational, Scientific, and Cultural Organization, 1968).

Adjacent to the shield and its associated basins

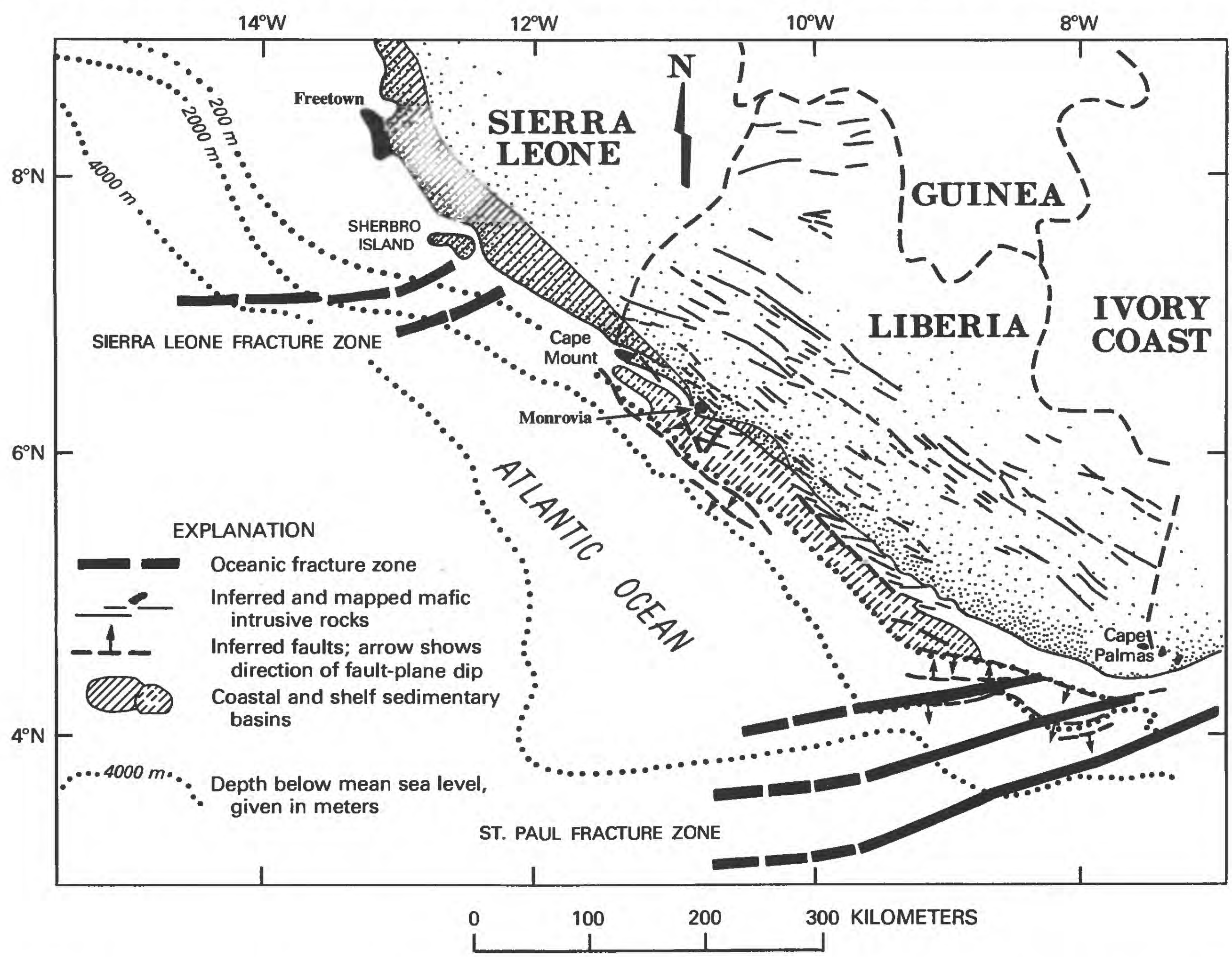

FIGURE 3.—Continental margin off Liberia and parts of Sierra Leone and Ivory Coast showing major oceanic fracture zones, inferred and mapped mafic intrusive rocks, inferred faults and the direction of fault-plane dip, coastal and shelf sedimentary basins, and the modifications of trend in bathymetry caused by the intersections of the fracture zones with the margin. Area of figure is shown in figure 1*B*.

are the Mauritanides, a belt of discontinuous folded mountains that crop out from Algeria in the north to Sierra Leone in the south. Sediments as young as Late Devonian in age were deformed during the Hercynian orogeny (Carboniferous); the presence of volcanic detritus and ophiolites caused Dillon and Sougy (1974) to speculate that the Mauritanides may have been part of a middle Paleozoic subduction zone, prior to the Hercynian orogeny. In the south, the Mauritanides split into two branches (Dillon and Sougy, 1974); the western branch goes along the southern side of the Mauritania-Senegal basin and the other goes into Sierra Leone.

North of the South Atlas fault (fig. 2), the Hercynian orogenic belt continues in the High Atlas and the Moroccan Meseta (fig. 2), where thick eugeosynclinal sediments were folded and thrust in an orogenic wave that moved east during the Devonian and Carboniferous. In contrast, miogeosynclinal sequences make up the Mauritanides south of the South Atlas fault.

West Africa and its margin are crossed by two major structural lineaments that divide the area into three subregions, both physiographically and tectonically. In the north, the South Atlas fault and the Alpine fold belt associated with it separate the fragmented crust (basins and adjoining mesetas) to the north from the series of seaward-opening coastal basins to the south (fig. 2). The same zone also marks a change in width of the shelf from an average 54 km in the south to 37 km in the north. South of the Mauritania–Senegal basin (fig. 2), the coastal area and margin are characterized by faulting, arching, and intrusion near the intersection of the Guinea fracture zone. A zone of mafic intrusive rocks (dolerites) trends northeast from the coast of Guinea (fig. 2).

The South Atlas fault (a right-lateral fault) is the latest expression of an ancient structural zone of weakness along which movement has taken place from the early Paleozoic to the present age (Rod, 1962). It juxtaposes eugeosynclinal rocks of early Paleozoic age and miogeosynclinal rocks of the same age. Indeed, the fault area may well have been a shelf edge during the early to middle Paleozoic (Dillon and Sougy, 1974). In the Tertiary, the fault zone formed the southern limit of orogenic movements that created the Atlas Range, Rif Mountains, and Tell Range of Morocco and Algeria. Rod (1962) speculated that the fault zone continued offshore toward the Canary Islands. The transverse structural zone off Guinea shows up as (1) an offset of the continental margin of about 230 km (Krause, 1964) in an east-west direction, (2) a narrowing of the Mauritania-Senegal basin against a broad east-trending basement rise thought to underlie the southern edge of the Guinea marginal plateau (Lehner and de Ruiter, 1976) near the margin extension of the Guinea fracture zone, and (3) a change in the pattern of magnetic anomalies (McMaster and others, 1971) under the shelf off of where the northeast-trending zone of mafic intrusive rocks ashore intersects the coast. South of Guinea (fig. 1*B*), in Sierra Leone, Liberia, and the Ivory Coast (fig. 3), the West African Shield extends to the coast, where it is bordered by narrow sedimentary basins (either beneath the Continental Shelf or on land).

Offshore, the West African margin (fig. 1*B*) consists of several kinds of Atlantic-type margins because the continent has been involved both in transform motion relative to South America and in crustal divergence away from North America. The transform motion took place along the southern part of West Africa (Liberia, Ivory Coast, Ghana) and resulted in the rifting of the West African Shield.

DIVISION OF THE CONTINENTAL MARGIN

TRANSFORM MARGIN

The Liberia-Ivory Coast part of West Africa (figs. 3 and 4) was the northernmost area affected by the separation of Africa and South America during the Early Cretaceous. Oceanic fracture zones approach the coast at low angles, subparallel to the trend of the southern bulge of West Africa. Their orientation to the coast suggests an oblique separation of the two crustal blocks. How has this oblique separation affected the shape of the coastal basins, and what are the ties between the equatorial oceanic fracture zones and coastal geology?

