# Robert R. Jordan, State Geologist VERMONT RHODE ISLAND ATLANTIS BASIN MASSACHUSETTS NANTUCKET BASIN RBLOCK ISLAND CONNECTICUT **NEW YORK** PENNSYLVANIA **NEW JERSEY** NEWARK BASIN **NEW JERSEY** UNNAMED BASIN ATLANTIC OCEAN TAYLORSVILLE BAS X CAPE HATTERAS **EXPLANATION** EARLY MESOZOIC RIFT BASINS/SYNRIFT ROCKS BURIED (OUTLINES INFERRED, QUERIED WHERE CONTROL IS ABSENT OR POOR) BORDER FAULT ZONE OF RIFT BASIN MULTICHANNEL CDP SEISMIC REFLECTION PROFILES ----- PROPRIETARY (BOLD IF IN DGS FILES)

#### DISCUSSION

INTRODUCTION A series of elongate rift basins of early Mesozoic age is exposed in eastern North America in a belt extending from Nova Scotia to South Carolina. The Upper Triassic-Lower Jurassic synrift rocks that fill the basins are called the Newark Supergroup comprising continental (fluvial and lacustrine) clastic sedimentary rocks (predominantly colored red) interbedded with basaltic volcanic rocks (Froelich and Olsen,

1985). Similar basins are buried beneath the sediments of the Atlantic

Coastal Plain and continental shelf. The rift basins formed during extension and thinning of the earth's crust along a curvilinear tract across the ancient supercontinent of Pangea. The Alleghanian orogeny at the end of the Paleozoic Era had completed the construction of Pangea by the convergence of continentbearing lithospheric plates. Extension and thinning eventually led to a breakup of part of Pangea during the Middle Jurassic when the continental fragments that became South America, Africa, and Europe separated from North America (Klitgord and Schouten, 1986). As the fragments drifted away from each other, the new oceanic crust of the Atlantic Ocean and Gulf of Mexico basins formed between them. Before separation, the U. S. mid-Atlantic continental margin fit against the northwest margin of Africa offshore Western Sahara and Mauritania (Klitgord and Schouten, 1986; Benson and Doyle, 1988). The Triassic-Jurassic rifting events that culminated in the breakup of Pangea are described in Manspeizer (1988).

Following the Middle Jurassic breakup of Pangea, the margins of the drifting continental fragments began to subside and receive sediments eroded from the interior landmasses. These postrift sediments buried the rift basins and surrounding pre-Mesozoic terranes of the eastern continental margin of North America in the region extending from what is now the Grand Banks offshore Canada to Florida. Postrift sediments of the U.S. mid-Atlantic continental margin reach thicknesses in excess of 13 km in the offshore Baltimore Canyon trough (Grow et al., 1988). The area of postrift rocks now above sea level comprises the Atlantic Coastal Plain. The maximum thickness of postrift rocks of the Coastal Plain in Delaware is over 3 km (Benson, 1984).

The map of exposed and inferred buried rift basins shown here is a revised version of an earlier map by Benson and Doyle (1988, Fig. 5-2). Revisions, discussed in the following sections, are based on recent publications by other researchers, new data provided by seismic reflection profiles and drill holes in the Coastal Plain, and reinterpretation of offshore seismic reflection profiles.

### **EXPOSED RIFT BASINS**

The inner limit of the Coastal Plain and the outlines of the exposed rift basins containing sedimentary and volcanic rocks of the Newark Supergroup are after Benson (1984 and references therein) and Benson and Doyle (1988). The basins in Virginia are after Wilkes et al. (1989). C. R. Berquist, Jr., (written commun.) provided a revised outline of the Richmond basin of Virginia.

The exposed rift basins, generally, are asymmetric half-grabens (Ratcliffe and Burton, 1985; Ratcliffe et al., 1986; Costain and Coruh, 1989). In a typical basin, strata dip toward the border fault zone, and basin deposits are thickest along that margin of the basin. The border fault separated the steep mountain front of the upthrown block from the most rapidly subsiding part of the rift valley adjacent to the fault on the downthrown side. Sediments supplied at a high rate from the mountainous region were deposited in the adjacent, rapidly subsiding basin to produce a thick sedimentary wedge that thinned toward the opposite side of the basin. During most of their history, the basins were isolated and had interior drainage. Lakes occurred during humid times, and organic-rich lacustrine sediments accumulated that, today, are of interest to the petroleum industry because they may be the source rocks for potential oil or gas deposits in the basins.

