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Stratigraphic Architecture and Paleomagnetic Reversal Stratigraphy of the Late Triassic Taylorsville Basin, Virginia and Maryland

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The Taylorsville basin in Virginia and Maryland is one of the largest of the subsurface Triassic–Jurassic rifts. It is covered mostly by Cretaceous and younger passive margin deposits, but a small area of the southeastern part of the rift is exposed. An industry data set from the Taylorsville basin consists of more than 6,800 m of continuous core, more than 7,000 m of well cuttings, and approximately 150 km of seismic reflection profiles, providing the opportunity to study in unprecedented detail the stratigraphic and structural history of this buried rift and its relationship to the exposed rifts of the Newark Supergroup. The new data reveal that the Taylorsville rift contains more than 4.5 km of vertical section in two unconformity-bounded tectonostratigraphic sequences of fluvial and lacustrine strata. Seismic profiles show that the rift evolved in two distinct stages from a series of small isolated half-graben to a single regional-scale half-graben. The upper and lower rift sequences are separated by a regional unconformity. The Taylorsville basin is assigned a Late Triassic, Carnian to Norian age based on pollen, plants, and vertebrate fossils and on paleomagnetic correlation with the Newark basin.

Rocks in the lower tectonostratigraphic sequence comprise the Carnian age Doswell Group (revised and raised in rank), which includes the fluvial South Anna Formation (new) and the overlying, lacustrine Falling Creek Formation (raised in rank). The latter formation consists of (from bottom to top) the Deer Creek (new), Stagg Creek (revised), and Poor Farm (new) Members. The late Carnian to Norian age rocks from the upper sequence form the King George Group (new), which includes the coarse, fluvial Newfound Formation (raised in rank), the lacustrine Port Royal Formation (new), and the fluvial and lacustrine Leedstown Formation (new). A new paleomagnetic reversal stratigraphy of the Taylorsville basin allows correlation with the published polarity stratigraphy of the Newark and Dan River basins, revealing the relative timing of rifting among the Newark Supergroup basins and the paleolatitudinal controls on depositional environments as the North American plate drifted northward through the Late Triassic. The large-scale stratigraphic pattern of fluvial-lacustrine-fluvial rocks within the two basin-fill sequences was controlled by tectonic subsidence and growth of the depositional basin. Fine-scale variations in the large-scale stratigraphic patterns are ascribed to hydrologic fluctuations resulting from astronomically forced climatic change.

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Numerous subsurface rifts likely of Late Triassic and Early Jurassic age are found beneath the Jurassic and younger passive margin sedimentary wedge in onshore and offshore areas along the eastern seaboard of North America (Klitgord and Hutchinson 1985; Benson 1992) (figure 3.1). The very poorly known subsurface rifts along with the exposed basins containing Newark Supergroup strata comprise a major geologic feature of the central Atlantic margin (CAM) of eastern North America. However, there is still no consensus on the number, location, size, structure, sedimentary fill, and age of the subsurface basins (Wentworth and Mergner-Keefer 1983; Wilkes, Johnson, and Milici 1989; Benson 1992), our knowledge of which is based mainly on interpretation of gravity and magnetic anomaly surveys and, in offshore areas, on ship-based seismic surveys (Hutchinson, Klitgord, and Detrick 1986; Hutchinson and Klitgord 1988; Klitgord, Hutchinson, and Schouten 1988; Wilkes, Johnson, and Milici 1989). Only the onshore basins have been drilled for water resource, geotechnical, or mineral resource investigations (Darton 1896; MacCarthy 1936; Anderson 1948; Applin 1951; Shomo 1982; Gohn 1983; Milici et al. 1991, 1995). Apart from having similar half-graben cross sections, the relationship between the sedimentology, paleontology, stratigraphy, structural evolution, and age of the subsurface rifts and the exposed rifts is unknown.

In contrast, the exposed rifts of the Newark Supergroup are known mainly from outcrop studies, and data are available from only a few nonproprietary seismic profiles and deep stratigraphic test wells (Costain and Coruh 1989; Milici et al. 1991, 1995; Olsen et al. 1996). Studies of the exposed rifts are hindered by poor exposure and by an apparently complex structure that often leads to considerable ambiguity in stratigraphic and structural interpretations. The relative age of the exposed rifts has been determined by biostratigraphy to range from at least Carnian to Hettangian (e.g., Cornet 1977; Olsen 1997). Radiometric dates from basalt flows and diabase dikes and sills intercalated with rift sediments indicate an Early Jurassic age of approximately 200 to 202 Ma for the regional volcanism of the CAM (Sutter 1988; Dunning and Hodych 1990; McHone 1996; Marzoli et al. 1999; Hames, Renne, and Ruppel 2000).