The northernmost of the equatorial fracture zones associated with the translation of Africa past South America is the St. Paul fracture zone, a complex of three zones (Behrendt, Schlee, and Robb, 1974) that intersect Liberia and the Ivory Coast near Cape Palmas. Where they intersect the coast, the margin is faulted in a series of broad crustal blocks that are tilted seaward. The blocks trend east, appear to be intruded, and underlie much of the Continental Slope as broad ramplike steps which strike parallel to the fracture zone and deepen toward the west. The Continental Shelf adjacent to Cape Palmas is probably Precambrian crystalline rocks covered by a thin veneer of sediments

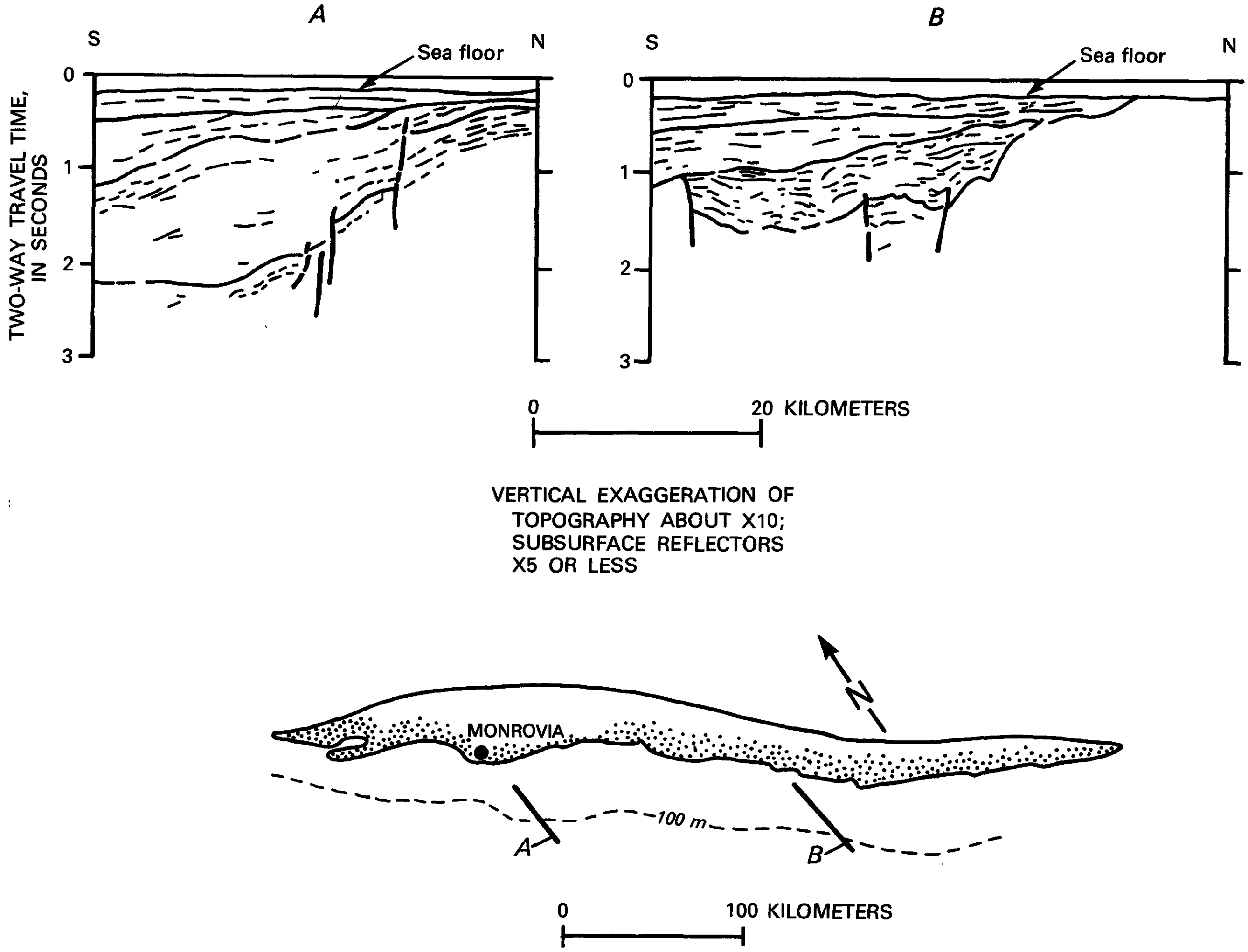

FIGURE 4.—Cross sections and location map of a shelf basin off Liberia. Note the block-faulted basement and the seaward-thickening prism of sediment. The sections are interpretations of multichannel seismic-reflection profiles. Modified from Schlee and others (1974).

generally less than 0.5 km thick. Onshore near Cape Palmas, a few mafic intrusive bodies cut isoclinally folded Eburnean paragneisses (~2,000 m.y. old) which strike east-northeast, subparallel to the trend of the intersecting fracture zones (Behrendt, Schlee, and Robb, 1974; Behrendt, Schlee, Robb, and Silverstein, 1974); in addition, coastal metamorphic rocks are faulted in the area where the St. Paul fracture zone is inferred to intersect the coast.

The other main tectonic trend in coastal Liberia is northwest as shown by the mafic intrusive rocks (fig. 3) that range in age from 176 m.y. old to 192 m.y. old. These diabase dikes and sills were intruded parallel to the magnetic grain created by the Pan African thermotectonic event (~550 m.y. ago; Hurley and others, 1971); rocks metamorphosed in that event are found in a narrow belt along the coast (White and Leo, 1969). An aeromagnetic survey of Liberia (Behrendt and Wotorson, 1970), revealed the mafic rocks to be associated with two broad northwest-trending belts of −50- to −150-gamma linear anomalies, one in the coastal area and shelf, and the second associated with dikes, 90 km inland. Tensional forces connected with crustal rifting and the regional grain of Precambrian crystalline rocks appear to have affected the trend of mafic rocks intruded during the separation of crustal blocks (May, 1971).

Shelf basins adjacent to the intersection of the St. Paul fracture zone and the margin are elongate narrow features that open in a seaward direction over a block-faulted basement beneath the slope. To the east, the Ivory Coast basin (Spengler and Delteil, 1966; Arens and others, 1971; Lehner and de Ruiter, 1977) trends east parallel with the coast (fig. 1*B*); the basin is bordered on the north by a major east-trending coastal fault (inner shelf continuation of St. Paul fracture zone) and on the south by the Romanche fracture zone (figs. 1*B* and 3). Beneath the Ivory Coast Shelf, Cretaceous and Tertiary sediments more than 5 km thick form a south-plunging monocline that thickens under the Continental Slope and thins seaward of the slope.

Northwest of Cape Palmas, another sediment-filled shelf basin also parallels the coast (fig. 3). Off central and northwest Liberia, it is built over an irregularly faulted basement (fig. 4) of presumed crystalline rocks, Paleozoic sedimentary rocks, and volcanic rocks (Schlee and others, 1974). The basin is faulted seaward, and at least as much or more sediment is under the rise and lower slope as is under the shelf. As can be seen from figure 4*A*, seismic waves passing through sediment in the coastal basin have two-way travel times of about 2 s; if the average velocity is assumed to be 2 km/s, this sediment is 1–2 km thick. The shelf basin extends northwest to the Liberia–Sierra Leone border; off southern Sierra Leone, two smaller isolated basins have been outlined by McMaster and others (1975, fig. 6). Jones and Mgbatogu (1977) inferred that Cretaceous and younger sediments are 2 km thick west of Freetown (fig. 3).

The Sierra Leone–Guinea area bridges the change from transform motion in the south to divergent motion in the north (described in the next section "Divergent Margin"). Ashore, it is intruded by a northeast-trending belt of intrusive rocks, and offshore, it is marked by east–west offsets of the Continental Slope (see the 200- and 2000-m isobaths, figs. 2 and 3) where the Sierra Leone and Guinea fracture zones intersect the margin (McMaster and others, 1973, McMaster and others, 1975). McMaster and others (1971) postulated that at least two normal faults are transverse to the margin; one of these faults intersects the shelf edge near where Krause (1964) postulated that the Guinea fracture zone projects along the slope (fig. 2). Lehner and de Ruiter (1976, 1977) inferred that at least 6 km of sedimentary rocks (Paleozoic and younger) is above an irregular Precambrian basement (acoustic velocity of 6.1–6.5 km/s) beneath the Guinea marginal plateau; the basement rises to within 3 km of sea floor beneath the slope south of the plateau. An extensive carbonate platform covered the plateau during the Mesozoic.