For many, if not all, of the exposed basins, the dips of the border faults decrease with depth, and the faults merge with low-angle thrust faults that formed during the compressional tectonics that characterized the Paleozoic orogenies. Reactivation of the Paleozoic faults, but with extension rather than compression, during the early Mesozoic led to the formation of the asymmetric rift basins (Ratcliffe and Burton, 1985; Ratcliffe et al., 1986; Costain and Coruh, 1989). The locations of the rift basins, therefore, were controlled by pre-existing structures; this is apparent from the map patterns in that the exposed rift basins align with the structural grain of the Appalachian orogen.

Except for the Deep River and Hartford-Deerfield basins, the border faults are on the western sides of the exposed basins and dip easterly, presumably merging at depth with easterly dipping, low-angle, reactivated Paleozoic thrust faults. As revealed by seismic reflection profiles, the border fault zone on the eastern side of the Deep River basin dips west at 18° and continues beneath the basin before merging with subhorizontal reflectors deep in the pre-Mesozoic metamorphic basement (Davis et al., 1991). Hutchinson and Klitgord (1988) describe three types of structures, mostly reactivated Paleozoic structures, that appear to be responsible for the formation of rift basins buried on the continental margin around New England. One type is paired border faults that extend deep into the crust, with rift basins along one or both faults. Other examples they cite are the facing border faults of the Newark and Hartford-Deerfield basins and the Deep River and Dan River-Danville basins.

If, in the past, a significant thickness of synrift and/or postrift rocks covered all the exposed basins, the erosional remnants we see today may just be the deepest parts or "keels" of the originally thicker and more extensive basins. Smith (1980) concluded that Upper Jurassic heavy mineral assemblages from the offshore COST B-2 well in the Baltimore Canyon trough could have been derived from erosion of extensive source areas of early Mesozoic synrift rocks. He further states that this was possible within the framework of the broad-terrane hypothesis of authors who believe that the present exposed basins are erosional remnants of a much larger and continuous area of synrift

to expose the rift basins, but modeling studies offer some insight into this problem. For the Richmond, Farmville, and Deep River basins, Benson and Doyle (1984) constructed two hydrocarbon-generation models that were constrained by vitrinite reflectance data determined for outcropping, dark-colored, carbonaceous, lacustrine shales they sampled from those basins. The average vitrinite reflectance value of 0.84 indicates that the rocks are within the oil-generation window, with an average time-temperature index of maturity (Waples, 1980) value of 39. In the first model, in which a constant geothermal gradient of 25°C/km was assumed throughout the basins' history, over 3 km of overlying rock must have been removed. For the second model, in which a basin heating event was assumed at the time of volcanic activity about 200 million years ago, between 1.5 and 2 km of cover would have been removed. In their study of the thermal maturity of the organic material in rocks from the Newark basin, Katz et al. (1988) concluded from their numerical modeling that 2 km of sediment covering the youngest formation of the basin had been removed by erosion.

It is not known how much rock cover has been removed by erosion

#### **BURIED RIFT BASINS** Atlantic Coastal Plain

The inferred areas of rift basins/synrift rocks buried beneath the Atlantic Coastal Plain were mapped on the bases of drill-hole data, aeromagnetic (Zietz et al., 1977, 1980; U. S. Geological Survey, 1979) and gravity anomaly (Haworth et al., 1980) maps, and data from seismic reflection profiles. Drill holes that penetrated beneath the postrift rocks into (1) unmetamorphosed sedimentary rocks described as "Triassic red beds" or as representative of the Newark Supergroup or (2) diabase interpreted to be of early Mesozoic (synrift) age are indicated by solid triangles. Solid circles identify boreholes that penetrated pre-Mesozoic basement without encountering synrift rocks. The drillhole data for South Carolina, North Carolina, New Jersey, and New York are from Daniels and Leo (1985), with additional data for Long Island, New York, from Rogers et al. (1989); for Virginia from Wilkes et al. (1989); for Maryland from Hansen and Edwards (1986) and Benson (1984); and for Delaware from Delaware Geological Survey (DGS) files.