The Taylorsville basin in eastern Virginia and Maryland consists of both exposed and subsurface portions and therefore provides a unique opportunity to integrate outcrop-based interpretations of rift structure and stratigraphic architecture with interpretations based on rock core, well cuttings, and seismic reflection profiles (figure 3.2). Proprietary information from oil and gas explorations conducted in the large, mostly subsurface Taylorsville basin was released to the Triassic–Jurassic Working Group at Columbia University for study. More than 13,800 m of stratigraphic test well cores and cuttings and approximately 150 km of seismic reflection profiles constitute the best available set of data for any exposed or buried early Mesozoic rifts in eastern North America; only the Newark Basin Coring Project (Olsen et al. 1996), including the NORPAC seismic profile, is comparable in scale.

This chapter presents the lithostratigraphic framework of the Taylorsville basin, including formalization of revised stratigraphic nomenclature. A generalized model of the basin structure is used to demonstrate the two-stage tectonostratigraphic development of the basin. The age of the subsurface part of the basin was determined using diagnostic fossils found in the Taylorsville cores along with biostratigraphic data from the outcrop area. Paleomagnetic reversal stratigraphy is used to correlate strata within the Taylorsville basin and to provide high-resolution correlation of the basin with other rifts of the Newark Supergroup. Tectonic and climatic controls on the depositional history of the basin are also discussed.

This study of the Taylorsville basin is important because previous studies of the subsurface onshore and offshore rifts emphasized either a few seismic reflection profiles (Klitgord and Hutchinson 1985; Hutchinson, Klitgord, and Detrick 1986; Costain and Coruh 1989) or information from limited drilling (Shomo 1982; Gohn, Houser, and Schneider 1983), which provided only rudimentary details on the probable age, structure, and stratigraphy of the rifts. The deep stratigraphic test wells in this study that penetrated basement provide a framework for determining the stratigraphy of the entire Taylorsville basin section. The seismic profiles provide important structural information about the deeper (and older) portions of the basin that are not typically accessible for study.

Comparison of the Taylorsville basin and exposed rifts provides the opportunity to test and improve

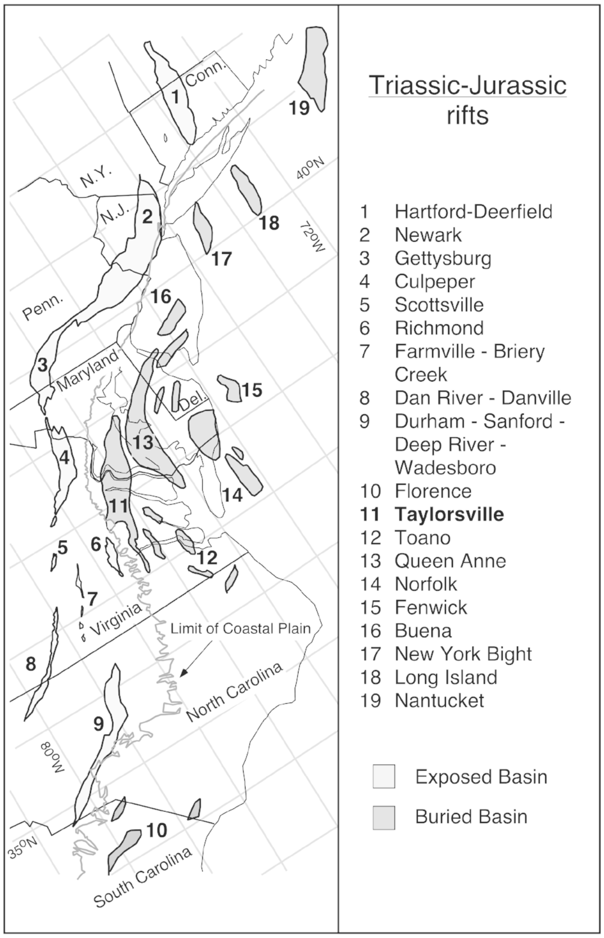

FIGURE 3.1 Triassic–Jurassic age rift basins of the mid-Atlantic coast, showing the onshore exposed basins of the Newark Supergroup and rifts covered by Coastal Plain and continental shelf deposits. The Taylorsville basin consists of both covered and exposed portions. (Adapted from Olsen 1990 and Benson 1992)

hypotheses on rift evolution (Schlische 1991; Schlische and Anders 1996), half-graben filling models (Schlische and Olsen 1990), rift and postrift tectonic development of passive margins (Withjack, Schlische, and Olsen 1998), and climatic controls on continental rift sedimentation (Olsen 1986, 1990).