To summarize, in the Liberia-Ivory Coast part of West Africa, the main responses to crustal separation of a shield area where Africa and South America moved away from each other at a low angle were: (1) the formation of narrow coastal and shelf sedimentary basins adjacent to the slope areas between fracture zones; they are built over block-faulted shield rocks and thicken in a seaward direction; (2) faulting and the intrusion of mafic rocks parallel to axes of the basins; and (3) the formation of a structurally complex ridge of tilted fault blocks and intrusions where extensions of the ocean fracture zones intersect the coast. The structural response of the Liberia-Ivory Coast area to rifting appears to lend support to Kinsman's (1975) concept of what a margin subjected to transcurrent separation should be like. The margin is narrow, is occupied by narrow basins, and lacks a thick postrifting sedimentary wedge.

DIVERGENT MARGIN

North America and West Africa, north of Sierra Leone, have been diverging from each other during the past 180 m.y. In response to the separation, several coastal basins (50–400 km wide) have formed; these basins contain Cretaceous and Cenozoic sediments deposited over a block-faulted crust of Paleozoic and older rocks (Aymé, 1965; Spengler and others, 1966).

A map of two-way travel time of seismic waves to basement (fig. 2) shows that postrift sediment is in linear basins beneath the West African Shelf and Slope and that two-way travel time through this sediment increases seaward to more than 4 s. Data used to draw basement contours were compiled by Uchupi and others (1976) from published literature for land isopachs and from their marine survey for offshore isopachs. Land data can be converted to thickness in kilometers by multiplying time figures by 3 km/s. This computation indicates that thickening exists underneath the seaward parts of the basins. Sediment thickness follows, in a general way, basin outcrop pattern; the thickness is less where the shield areas approach the coast or intersect it (as off Guinea-Bissau). The trend and values of the contours change significantly at zones of crustal weakness (extension of the South Atlas fault) or where oceanic fracture zones approach the coast. The most pronounced change is in the vicinity of the Canary Islands, a zone of weakness along which Tertiary volcanic rocks were extruded (fig. 5). Adjacent to this zone and north of it, coastal basins are more restricted, the continental margin (particularly the shelf) is narrowed, and the onshore geology is characterized by block-faulted

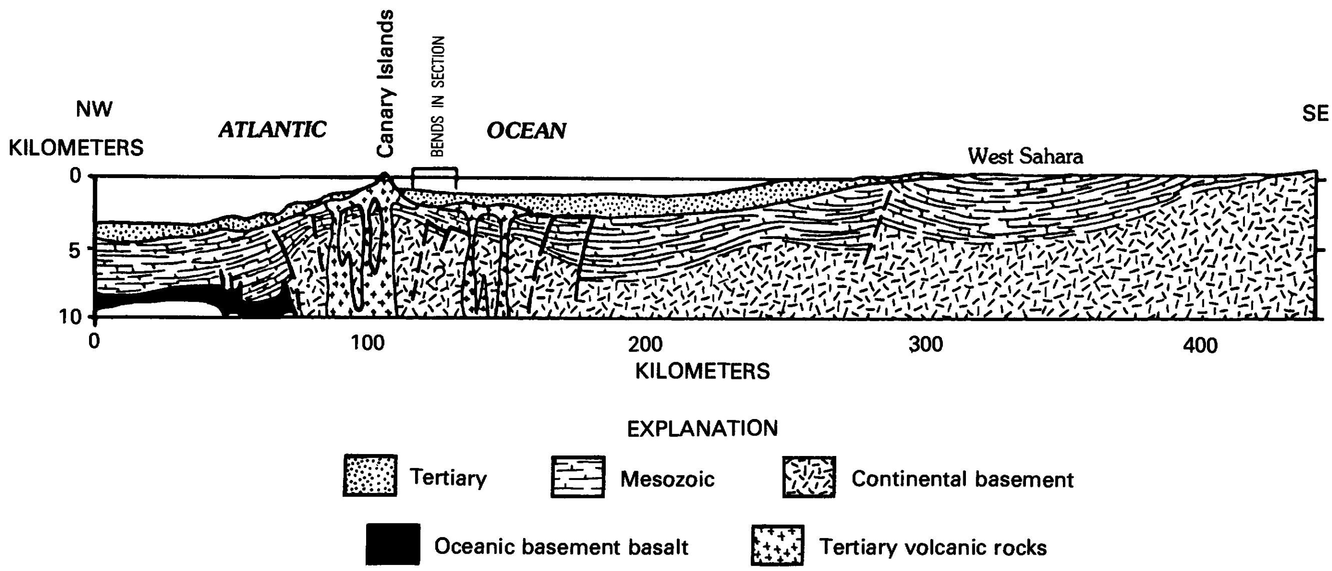

FIGURE 5.—Cross section across the continental margin from West Sahara northwest to the eastern Canary Islands. Taken from Beck and Lehner (1974). Location of profile is shown on figure 2.

basins (of Late Triassic and Early Jurassic age) and basement blocks (Van Houten, 1977). Along the offshore extension of the South Atlas fault, intruded faulted continental basement rises in a manner similar to the continental basement south of the Guinea marginal plateau (Lehner and de Ruiter, 1976).

Sedimentary rocks within the coastal basins (figs. 6*B* and *D*) are mainly continental clastic rocks of Mesozoic and Cenozoic age toward the east; they change to marine shale, limestones, and evaporites marked by conspicuous unconformities and diapirs (Dillon and Sougy, 1974; Aymé, 1965; Templeton, 1971) in the west. The salt is inferred to be Triassic or Early Jurassic in age (Uchupi and others, 1976; Beck and Lehner, 1974), and it intrudes Cretaceous and younger strata in the southern part of the Mauritania-Senegal basin, and off Morocco and West Sahara.

On land, outcrops of Late Triassic age are red beds of conglomerate, sandstone, and mudstone associated with some salt. They are interlayered with basalts in the upper part and are restricted mainly to Morocco and Algeria (Van Houten, 1977); drilling in West Sahara has penetrated evaporite deposits of Triassic age. Dolerites intruded between the Carboniferous and Late Triassic are associated with the West African Shield (Mauritania, Mali, Guinea, Ivory Coast).

In the northern basins, the sedimentary section changes from continental red beds of Early Jurassic age to marine carbonate and evaporite deposits of Middle and Late Jurassic age (Dillon and Sougy, 1974). Jurassic and younger limestones formed carbonate platforms off Senegal and Guinea; during the Jurassic, the platforms flanked evaporite basins (Lehner and de Ruiter, 1976), but the banks persisted into the middle Cretaceous, unlike those flanking the basins further north. The lower Tertiary sedimentary rocks in Senegal are thin beds of phosphatic glauconitic limestone, chert, and shale. Off part of Morocco, effective deposition ceased after the Eocene or Oligocene time (Summerhayes and others, 1971) because of upwarping which shifted the loci of deposition to the slope and rise.

The main response of the West African margin (north of Sierra Leone) to crustal divergence is a central zone of coastal basins built over a block-faulted basement of deformed Paleozoic rocks; broad highs of Precambrian crystalline rocks separate these depocenters. The basins range widely in their width and appear narrowed where the West African Shield and Mauritanides are close to the coast. North of the Canary-South Atlas lineament, the margin is intricately faulted and deformed (figs. 3 and 6) in the part of Africa that has interacted with the European plate. In the south off Guinea, the change from a divergent margin to one affected by transform motion is marked by a narrowing of the basins, a lessening of subsidence, the absence of evaporite sequences, and a rise in the continental basement.