The Florence basin in South Carolina and the other three small basins in South Carolina and North Carolina are after Thomas et al. (1989, pl. 6). The outlines of the Taylorsville basin beneath the Coastal Plain of Virginia and Maryland and the three small basins east of the Taylorsville are after Wilkes et al. (1989). Those areas enclose aeromagnetic lows where, except for the Toano basin, drill holes recovered synrift rocks. Costain and Coruh (1989) show the Toano basin on the I-64 seismic reflection profile which crosses the northern tip of the basin. The Taylorsville basin, which is exposed at its southwestern tip, also encloses a broad gravity low. I have extended the Taylorsville northward to include one drill hole in Maryland that recovered Newark Group(?) red beds (Hansen and Edwards, 1986).

The Taylorsville basin is currently being explored for oil and gas. Although locations of proprietary seismic reflection profiles are unavailable for Virginia, they are known for Maryland (K. A. Schwarz, written commun.; Benson, 1990), and several lines cross the basin in that state. Bowman et al. (1987) show a seismic reflection profile (Teledyne line on map) across the basin in Virginia. Although one 3,048-m (10,000-ft) exploration well in Virginia, the Texaco No. 1 W. B. Wilkins located 20 km north of the Teledyne line, discovered no commercial accumulations of hydrocarbons, indications are that natural gas would be the likely resource (Weaver and Schwarz, 1991).

On the Maryland Eastern Shore, Hansen (1988) identified a rift basin on Vibroseis profile TXC-10C and tentatively named it the Queen Anne basin. The profile did not extend westward to the basin's border fault zone which may be located along the southeastern side of a NE-trending magnetic and gravity high that probably separates the Queen Anne basin from the Taylorsville basin on the west. Other than profile TXC-10C, no other seismic reflection profiles are available for study in order to delineate the basin. I have tentatively extended the basin southward to coincide with the area of extensive proprietary seismic reflection profiling in Chesapeake Bay and on the Maryland Eastern Shore and, at its southern end, with an elongate gravity low oriented north-south in the Bay. In doing this I have assumed that the profiles are concentrated over one or more buried rift basins. Although I show the area as one basin, it may be subdivided by the "island" that

marks a magnetic and gravity high. On the Smith Point seismic reflection profiles at the southern end of the basin, Dysart et al. (1983) analyzed velocity spectra that indicate an indurated unit 90 m thick of Triassic(?) age overlying crystalline basement. Sabat (1977) calculated a basement depth of about 2.4 km for the gravity low at the southern end of the basin and postulated that this may reflect the presence of a Triassic basin. In contrast, Dysart et al. (1983) interpreted the gravity low as a granite and calculated the average depth of basement at 950 m.

Only one borehole within the area of the Queen Anne basin reached Coastal Plain basement. Well SM-DF 84 recovered diabase that may be from a sill or dike that may or may not be associated with synrift rocks (Hansen and Edwards, 1986). The diabase gave a K-Ar date of 169±8 Ma (Hansen and Wilson, 1984). If correct, this Middle Jurassic date corresponds to the time of breakup of Pangea and the development of the volcanic wedge sequence interpreted from offshore seismic reflection profiles (Benson and Doyle, 1988). The date is younger than the 184±3.3 Ma age of the "J" basalt traceable as an extensive reflector over the South Georgia rift basin (McBride et al.,

I extended the Queen Anne basin into Delaware and New Jersey to coincide with a narrow magnetic low that ends against a prominent magnetic high trending ESE across the Coastal Plain of New Jersey (U.S. Geological Survey, 1979). In Delaware, the postulated border fault zone extends beneath an area of faulted Coastal Plain rocks (research in progress).