The Taylorsville Basin

The Taylorsville basin, located in Virginia and Maryland (figure 3.1), is one of the largest of the Triassic–Jurassic rift basins in eastern North America (Wilkes, Johnson, and Milici 1989; Benson 1992). It is approximately 175 km long by 50 km wide (Benson 1992) and contains a thickness of more than 4 km of sedimentary rocks (figure 3.2). Most of the Taylorsville basin is buried beneath Coastal Plain deposits, but a small portion is exposed in the vicinity of Ashland, Virginia. The subsurface portion of the basin extends from the edge of the area of exposures near Ashland, Virginia, northeast to eastern and central Maryland (Hansen 1988; Wilkes, Johnson, and Milici 1989; Benson 1992). The thin southeastern extension of the Taylorsville basin (Studley subbasin) is located in the vicinity of Hanover and Studley, Virginia. The approximate boundaries of the Studley subbasin have been delineated by water wells, geotechnical test wells, and geophysical surveys (Daniels 1974; Daniels and Onuschak 1974; Weems 1980b; Shomo 1982), including seismic line TX85T10 used in this study (figure 3.2).

The exposed portion of the Taylorsville basin occupies an area of approximately 200 km^2 located north and northwest of the growing municipality of Ashland in Hanover County, Virginia (figure 3.2). Triassic rocks are exposed in the gullies, creeks, and river valleys that cut through the overlying and blanketing Cretaceous and younger Coastal Plain sand and gravel. Unlike most of the other Triassic–Jurassic rift basins, there are no quarries or extensive road cuts in the Mesozoic rocks of the Taylorsville basin. The extreme southwestern terminus of the Taylorsville basin is also covered by Coastal Plain deposits (Goodwin 1981; Weems 1981; Robbins and Weems 1988), but its presence was revealed by a temporary exposure (Weems 1980a) and by one water well that penetrated Triassic rocks south of Ashland (Goodwin 1970).

The discovery of Triassic rocks beneath Coastal Plain deposits in eastern Virginia and in central and eastern Maryland was a result of deep drilling and geophysical surveys (Richards 1945, 1948, 1949). In the 1950s, deep stratigraphic test wells for gas storage drilled in the Brandywine, Maryland, area (Prince Georges County) encountered red clastic sedimentary rocks of probable Triassic age (Richards 1945, 1948, 1949; Edwards 1970). Deep test wells in King George (Mixon and Newell 1977) and Bowling Green, Virginia (Richards 1949; Hubbard, Rader, and Berquist 1978), also encountered red clastic rocks of probable Triassic age beneath Coastal Plain deposits. Moreover, the wells encountering probable Triassic rocks were found to be situated along a NE–SW-trending zone of Coastal Plain faults and geophysical lineaments (Jacobeen 1972; Mixon and Newell 1977).