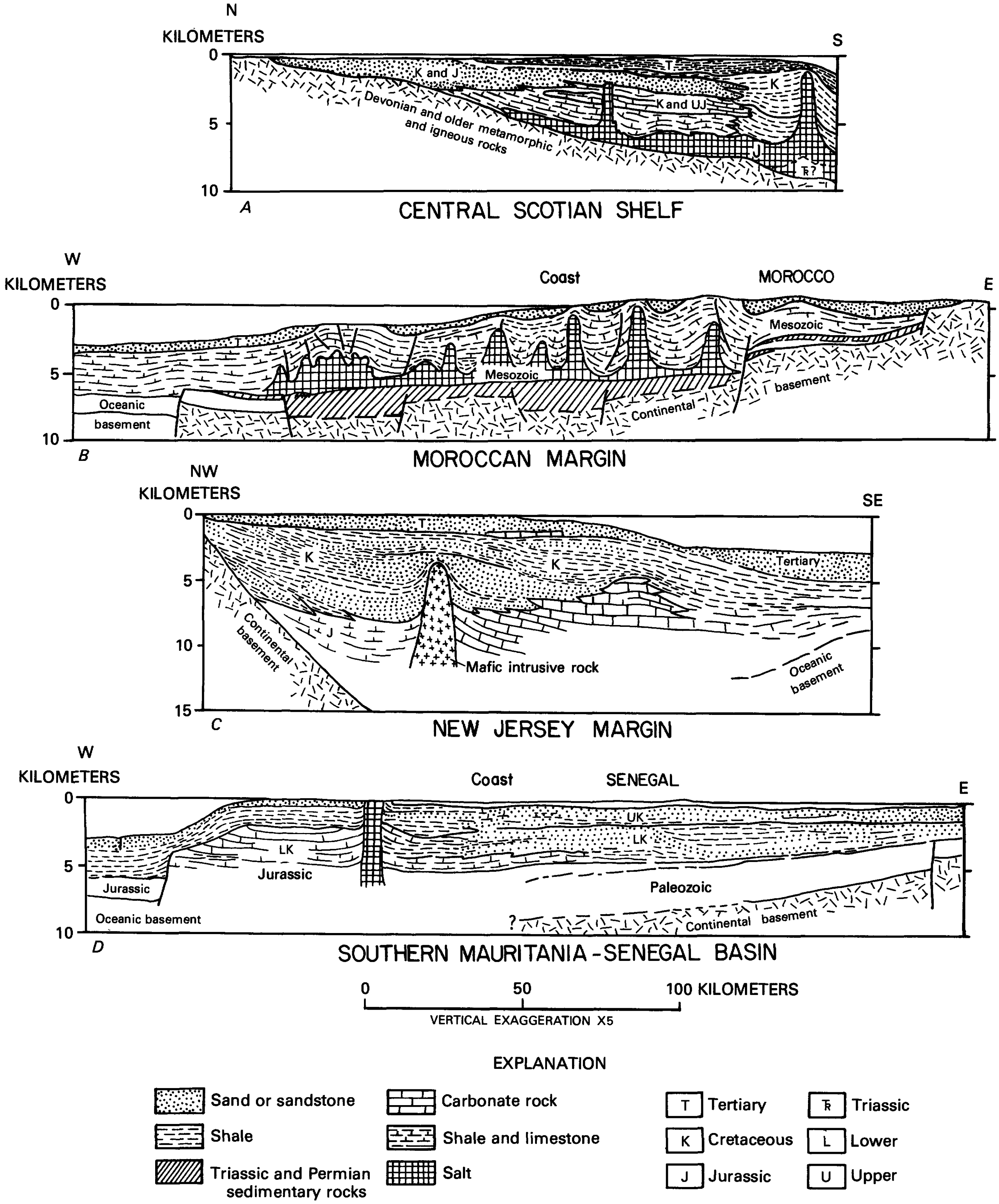

Figure 6.—Schematic cross sections through the West African (*B* and *D*) and eastern North American (*A* and *C*) margins at the locations indicated in figures 2 and 8. *A*, The Scotian Shelf profile is from Bhat and others (1975). *B*, The Moroccan profile is modified from Beck and Lehner (1974). *C*, The New Jersey profile is from Schlee and others (1976). *D*, The Senegal profile is a composite of data from Aymé (1965) and Uchupi and others (1976). All sections are the same scale.

NORTH AMERICA

STRUCTURAL ELEMENTS OF THE REGION

The North American continental margin (fig. 1*A*) has many of the same features just described as being on the West African margin—coastal basins, transverse structural zones, a bordering folded mountain belt, and a crystalline shield. An additional feature is a series of fault basins (Triassic to Early Jurassic in age), adjacent to much of the Appalachian fold belt.

The structural elements of the North American margin (King, 1969) are (1) the Canadian Shield of Precambrian crystalline rocks, (2) a platform cover of Paleozoic sedimentary rocks, (3) the Appalachian mountain system (extending from Alabama to Newfoundland), (4) discontinuous fault basins (and associated mafic volcanic rocks), and (5) the Atlantic Coastal Plain, the exposed part of a series of coastal basins and troughs filled with sediments of Mesozoic and Cenozoic age, most of which are under the Continental Shelf and Slope (fig. 7).

The southeastern part of the Canadian Shield is the Grenville Province—a sequence of marble and quartzite associated with syenite and anorthosite 800 m.y.–1,000 m.y. old (King, 1959). Shield rocks crop out along the Labrador coast, but farther south they are 200–600 km inland; shield rocks of West Africa are 50–450 km inland. Gently dipping Paleozoic sedimentary rocks, as much as several kilometers thick, overlie Precambrian crystalline rocks in the east-central United States. As in West Africa, these rocks have been broadly warped into domes, arches, and basins by epeirogenic movements which affected certain areas during the Paleozoic and later.

The Appalachian orogenic belt borders both the Canadian Shield and the cover of Paleozoic rocks of the central United States. It is exposed as a belt 100–600 km wide (the Mauritanides are 0–150 km wide); in the Eastern United States, the northeast-trending belt consists of metamorphosed eugeosynclinal rocks (the Piedmont) of Paleozoic age to the southeast thrust northwest along with a core of Precambrian crystalline rocks (gneiss and granite) against a parallel trending trough of folded (or faulted) miogeosynclinal rocks also of Paleozoic age.

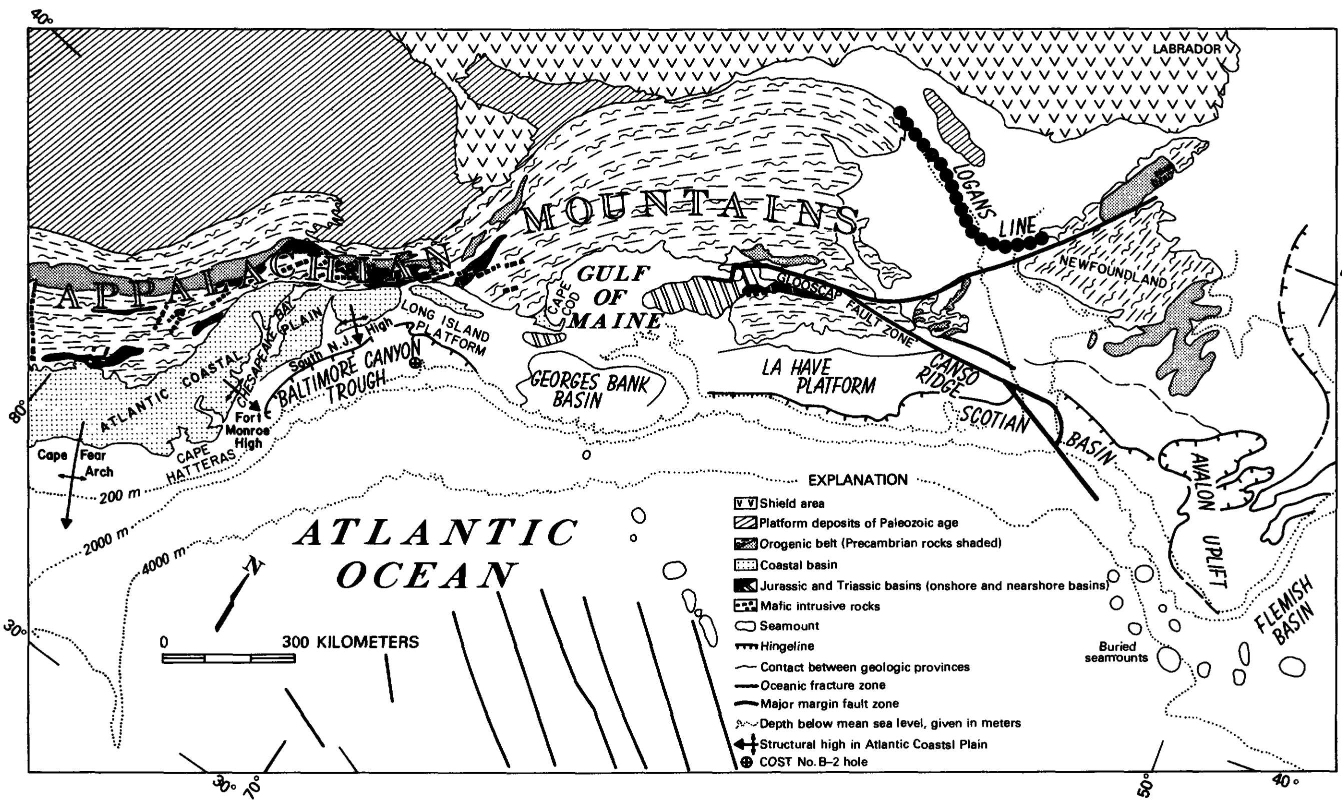

FIGURE 7.—Structural and stratigraphic elements of the eastern North American continental margin and the adjacent western Atlantic basin, Cape Hatteras to Newfoundland. A composite map from King (1969); Jansa and Wade (1975a); King (1975); Schlee and others (1976); Mattick and others (1974); Ballard and Uchupi (1975); Schultz and Grover (1974); Hans Schouten and K. D. Klitgord, unpub. data (1977).