Two small basins are indicated on Vibroseis profile TXC-10 across southern Delaware and into Maryland (Benson, 1990). I show their trend as parallel with two magnetic highs (U.S. Geological Survey, 1979) crossed by the profile. The basins do not extend under Delaware Bay as no rift basins are imaged on proprietary seismic reflection profile S19-DB (DGS files). I propose the names Greenwood basin after Greenwood Delaware, for the basin shown on TXC-10R and Bridgeville basin after Bridgeville, Delaware, for the one shown on

South of Delaware, there is an area of synrift rocks that includes the Hammond and Bethards wells in Maryland and the Taylor well in Virginia. Anderson (1948) identified 41 m (135 ft) of "Newark Series" rocks above pre-Mesozoic basement in the Hammond well and 178 m (585 ft) of that "series" in the Bethards well. Onuschak (1972) described 35 m (116 ft) of "Triassic red beds" in the Taylor well. Doyle and Robbins (1977) found only post-Jurassic palynomorphs in the few samples they examined from the red beds above basement in the Bethards and Taylor wells, but they admit that those specimens could be contaminants. Regardless, they assigned the basal red beds in all three wells to the Lower Cretaceous. Because the red beds indicate oxidizing conditions, it is possible that any palynomorphs originally deposited with the sediments were not preserved. Although unequivocal evidence for the age of the red beds is lacking, I accept Anderson's (1948) and Onuschak's interpretations (1972) that those rocks are "Triassic" (or Early to Middle Jurassic), comprising a thin wedge of synrift rocks that may thicken seaward. Alternatively, the red beds may be postrift sediments (Hansen and Edwards, 1986).

On the northwest part of the Buena Vibroseis profile in New Jersey, Sheridan, Olsson, and Miller (1991) interpreted a Mesozoic rift basin they named the Buena basin. I show the basin's probable northern limit as a border fault zone marked by the abrupt change from low frequency magnetic anomalies on the south to high frequency ones on the north (U. S. Geological Survey, 1979). The other three sides of the basin conform to the shape of the northern side of the ESE-trending magnetic high mentioned previously.

Sheridan, Olsson, and Miller (1991) postulated a Mesozoic rift basin southeast of the Buena Vibroseis line in New Jersey in their gravity model along the trend of that line. If it exists, the basin may coincide with a narrow WNW-trending magnetic low that crosses Delaware Bay just north of the end of seismic profile S19-DB and ends in

## Continental Shelf

The inferred buried rift basins beneath the mid-Atlantic continental shelf were identified on the seismic reflection profiles shown on the map (Hutchinson et al., 1986; Benson and Doyle, 1988; Klitgord et al., 1988; Benson and Roberts, 1989). The offshore region south of Cape Hatteras, North Carolina, was not studied.

COASTAL PLAIN BASEMENT ROCKS RECOVERED FROM BOREHOLES

TRANSVERSE MERCATOR PROJECTION

UNMETAMORPHOSED, PRESUMED LOWER MESOZOIC (UPPER TRIASSIC –

OWER JURASSIC) SYNRIFT SEDIMENTARY ROCKS AND/OR DIABASE

0 KILOMETERS

50 MILES

PRE-MESOZOIC ROCKS

The largest area of synrift rocks, as yet unnamed, extending from seismic profile USGS 10 to USGS 24 also is the most deeply buried of the areas shown on the map as it underlies the thickest section of postrift rocks that comprise the Baltimore Canyon trough (Grow et al., 1988). Because of the deep burial, only the landward margin of synrift rocks is discernible on the seismic profiles. A zone of normal faulting and thickening of basin rocks seaward of the landward border of the synrift rocks is evident on several of the profiles and is indicated on the map as a fault zone which, along most of its length, is parallel to the border fault of the Newark basin. The seaward border of the basin is undefined because it is not apparent on the seismic profiles.