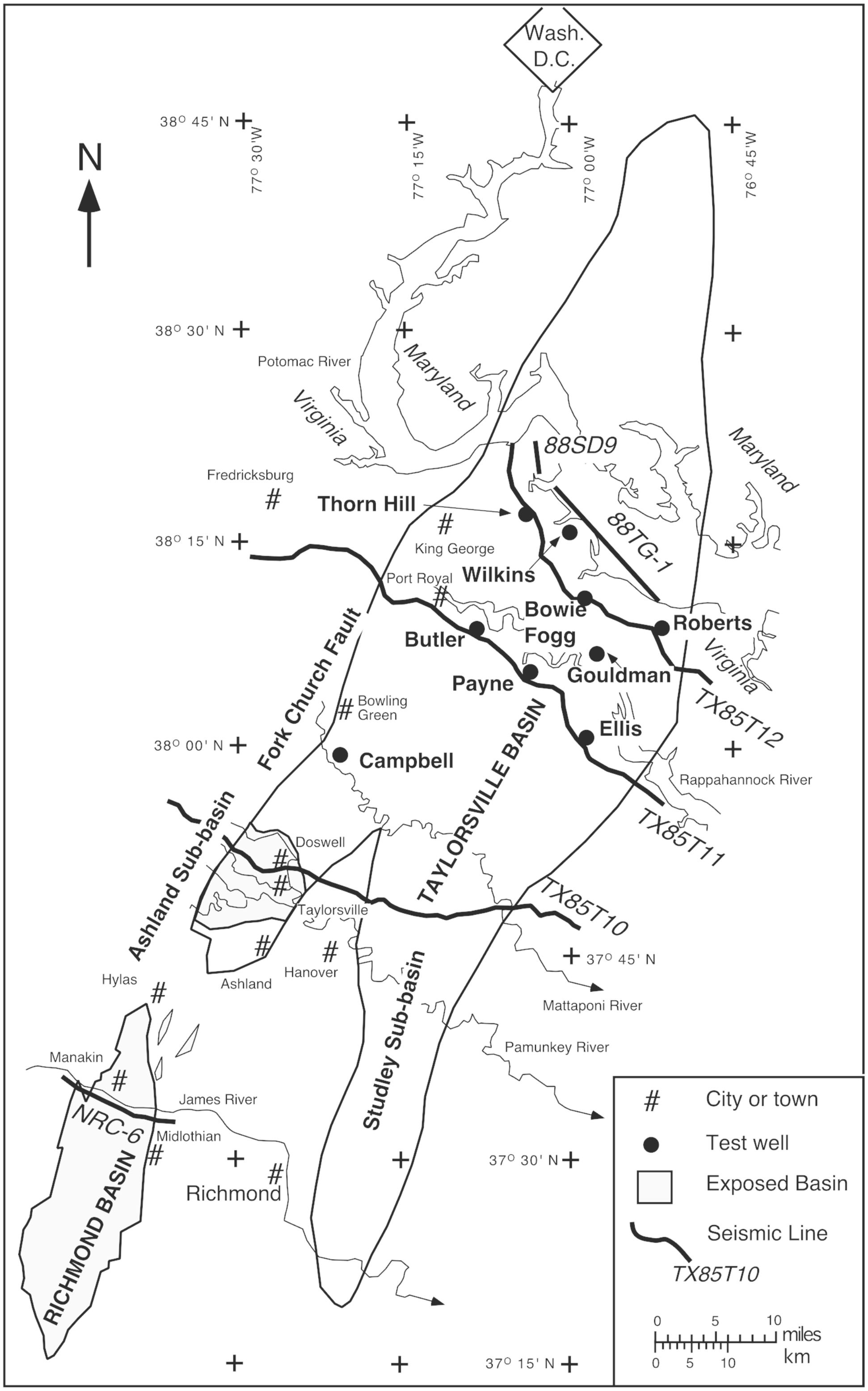

FIGURE 3.2 The Taylorsville and Richmond basins, showing key geographic features and locations of coreholes, test wells, and seismic reflection profiles discussed in this chapter. (Adapted from Shomo 1982; Schorr 1986; Wilkes 1988; Benson 1992; and Texaco, Inc., exploration plat [1993]. Base map from DeLorme Atlas of Virginia [1995]).

Wentworth and Mergner-Keefer (1983) clearly showed a connection between the exposed Taylorsville basin and the Triassic rocks encountered in the Brandywine, Maryland, area and suggested, perhaps overenthusiastically, that this basin connects with the Hartford basin more than 400 km to the northeast. Hansen and Edwards (1986) stated that the Brandywine area is near the northwestern boundary of a buried rift basin of indeterminate size. Hansen (1988) combined data from geophysical surveys, structural trends, and drilling to delineate the approximate boundaries of a probable subsurface extension of the Richmond–Taylorsville rift basin terrane in Maryland but did not continue the basin southwestward to the well in Bowling Green, Virginia, that encountered likely Triassic rocks (Mixon and Newell 1977) or to the exposed Taylorsville basin. Hansen (1988) tentatively named the subsurface basin the Queen Anne basin.

Based on seismic and drill hole data, Benson (1992) showed the connection of the exposed Taylorsville basin to the sedimentary basin underlying the Coastal Plain in the Bowling Green and King George, Virginia, area. Benson (1992) showed the Queen Anne basin of Hansen (1988) in the Brandywine, Maryland, area as an adjacent, separate basin and also showed a narrow southeastern extension of the Taylorsville basin based on drill hole, aeromagnetic, and gravity surveys (Daniels and Onuschak 1974; Shomo 1982). Weems (1980b) named this area the Studley basin because many of the shallow water wells and test borings that encountered probable early Mesozoic rift basin rocks were located near the town of Studley, Virginia (Daniels 1974; Daniels and Onuschak 1974).

The Taylorsville basin was the focus of oil and gas exploration in the mid- to late 1980s and the early 1990s (Cochran 1985; Wilkes 1988; Milici et al. 1991; Weaver and Schwartz 1991). Oil and gas shows have been reported from the Taylorsville basin (Milici et al. 1991; Weaver and Schwarz 1991), but in spite of encouraging shows no proven oil and gas reserves were identified in the Taylorsville basin (Weaver and Schwarz 1991).