To the northeast in northern New England and the Canadian Maritime Provinces, the general subdivisions are the same except that two additional belts of rocks are exposed in the southeastern part of this area. Bird and Dewey (1970) suggested that in New England and the Canadian Maritimes, island arcs may have been present beginning in the Early Ordovician, and that these arcs plus remnants of a proto-Atlantic oceanic crust were compressed during the Silurian and Devonian to form a belt of metasedimentary and metavolcanic rocks (Zone B of Bird and Dewey, 1970) between the Piedmont rocks to the northwest and a platform of Precambrian crystalline rocks, the Avalon platform, to the southeast (Ballard and Uchupi, 1975; Emery and Uchupi, 1972); fragments of the platform are exposed in southeastern Newfoundland, northern Nova Scotia, and southern New Brunswick, but much of it is covered beneath Georges Bank and areas of the shelf to the southwest. Rocks from this ancient platform exposed in Newfoundland are mainly Precambrian metasedimentary and volcanic rocks overlain by Cambrian and Ordovician rocks; by their faunal remains, these lower Paleozoic rocks show affinities with the rocks of Africa and Spain (Schenk, 1975), thereby suggesting that the platform may be a fragment of Europe and Africa that broke off and remained attached to North America during the latest opening of the Atlantic Ocean.

Stretching from Nova Scotia to the southern Appalachians are a series of elongate basins which are on the Acadian and Alleghenian orogenes. These basins contain as much as several kilometers of Upper Triassic to Lower Jurassic red beds (fig. 7) associated with basalt and diabase (Klein, 1962; Sanders, 1963; Faill, 1973; Ballard and Uchupi, 1975; Van Houten, 1977). Where exposed on land, they form north- to northeast-trending elongate belts as downwarps (Faill, 1973), grabens, and half grabens (Sanders, 1963) as much as 50 km across. The basin sediments were locally derived from adjacent highlands and were deposited as fans and fluvial deposits. The lowermost part of the section is intruded by diabase and contains basalt flows; the uppermost part of the section is also intruded by diabase.

Most recent workers think that the basins formed just prior to the last opening of the Atlantic, in response to tensional forces (May, 1971). Van Houten (1977, fig. 4) postulated that cratonic stretching in the Late Triassic may have resulted in faulting and continental sedimentation in basins along the eastern United States, Gulf of Mexico, Bay of Fundy, and the east-trending South Atlas fault and Kelvin-Cornwall lineament. In the Early Jurassic, the rifting spread to include basin development and evaporite deposition off Nova Scotia and Newfoundland and Morocco, as the margin in these areas fragmented during the initial rifting of Africa and North America. Early stages of fault–basin formation are on the sites of earlier orogenies (Alleghenian and Acadian) that affected eastern North America. Other investigators (Faill, 1973; Sanders, 1963; Ballard and Uchupi, 1975) have proposed more detailed models of crustal extension, thinning, graben formation, downwarping, and volcanism for certain areas of the eastern North American margin.

DIVISION OF THE CONTINENTAL MARGIN

Like West Africa, eastern North America has transverse structural lineaments (fig. 8) that subdivide the margin into three segments; one lineament is south of Long Island (Kelvin-Cornwall) and the other is south of the Grand Banks of Newfoundland (fig. 1*A*). They show up by changes in the trend of the continental margin from northeast to east; the changes are 240 km southwest of Georges Bank and 500 km south of the Grand Banks of Newfoundland. The geology also shows major changes across both these areas (fig. 7).

Beneath the Scotian basin, a major fault zone is inferred to bound block-faulted basins northeast of Nova Scotia and possibly to continue down into the Bay of Fundy as the Glooscap fault zone (fig. 7). Southeast of this zone, Nova Scotia and its margin are inferred to have separated from the main part of North America during the Jurassic (Van Houten, 1977, fig. 4). Along the southern side of the Grand Banks, the Newfoundland lineament also originated as North America and Africa-Europe separated. The feature is southeast of Logans Line, the east-southeast-trending lineament along which the northern Appalachians appear to be offset (Drake and Woodward, 1963). The line (shown by dots on fig. 7) also marks a major change in the pattern of the magnetic and gravity anomalies beneath the Gulf of St. Lawrence (Haworth, 1975). Drake and Woodward (1963) speculated that the wrench fault (Logans Line?) that offset the Appalachians in the Gulf of St. Lawrence may tie across the shelf to the Newfoundland lineament. Haworth (1975) suggested that Logans Line may represent an offset in the continental edge of North America during the early Paleozoic.

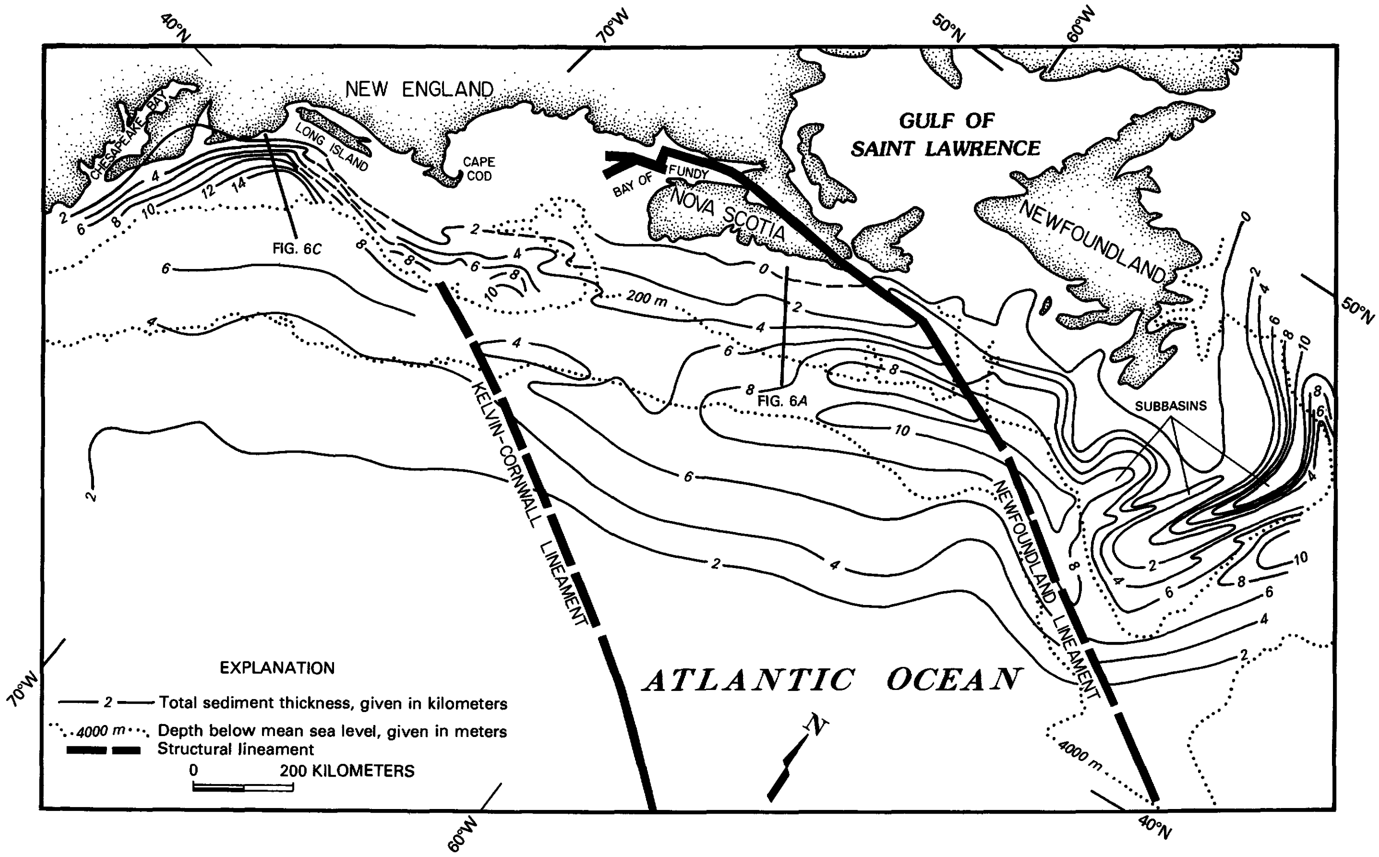

FIGURE 8.—Isopach map of Jurassic(?) and younger sediments on the Atlantic continental margin, Chesapeake Bay to Newfoundland. Data sources: King (1975) and Schlee and others (1976). Locations shown for figures 6*A* and *C*.