Benson and Doyle (1988, Fig. 5-2) showed the southern limit of the basin at profile USGS 3. In contrast, what they considered as synrift rocks on that profile and on USGS 27 I now reinterpret as part of the younger wedge sequence (Benson and Doyle, 1988) of volcanic and volcaniclastic rocks that resulted from an intensive phase of volcanism that occurred during and immediately after the breakup of Pangea and possibly contemporaneous with the formation of the first oceanic crust of the Atlantic Ocean basin. With this interpretation I restrict the definition of synrift rocks to those filling rift basins developed within continental crust. The volcanic wedge sequence originated from the narrow region where Pangea broke up, and it eventually buried both the synrift rocks and surrounding pre-Mesozoic terranes at the edge of the newly formed continental fragment. Sheridan, Musser, et al. (1991) identified the wedge sequence seaward of the Norfolk basin on recently acquired EDGE seismic profiles and observed that the wedge appears to downlap on the hummocky oceanic basement under the continental rise. If correct, this indicates that the wedge is post-synrift, and those authors, therefore, are in agreement with Benson and Doyle's interpretation (1988) that the wedge sequence is younger than synrift rocks but is truncated by the postrift unconformity. The wedge sequence, therefore, preceded the postrift sedimentary rocks. Given this interpretation, the synrift sequences recognized by Klitgord et al. (1988) on USGS seismic lines 28, 10, and 25 (their figures 6C,

On the Long Island platform north of the unnamed basin just described, the New York Bight, Long Island, Nantucket, and Atlantis basins are shown as mapped by Hutchinson et al. (1986). Included are the locations of the seismic reflection profiles they used in their study. Rogers et al. (1989) suggest the possibility of a buried rift basin on Long Island within a "permissible zone" between the Hartford basin onshore and the New York Bight basin offshore. They raise doubts about the accuracy of the unpublished information from the one well (Duck Island well) that reportedly recovered 300 m of brown sandstone (synrift rocks?) beneath the Coastal Plain sediments. Hutchinson et al. (1986) cite the Lower Jurassic (therefore synrift?) weathered basalt recovered from the bottom of the borehole shown on Nantucket Island, but they did not extend the Nantucket basin northeasterly to include it.

11A, and 11B, respectively) were assigned to the wedge sequence by

Benson and Doyle (1988, figs. 5-4, 5-5, and 5-7).

The complex area of small basins and horsts just offshore Delaware is after Benson and Roberts (1989). For the L-shaped basin imaged on seismic reflection profiles D102 and USGS 37 (Benson and Roberts, 1989), DGS-001 (Benson et al., 1986), and USGS 10 (Benson and Doyle, 1988) I propose the name Fenwick basin after Fenwick Island, the barrier island that forms part of the Delaware-Maryland

The Norfolk basin offshore the southern end of the Delmarva Peninsula was named by Klitgord and Hutchinson (1985) for a welldefined basin with landward-dipping internal reflectors shown on seismic profile USGS 28 (see also Benson and Doyle, 1988). They mapped the areal extent of the basin to coincide with a broad magnetic low. However, I show the basin about one-third that size as verified by seismic profiles M102, M103, USGS 28, and V104. The smaller size was confirmed by both strike and dip EDGE profiles (Sheridan, Musser, et al., 1991). The border fault on the west side of the basin is oriented north-south and dips east; at depth, it merges with a low-angle, eastdipping reflector that may represent a reactivated Paleozoic fault (Benson and Doyle, 1988; Sheridan, Musser, et al., 1991). Bayer and Milici (1987) also mapped the Norfolk basin with about the same areal extent as I show, but they did not use profiles M102, M103, and V104 in their study. They also joined the three small basins east and south of the Norfolk basin, whereas in my interpretation they are isolated.

#### CONCLUSIONS

In compiling a map of buried rift basins from geophysical evidence in combination with borehole records that, in nearly all cases, provide no biostratigraphic information on the geologic age of suspected synrift rocks recovered, there are few constraints. One must rely on comparisons with the exposed rift basins of which more is known from study of outcrops than from subsurface geological and geophysical

The areas of inferred buried rift basins/synrift rocks shown on this map might best be considered as areas where efforts should be concentrated to verify their presence or absence. It is striking that the buried basins show a high degree of parallelism with the exposed basins and, in turn, with the Paleozoic structural grain of the Appalachian orogen. Whether or not this reflects a preconceived notion on my part or is a true representation must await future study.

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