Previous Work

In comparison with the strata of other basins of the Newark Supergroup—for example, those of the Hartford and Newark basins—the strata of the Taylorsville basin were formally named only recently (Weems 1980a), perhaps due to limited interest in the basin resulting from its small size, its lack of apparent economic mineral resources (Rogers 1841), or the overshadowing importance of the neighboring larger and coal-producing Richmond basin (Wilkes 1988).

Weems (1980a, 1981, 1986) first proposed the stratigraphic nomenclature for the exposed portion of the Taylorsville basin based on his graduate thesis in geological and paleontological studies (Weems 1974, 1977). In the first stratigraphic scheme for the Taylorsville basin, Weems (1974) proposed four formations, from base to top: the Falling Creek Formation, the Gum Tree Conglomerate, the Stagg Creek Sandstone, and the Cherrydale Formation. Weems (1980a) subsequently renamed and grouped all the formations into the Doswell Formation, which contains the entire section of the Ashland subbasin. The Doswell Formation of Weems (1980a) contains three members: the basal fluvial Stagg Creek Member, the middle lacustrine Falling Creek Member, and the upper fluvial Newfound Member. The 600 to 1,200 m thick Newfound Formation includes a sandstone-conglomerate facies and a sandstone-siltstone facies (figure 3.3).

Cornet and Olsen (1990) proposed a substantial reinterpretation of the stratigraphy of Weems (1980a) based on pollen biostratigraphy, lithostratigraphy, and reference to the then-proprietary seismic data of Texaco (figure 3.3). Cornet and Olsen (1990) retained the Doswell Formation as a unit that includes all the strata in the basin, but separated the Falling Creek Member into three divisions: lower lacustrine, middle fluvial, and upper lacustrine. Cornet and Olsen (1990), however, did not rename or formally redefine the Falling Creek stratigraphy, but used informal names to identify the newly recognized lacustrine and fluvial subdivisions of Weems's (1980a) Falling Creek Member. It is important to note that Cornet and Olsen (1990) did recognize that the Falling Creek is not a homogeneous lacustrine interval, but rather consists of definable subdivisions that are traceable in outcrop.

The stratigraphy of Weems (1980a, 1981, 1986) was followed by that of Milici et al. (1991, 1995) in their study of the subsurface portion of the Taylorsville basin. Milici et al. (1995) reviewed cuttings from a portion of the Wilkins test well, geophysical logs from the six continuous coreholes, and the NAB-11A seismic

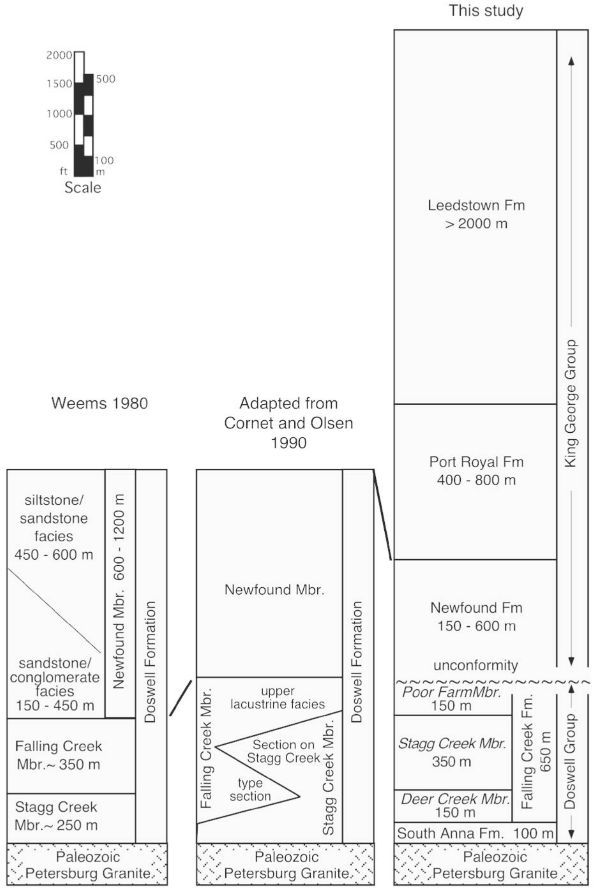

FIGURE 3.3 Comparison of revised stratigraphy of the Taylorsville basin with previous stratigraphy proposed by Weems (1980a) and by Cornet and Olsen (1990).

profile through the central portion of the basin. The seismic line NAB-11A of Milici et al. (1995) is the same as the eastern two-thirds of the seismic line TX85T11, which crosses the entire basin (figure 3.2).