The Kelvin-Cornwall lineament south of New England is thought to be a wrench fault (Drake and Woodward, 1963); its existence is inferred from bathymetric, magnetic, and seismic-refraction data offshore and from a noticeable change in the trend of Triassic and Jurassic basins and thickness of pre-Mississippian rocks onshore. The fault may tie into the New England Seamount Chain which trends east-southeast (fig. 1*A*). The position of the lineament south of Long Island is uncertain. Drake and Woodward (1963) projected it obliquely across the shelf, and Schultz and Grover (1974) put it parallel to the base of the Continental Slope along the East Coast magnetic anomaly. Sheridan (1974a, b) interpreted the lineament to be a part of the edge of an oceanic block, defined in a seaward direction by oceanic fracture zones and at the margin, by the seaward edge of a sedimentary basin. These offshore studies indicate that some sort of zone of deep-seated faulting probably existed along the present zone between the Baltimore Canyon trough and the Georges Bank basin (fig. 7) during the initial phase of crustal separation. The fault zone appears to have formed in an area of rapid sediment thickening (fig. 8). This cross-shelf fault, like those adjacent to northwest Africa, may be "continued" offshore in a zone of volcanoes (seamounts) perhaps lined up along a zone of weakness in the oceanic crust (Vogt, 1973).

MARGIN SOUTH OF LONG ISLAND

Along the eastern United States, several younger coastal basins are built over Triassic and older rocks. Their emerged part is the Atlantic Coastal Plain (maximum width as much as 190 km in the study area, fig. 7) which extends southward from Long Island to the Gulf of Mexico. Northwest of Long Island, N.Y., coastal basins are all under the Continental Shelf. On the Atlantic Coastal Plain, the Mesozoic and Cenozoic sedimentary rocks attain a maximum thickness of 3 km near Cape Hatteras (fig. 1); north of there, the sedimentary rocks of Late Jurassic age and younger are 1–2 km thick and are contained in a broad series of embayments (Perry and others, 1975).

The sediments of the Atlantic Coastal Plain are broadly warped over structural highs and lows (embayments). Minard and others (1974) showed that three embayments and two structural highs are north of Cape Hatteras. One, the Fort Monroe high, is near the entrance of Chesapeake Bay, and the other, the South New Jersey high, is north of Delaware Bay (fig. 7). To the north, sediments of the Coastal Plain thin against the complexly faulted Long Island platform.

The Baltimore Canyon trough is 150 km wide and 400 km long. It contains as much as 14 km of strata, including most of the sedimentary section under the Continental Shelf, Slope, and Rise (figs. 6*C* and 8). From an analysis of 3,800 km of multichannel seismic-reflection profiles over the Baltimore Canyon trough (Schlee, unpub. data; Grow and others, 1979), the oldest sedimentary rocks in the trough are inferred to be as much as 5 km of Upper Triassic and Lower Jurassic red beds and evaporite deposits that accumulated in a series of rifts. During the Jurassic, the trough expanded southward when as much as 3 km of nonmarine sediment (mainly sand) was deposited in a broad seaward-opening wedge. Discontinuous carbonate platforms appear to have bordered the trough during the Jurassic and Early Cretaceous (Schlee and others, 1976; Sheridan, 1976). In the northern part of the trough, the reef complex is a lensoid mass that has acoustic velocities of 3–5 km/s—similar to those velocities found in carbonate sequences. Well-bedded sediments grade laterally into the "reef," and the unit appears to be associated with a "fore reef" facies on the seaward side.

Diapirs are present within the trough, particularly near Cape Hatteras (Grow and Markl, 1977; Grow and others, 1979). Salinity gradients in some shallow slope holes drilled in 1967 led Manheim and Hall (1976) to suspect that Jurassic evaporite deposits may underlie the slope off New Jersey and New York.

The only deep stratigraphic information comes from the COST (Continental Offshore Stratigraphic Test) No. B–2 hole (location shown on fig. 7) drilled in 1975 off New Jersey (Smith and others, 1976; Scholle, 1977). The COST No. B–2 hole bottomed in Upper Jurassic sandstone of deltaic–nearshore origin at 4,772 m below the sea floor. The Lower Cretaceous sequence is about 1.3 km thick and is mainly a shelf sequence of shale and sand (minor carbonate rock). Upper Cretaceous rocks (950 m thick) are a sequence of marine shelf and upper slope calcareous shale, sandstone, and dense limestone, which record at least two marine transgressions. A thin sequence (400 m) of slope-outer shelf limestone, claystone, and shale was deposited during the Eocene and Oligocene. It is overlain by a thick sequence (800 m) of poorly consolidated sand, gravel, and clay of Miocene age deposited in a shelf environment. Compared to the sequence of Coastal Plain rocks in the Island Beach, New Jersey, well, approximately 100 km away (Gill and others, 1963), the sequence in the COST No. B–2 hole is thicker (the Cretaceous section is three times thicker, and the Tertiary is four times thicker) and tends to be more marine.

Gravity and magnetic studies of the deep crustal structure beneath the Baltimore Canyon trough (Grow and others, 1979; Klitgord and Behrendt, 1979) show that the trough is probably built over a zone of thinned and intruded continental crust. Oceanic crust beneath the Continental Rise is about 10–12 km below sea level and is overlain by 6–8 km of sedimentary rocks. Between the trough and the rise wedge is an acoustical basement ridge 25–75 km wide that is mainly under the slope; here, acoustic penetration does not exceed 6 km below sea level. The acoustic basement ridge is marked by faulting and is overlain by the carbonate platform complex. In part because the ridge coincides with the East Coast magnetic anomaly, it is interpreted as thickened oceanic basement (layer 2) formed during the initial phase of sea-floor spreading.

In summary, the main response of the margin south of Long Island to separation of Africa and North America was subsidence, first in more restricted rift basins where probable nonmarine sediments and evaporite deposits accumulated and later in a broader trough as marine deposits of Late Jurassic and Cretaceous age were deposited. Marine strata were deposited on the seaward side of the trough, initially as carbonate platforms which formed the ancestral slope and later as fine-grained clastic sediments which prograded over the platform to create a constructional slope seaward of the present one (Schlee and others, 1979). An African counterpart would be the Mauritania-Senegal basin where Lehner and de Ruiter (1977, Fig. 5) indicated the presence of a carbonate shelf edge (as young as Cenomanian) beneath the present Continental Slope and outer shelf. There, a cluster of salt domes off Senegal, Gambia, and Guinea–Bissau indicate that a Lower Jurassic evaporite basin is beneath the shelf.

MARGIN BETWEEN LONG ISLAND AND NEWFOUNDLAND

Between the two major physiographic offsets (near Long Island and Newfoundland), the margin is characterized by several basins and platforms. From south to north, these are the Long Island platform, the Georges Bank basin, the La Have platform, the Scotian basin, the Avalon uplift, and the Flemish basin (fig. 7). Many of these features are further subdivided off the Canadian Maritimes into smaller subprovinces (ridges, subbasins, and banks), and the reader is referred to Jansa and Wade (1975a) and L. H. King (1975) for a complete description of all these features. The basins are open toward the sea and contain 8 to 14 km of Jurassic and younger sedimentary rocks. In part, they are built over block-faulted troughs probably containing Triassic or Lower Jurassic continental clastic sedimentary rocks (Ballard and Uchupi, 1975; Van Houten, 1977); hence, the fragmented character of the continent inherited during the Triassic continues in later periods as exemplified by the configuration of younger deposits in basins off New England and eastern Canada (fig. 8). Some offshore basins are bounded on their landward flanks by a zone of rapid thickening—a hinge zone, which can also be continued as a zone of faulting into the overlying sediments (Jansa and Wade, 1975a).