Data and Methods

The stratigraphic and structural analysis of the Taylorsville basin in this chapter is based primarily on petroleum exploration data generated by Texaco and Exxon, including more than 6,800 m of continuous core, more than 7,000 m of test well cuttings, and approximately 150 km of seismic reflection profiles, supplemented by examination of outcrops. I obtained samples for paleomagnetic analysis from the experimental half-core. I also evaluated and interpreted four seismic profiles (figure 3.2) to determine the structural history of the Taylorsville basin (LeTourneau 1999).

Cuttings and cores from the test wells in the subsurface portion of the Taylorsville basin reveal a complete stratigraphic section from basement up to the overlying Coastal Plain deposits. The test wells are located mainly in the vicinity of the Potomac and Rappahannock Rivers, and one corehole is located near the western margin of the basin just south of Bowling Green, Virginia (figure 3.2). The names, locations, and depths of the wells drilled in the Taylorsville basin are summarized in table 3.1. The test wells were measured originally in the English system according to U.S. industry standards; well depths were converted to metric for this report.

Well Cuttings

Approximately 7,000 m of cuttings from the Gouldman, Thorn Hill, and Wilkins wells were logged in this study by visual inspection of color and grain size in cuttings provided in 9.1 m intervals (cuttings provided in 30 ft. intervals) (figure 3.4). The well cuttings were categorized by lithology as a percentage of the 9.1 m sample interval totaling 100%: for example, 30% black shale, 30% gray siltstone, 40% gray sandstone. The relative width of the symbols in figure 3.4 indicates the percentage of each lithology in the sample interval. Data were smoothed using a moving average with a 20 ft. window to identify major lithologic trends and to facilitate comparison with the cores.

The 3,090 m (10,135 ft.) deep Wilkins test hole (figure 3.4) drilled 2,524 m (8,280 ft.) of Triassic strata and encountered basement at 3,048 m (10,000 ft.). Cuttings from this well show the vertical arrangement of strata in the central portion of the basin. Comparison of the lithostratigraphy from this well with that of the other test holes and coreholes reveals that the architecture of the basin fill and lateral facies changes across the basin. This information, coupled with the seismic interpretation, provides the framework for understanding the stratigraphy of the exposed portion of the basin. The Wilkins well penetrated approximately 150 m (500 ft.) of black shale and gray sandstone overlying the metamorphic basement. The black shale strata are overlain by 150 m (500 ft.) of red and gray sandstone and conglomerate. The next lithologic division in vertical section is a thick interval of black shale and gray sandstone occurring from approximately 2,740 to 1,980 m well depth (9,000 to 6,500 ft.). The upper portion of the Wilkins well consists of red

TABLE 3.1 Summary of Subsurface Explorations in the Taylorsville Basin

Well Name	*Date*	*Interval (depth, ft.)*	*Thickness Triassic*	*Latitude/ Longitude*	*Quadrangle/County*
Campbell (CH1)	1986	0430–5500† ft. continuous core	5070 ft. (1545 m)	37° 58′ 42″N 77° 36′ 12″W	Penola, Va. Caroline Co., Va.
Butler (CH2)	1986	1125–5500 ft. continuous core	4375 ft. (1334 m)	38° 08′ 48″N 77° 08′ 48″W	Port Royal, Va. Caroline Co., Va.
Payne (CH3)	1986	1365–5500 ft. continuous core	4135 ft. (1260 m)	77° 04′ 00″N 38° 05′ 10″W	Loretto, Va. Essex Co., Va
Ellis (CH4)	1986	1680–5500 ft. continuous core	3820 ft. (1164 m)	76° 58′ 44″N 38° 00′ 31″W	Champlain, Va.–Md. Essex Co., Va.
Bowie-Fogg (CH5)	1986	1840–5500 ft. continuous core	3660 ft. (1116 m)	76° 58′ 30″N 38° 10′ 42″W	Colonial Beach South, Va. Westmoreland Co., Va.
Roberts (CH7)	1986	2045–3405 ft. continuous core basement at 3400	1360 ft. (415 m)	76° 52′ 12″N 38° 08′ 32″W	Stratford Hall, Va.–Md. Westmoreland Co., Va.
Gouldman	1991	1810–8025 ft. cuttings basement at 7840	6215 ft. (1894 m)	38° 06′ 15″N 76° 57′ 20″W	Champlain, Va.–Md. Westmoreland Co., Va.
Thorn Hill	1992	1840–10215 ft. cuttings	8375 ft. (2553 m)	38° 16′ 30″N 77° 04′ 17″W	Dahlgren, Va. Westmoreland Co., Va.
Wilkins	1989	1720–10135 ft. cuttings basement at 10000	8415 ft. (2565 m)	38° 14′ 29″N 77° 00′ 45″W	Dahlgren, Va. King George Co., Va.
Total			45,425 ft. (13,846 m)		

* Core hole number.