The platforms (Long Island, La Have) are characterized by an extensively faulted basement to form whole and half grabens, a thin sequence of postrift sediments, and a thickened wedge of sediments along their seaward flanks (Given, 1977; Grow and others, 1979). The grabens and half grabens are as much as 10–20 km wide and can contain several kilometers of rift sediment. The postrift sequence is usually less than 3–4 km over the platform; except for the oldest units (Upper Triassic(?) to Middle Jurassic), many of the same acoustic units appear to extend onto the platform though they are much thinned (Schlee, unpub. data). Well data (Given, 1977, fig. 6) shows that Lower and Middle Jurassic stratigraphic units present in the Scotian basin are missing from the La Have platform. The seaward edges of the platforms are marked by wedges of rapidly thickening postrift sediment (Jansa and Wade, 1975a; Given, 1977; Grow and others, 1979). The seaward zone of the Long Island platform is presumably where the Kelvin-Cornwall lineament projects through the margin.

Georges Bank basin is likewise built across a block-faulted basement to a thickness of more than 10 km (Schlee, 1978). On the basis of an interpretation of 1,650 km of multichannel seismic-reflection profiles (plus correlation to Scotian Shelf and Massachusetts well data), the basin appears similar to the sequence that is found in the Baltimore Canyon trough. The sequence is inferred to be Triassic(?) and Lower Jurassic nonmarine clastic rocks and evaporite deposits (0–8 km thick), Middle and Upper Jurassic nonmarine clastic rocks and marine carbonate rocks (0–4 km thick), Cretaceous marine and nonmarine sedimentary rocks (0–2 km thick), and Cenozoic marine and glacial deposits (0.2–0.5 km thick). Georges Bank basin is bordered along the southern edge by a probable carbonate platform; though buried in most areas, the platform is exposed and has been sampled on the eastern end of Georges Bank by Ryan and others (1978). They collected Neocomian biohermal limestone in a canyon on the south side of the bank.

Under the Scotian Shelf (fig. 1), several deep holes revealed a dominantly carbonate-calcareous shale-salt sequence of Late Triassic and Jurassic age that changes upward to sandstone, shale, and mudstone of Cretaceous and Tertiary age (Williams, 1975; Jansa and Wade, 1975a, b; Parsons, 1975; Given, 1977). As noted by Given (1977), the pattern of sedimentation was influenced by the configuration of the Paleozoic basement during the initial stages. As in basins already described, red beds, halite sequences, and dolomite (Upper Triassic and Lower Jurassic) characterized the rift phase of margin formation. The postrift phase of basin evolution (Jurassic) was characterized by discontinuous carbonate buildup along the seaward sides of the basins and by deposition of nonmarine clastic sediments inshore. During the Early Cretaceous, regressive deltaic wedges built over the carbonate rocks and shed detritus into the slope area. In the Late Cretaceous, a marine transgression deposited deep-water chalks and shales over the shelf part of the Scotian basin (Given, 1977). A regressive deltaic wedge occupied the Scotian basin during the Paleocene age, offlapping shales of Late Cretaceous age and contributing sediment through canyons to the Continental Rise sedimentary wedge.

The sedimentary patterns of both the Georges Bank basin and the Scotian basin are generally similar to those of the Baltimore Canyon trough. The Canadian rocks are documented in much better detail because of the many deep holes drilled on the Scotian Shelf and the correlation of the results to seismic-reflection profiles (Jansa and Wade, 1975b;

Given, 1977). As Bally (1976) and Given (1977) both pointed out, the patterns of subsidence and rock types support the Falvey (1974) model of a rift stage (Late Triassic and Early Jurassic) followed by a postrift stage (Jurassic and later) during which subsidence and marine transgression took place.

MARGIN NORTH OF THE NEWFOUNDLAND LINEAMENT

Off southern Newfoundland north of the Newfoundland lineament, the margin shows a change in structural style (figs. 7 and 8) in that the Scotian basin changes across the Avalon uplift into a series of narrow northeast-trending subbasins (fig. 8) that contain as much as 10–12 km of sediment; adjacent highs are covered by less than a kilometer of sediment. The basement is more fragmented beneath the eastern Grand Banks of Newfoundland (fig. 1*A*) and, therefore, shows a different tectonic framework than the one of general subsidence seen farther south. The Avalon uplift is a positive area that was active during the Early Cretaceous (Jansa and Wade, 1975a); it is covered by a thin sequence of Upper Cretaceous and Cenozoic sedimentary rocks. Clearly, the rifting phase (horsts and grabens) ceased much later in the southern Newfoundland area than it did to the southwest. Yet the lithological sequences are similar.

Beneath the Grand Banks of Newfoundland (Amoco Canada Petroleum Company Limited and Imperial Oil Limited, Offshore Exploration Staffs, 1974), the section is Triassic nonmarine shales and evaporite deposits in fault-bounded troughs. They are unconformably overlain by Jurassic evaporite deposits and marine calcareous shale, limestone, and sandstone. The carbonate rocks (Middle and Upper Jurassic) formed as part of a discontinuous series of banks at the seaward edge of the Scotian basin, both under the southern Grand Banks of Newfoundland and under the Scotian Shelf. These rocks are overlain by sandstone, siltstone, and shale of Cretaceous age and mudstone of Tertiary age. Major uplift and tilting of Jurassic and older strata took place during the latest Jurassic and Early Cretaceous under the Grand Banks of Newfoundland.

The response of the southern Newfoundland margin to crustal separation has been broad subsidence along the southern edge (adjacent to the lineament) and restricted deep subsidence in the subbasins of the Grand Banks of Newfoundland. The pattern is similar to that in the Long Island Platform where northeast-trending narrow rifts extend through the Long Island Platform and sediment accumulation is as much as 3–4 km within the rift (Klitgord and Behrendt, 1979) as compared to 1–2 km on the platform away from the rifts.

The deep crustal transition (continental to oceanic) beneath the Newfoundland Continental Slope has been inferred to be abrupt (King and others, 1975). It is marked by relief of as much as 4 km in the basement—possibly caused by volcanic extrusion and block faulting at the time of continental separation. The abrupt transition is in contrast to the Scotian margin where refraction studies (King and others, 1975) appear to indicate a zone of crustal thinning that is about 60 km wide and that is mainly under the slope. King and others (1975) thought that the crustal structure of the Scotian margin was caused by rifting during divergence, whereas the structure of the margin off the southern Grand Banks resulted from transform faults that formed along old lines of weakness (Glooscap fault zone) as adjacent crustal fragments moved by each other (see Discussion section that follows).

DISCUSSION

Several features of the structural–stratigraphic frameworks of the North American and West African margins are similar, whereas some others appear uniquely related to the earlier tectonic features in the particular area. I wish to discuss four aspects of these Atlantic-type margins: (1) similarities and dissimilarities in patterns of continental margin response to crustal separation, (2) stratigraphic sequences formed during the crustal separation, (3) the relationship of oceanic and margin tectonic features, and (4) the effects of transform and divergent crustal motion in continental margin formation.

SIMILARITIES AND DISSIMILARITIES IN THE STRUCTURE OF MATCHING MARGINS

Parts of both margins are built over a block-faulted continental crust marked by hinge zones, subparallel to the coast or subparallel to older structural lineaments inherited from ancient orogenic belts. The parallelism of coastal basins to ancient fold belts is fairly clear off the central bulge of West Africa and off the northeastern United States. Adjacent to New England and the Canadian Maritime Provinces, the pattern is complicated by the fragmented nature of the margin. The Canadian margin and its matching counterpart in Morocco show a wider pattern of rifting and basin formation ashore than in some areas to the south (figs. 6*A* and *B*).