† Datum is drill rig kelly bushing.

and gray sandstone and siltstone, with subordinate amounts of conglomerate. Red-colored strata dominate the 1,980 to 1,520 m (6,500 to 5,000 ft.) interval and again become abundant above 910 m (3,000 ft.), with approximately 460 m (1,500 ft.) of gray sandstone between 1,520 and 1,070 m (5,000 to 3,500 ft.).

The 3,110 m (10,215 ft.) Thorn Hill well (figure 3.4) penetrated 2,553 m (8,375 ft.) of rift basin strata but did not encounter basement. The bottom of the Thorn Hill well drilled approximately 150 m (500 ft.) of red and gray coarse sand and minor conglomerate. From approximately 2,960 to 2,500 m (9,700 to 8,200 ft.), core-depth lacustrine black shale and gray siltstone and sandstone were encountered in Thorn Hill. The interval between 1,890 and 2,195 m (6,200 to 7,200 ft.) is characterized by gray sandstone and red siltstone, and from 2,195 to 1,951 m (7,200 to 6,400 ft.) sparse cuttings of black shale are found with the predominantly gray clastics. Above 1,951 m (6,400 ft.) core depth, the Thorn Hill well consists of interbedded gray sandstone with subordinate amounts of red sandstone, siltstone, and conglomerate that increase toward the top of the well.

The Gouldman well (figure 3.4) drilled through approximately 1,894 m (6,215 ft.) of red and gray rift basin strata and penetrated the Paleozoic schist basement rocks at 2,450 m (8,025 ft.) well depth. From 2,450 to 2,134 m (8,025 to 7,000 ft.), the well encountered gray sandstone and siltstone with smaller amounts of red sandstone and coal, as well as trace amounts of black shale. From 2,134 to 1,520 m (7,000 to 5,000 ft.) well depth, the strata consist predominantly of red siltstone and sandstone, and the interval from 1,520 to 760 m (5,000 to 2,500 ft.) is mostly gray sandstone. Above 760 m (2,500 ft.), red sandstone again characterizes the section.