The broader pattern of basins, ridges, and platforms off eastern Canad is paralleled ashore by a more complex tectonic pattern in the Appalachian fold belt. The northern Appalachians are marked by Logans Line, thought by some to represent a zone of ancient crustal offset. They contain the Avalon platform (possibly a continental fragment of Africa at one time) and an additional belt of metasedimentary and volcanic rocks between the platform and a belt of eugeosynclinal rocks to the northwest. The complexities of offshore basin formation seem, in part, to mirror the onshore patterns of the tectogene. North of Newfoundland, where the margin trends across the northeast strike of the Appalachians, the crust has been greatly fragmented in formation of elongate block-faulted basins (Van der Linden, 1975) under the shelf and slope.

Major dissimilarities exist between the two margins in the magnetic anomaly patterns and in the distribution of postorogenic basins. Many investigators have pointed out that the magnetic quiet zone off Africa is narrower than the matching zone off North America (Pitman and Talwani, 1972; Vogt, 1973; Luyendyk and Bunce, 1973; Uchupi and others, 1976; Hayes and Rabinowitz, 1975). A plausible explanation for the difference is that the rift axis jumped eastward early in the opening of the Atlantic, to leave behind a defunct spreading center in the western Atlantic. Some investigators have postulated that the East Coast magnetic anomaly (Emery and others, 1970) may be such a center, though others (Uchupi and others, 1976) thought that the anomaly may have been caused by an intrusion of mafic dikes and sills prior to the breakup of the continents. Along the eastern United States is a discontinuous string of fault basins which apparently are not present in West Africa. This string of basins (of Triassic to Early Jurassic age) seems to suggest that eastern North America was stretched more than West Africa. Though intrusive rocks are present along the coast of Africa, basins are not exposed except for those in Morocco discussed above. Some basins may underlie the younger coastal basins or the margins but even if they do, their presence there would seem to indicate that the present site of the West African margin subsidence coincided with the site of earlier rifting in West Africa, whereas in eastern North America, the rift formed earlier to the west and subsequently shifted to the site of the present margin in the Late Triassic (Van Houten, 1977).

STRATIGRAPHIC SEQUENCES

The strata deposited during rifting are similar on both margins and are similar to the types of deposits for newly rifted areas like the Red Sea. In the Red Sea, Miocene clastic rocks (sandstone and shale) are interbedded with basalt, volcanic tuff, and an evaporite sequence; the evaporite sequence is as much as 3.5 km thick and has flowed to form diapirs (Lowell and Genik, 1972; Ross and Schlee, 1973). Similar rocks have been drilled off the Canadian Maritime Provinces (Given, 1977), have been exposed in outcrops along the Eastern United States and Africa (fig. 6), or have been inferred to be offshore (Beck and Lehner, 1974; Emery and others, 1975; Van Houten, 1977). Associated with the older continental clastic rocks and evaporite deposits are diabase and basalt, emplaced as tabular bodies subparallel to the subsiding basins offshore (Emery and Uchupi, 1972). Along with the subsidence and block faulting, these intrusions suggest possible thinning of continental crust as a part of the process of crustal breakup.

In Africa–North America, discontinuous carbonate banks and reef complexes formed during an early phase of continental separation-subsidence, as marine waters spread southward into the newly forming Atlantic during the Jurassic (Bhat and others, 1975; Jansa and Wade, 1975b; Schlee and others, 1976; Given, 1977). The banks acted as partial barriers to dispersal of sediment into the deep sea and as a support for the shelf edge (Lehner and de Ruiter, 1976). Establishment of these banks may relate to the block-faulted foundation inherited from the rifting phase. As in the Red Sea (Carella and Scarpa, 1963), reefs may have been established on the upthrown blocks and may have become quite large (Guilcher, 1955).

Deposition of a thick carbonate sequence appears to have been discontinuous. Carbonate rocks appear to be widespread off the Canadian Maritimes, along part of the Eastern United States margin, off West Africa (fig. 6), and in the Gulf of Mexico. Conditions did not facilitate their formation off the Liberia-Ivory Coast area. When the coverage of offshore well data becomes extensive enough in each area, the presence or absence of carbonate banks during the Late Jurassic and Early Cretaceous probably will be found to be related to the interplay of coastal sediment sources and bathymetry. In areas where the rivers delivered enough sediment to the shelf to construct a deltaic complex, major accumulations of lime mud would not have formed. This pattern is similar to the one that Jansa and Wade (1975b, fig. 1) have postulated to exist off eastern Canada during the Late Jurassic.

Eventually the banks were overwhelmed by marine and nonmarine clastic deposits that covered them and prograded the shelf edge seaward. For both North America and Northwest Africa, the main phase of buildup after reef formation was during the Cretaceous (Jansa and Wade, 1975b; Beck and Lehner, 1974; Schlee and others, 1976; Bhat and others, 1975; Lehner and de Ruiter 1976, 1977; Given, 1977); as much as several kilometers of sandstone and shale of deltaic, alluvial, and marine-shelf origin were deposited during the interval. During the Cenozoic, much less sediment accumulated on the shelf (generally less than 1.5 km), and it is composed of marine clay and sand, some of which is phosphatic and glauconitic.

OCEANIC-MARGIN TIES

A variety of features suggest that the initial break between North America and Africa was jagged and that irregularities in the edges of the continents may have influenced orientation of structures both in the newly formed oceanic crust and under the margins. Matching zones of seamounts line up with ancient continental lineaments—the Canary-South Atlas fault trend, the Guinea fracture zone–Guinea zone of intrusive rocks and faulting, the Newfoundland lineament–Glooscap fault zone, and the New England Seamount Chain—Kelvin-Cornwall lineament. Besides being marked by faulting and intrusions, these zones are marked in some places by offsets in the trend of the margin and by substantial changes of sediment thickness within the zone. The alinement of some of these features along a major change in the orientation of the margin, *and* along hypothesized zones of ancient continental offset, suggests that they are following ancient lines of weakness that crossed both continents prior to their separation (Wilson, 1970, fig. 7). The sliding of these irregular continental projections by each other may have been accompanied by volcanism and block faulting of the basement, much as King and others (1975) inferred for the southern edge of the Grand Banks of Newfoundland, and Schlee and others (1974) described as taking place off Liberia. If so, *some* fracture zones may be related to marginal offsets, as has been postulated by Le Pichon and Hayes (1971) for the South Atlantic, and by Le Pichon and Fox (1971) for the North Atlantic. For many other fracture zones, the tie to continental features is more nebulous, particularly where the crustal blocks diverged and the sediment wedge over them is large.

DIVERGENT-TRANSFORM MARGINS

The divergent margins that have been examined in this paper are characterized by broadly subsided basins, probably built over a zone of block-faulted and intruded basement rocks. The critical boundary between continental and oceanic crust is in part marked by faulting, diapirism, and an extensive zone of Jurassic and Early Cretaceous carbonate platform deposits which are found in both Africa and North America. The crucial boundary may be a thickened zone of oceanic crust or a zone of transitional crust (marked by slivers of both types of crust).

The structural pattern of a divergent margin can change laterally from broad basins under the shelf (Mauritania-Senegal basin; Baltimore Canyon trough) to more of a fragmented margin marked by platforms and ridges and having basins under the slope rather than under the shelf (figs. 2 and 8). As discussed in the previous section, this change may reflect the irregularity of the crustal break during the latest stage of ocean formation. Where the break was subparallel to the direction of plate movement, transform motion would dominate and a transition zone of block-faulted platform would be anticipated. In areas like the Guinea marginal plateau (Lehner and de Ruiter, 1976) and the eastern Canary Islands (Beck and Lehner, 1974), a suggestion of a marginal ridge is given by the rise in the continental basement adjacent to the junction with oceanic crust. Along the southern side of the Grand Banks of Newfoundland (near the Newfoundland lineament), the abrupt transition from continental to oceanic crust has already been described. The clearest form of this type of a margin is off equatorial Africa where the sediment cover is thin and ridges and escarpments show through as the major tectonic features (Delteil and others, 1974; Emery and others, 1975; Schlee and others, 1974; Behrendt, Schlee, Robb, and Silverstein, 1974). The low-angle intersection of two fracture zones has resulted in two southward-facing escarpments separated by the elongate Ivory Coast basin (Emery and others, 1975; Spengler and Delteil, 1966; Delteil and others, 1974). The basin is limited laterally by these escarpments or ridges, and sediments in it thicken to more than 4 seconds (two-way travel time) in a seaward direction (Emery and others, 1975) and then thin against the southern of the two escarpments; the greatest accumulation of sediment is adjacent to the coast, where more than 5 km of sediment has been drilled.

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