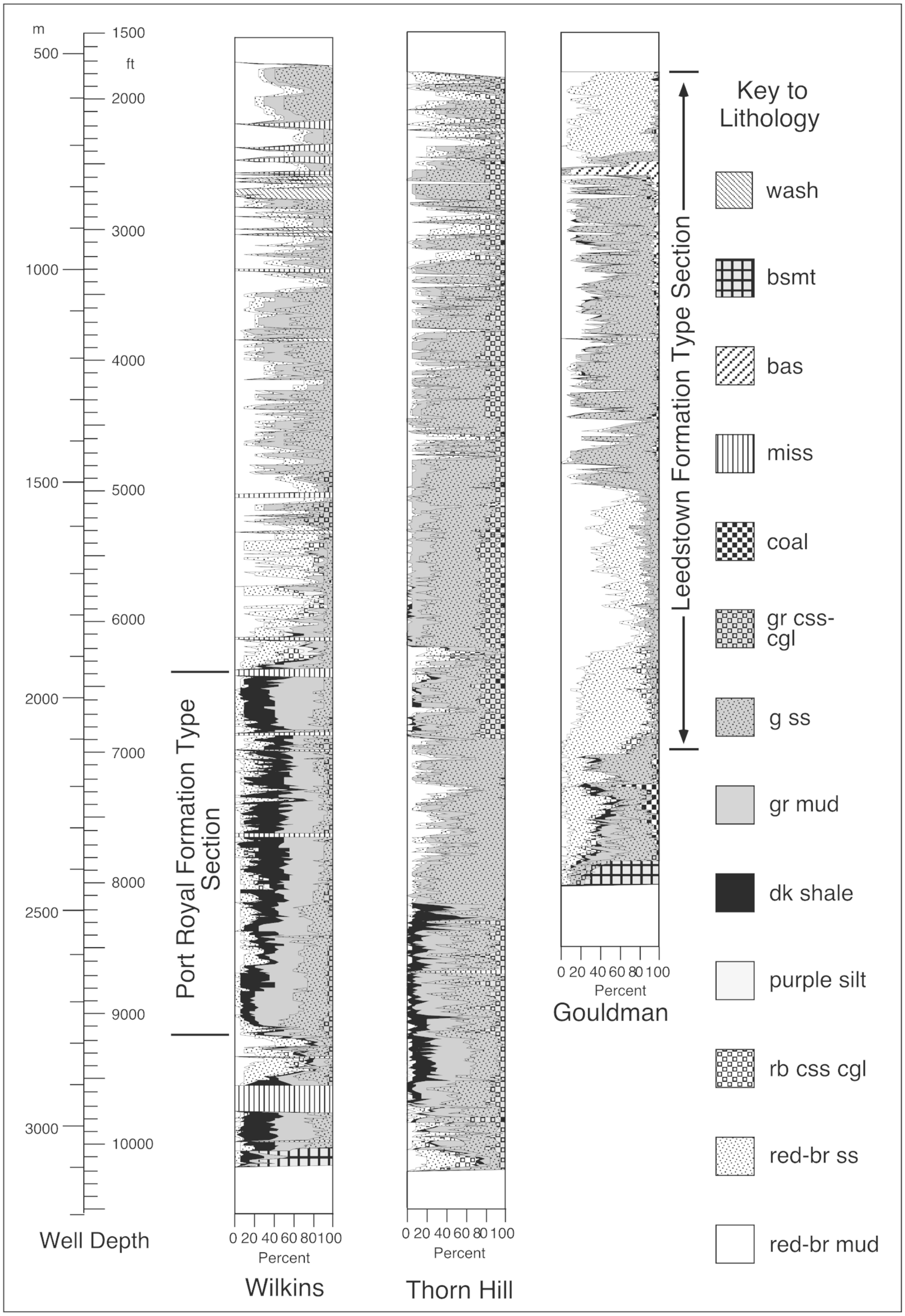

FIGURE 3.4 Geologic logs of cuttings from deep test holes in the Taylorsville basin. For locations, see figure 3.1. The *x*-axis scale is percent of lithology in 3.1 m (10 ft.) intervals; for example, at 2,743 m (9,000 ft.) depth in the Wikins test hole cuttings consist of 5% red sandstone, 10% black shale, 40% gray mudstone, 40% gray sandstone, and 5% gray coarse sandstone and conglomerate; *wash,* post-Triassic passive margin sand; *bsmt,* basement rocks; *bas,* basalt/diabase; *miss,* missing; *coal,* coal; *gr css-cgl,* gray coarse sandstone and conglomerate; *g ss,* gray medium to fine sandstone; *gr mud,* gray siltstone and claystone; *dk shale,* dark-gray to black shale; *purple silt,* purple to light-gray siltstone; *rb css cgl,* red-brown coarse sandstone and conglomerate; *red-br ss,* red-brown medium to fine sandstone; *red-br mud,* red-brown siltstone and claystone.

Cores

Although the cuttings provide a complete reference section of the Taylorsville basin, the continuous cores (figure 3.5) provide high-quality, unweathered rock samples for identification of grain size, color, sorting, sedimentary structures, and bedding contacts. Texaco sectioned the continuous cores longitudinally into experimental and archive halves to facilitate observation of sedimentary structures and textures. The cores contain fossils, including fish scales, a single archosaur scute, conchostracans, ostracodes, and palynomorphs, as well as plant foliage, branches, and trunks. I prepared descriptive logs of color, grain size, sedimentary structures, and special features for 5,300 m (17,240 ft.) of continuous core from the Bowie-Fogg, Butler, Campbell, and Payne wells (figure 3.5). The lithologic patterns observed in the cores and cuttings provided the basis for correlation of the basin strata.

Approximately 1,545 m (5,000 ft.) of rift basin rocks were recovered from the Campbell core (figure 3.5). The core was drilled near the western fault margin of the Taylorsville basin, and coarse conglomerate and sandstone with interbedded black shale dominate the cored interval. The Campbell core consists of three main divisions: interbedded black shale and conglomerate from 1,676 to 910 m (5,500 to 3,000 ft.) core depth; predominantly red sandstone and siltstone with gray sandstone and siltstone from 910 to 305 m core depth; and interbedded black shale and gray sandstone from 305 to 130 m (1,000 to 430 ft.) core depth.

The Butler well cored 1,334 m (4,375 ft.) of mostly gray fine sandstone and siltstone, with subordinate amounts of red sandstone and siltstone. Significant quantities of greenish-black, coarse-grained diabase were encountered in the Butler well (figure 3.5). The Payne well was drilled through approximately 1,260 m (4,135 ft.) of mostly red-colored sandstone and siltstone, with increasing amounts of gray sandstone below about 1,220 m (4,000 ft.) core depth. The Bowie-Fogg corehole was drilled through approximately 1,116 m (3,660 ft.) of mostly gray sandstone and siltstone, with red strata occurring primarily below 1,490 m (4,900 ft.) and above 670 m (2,200 ft.) core depth (figure 3.5).

The Wilkins, Gouldman, and Roberts test wells penetrated basement rocks, consisting of schist, chloritic schist, and minor granite or granite-gneiss (table 3.1; figure 3.5). The basement rocks recovered from the test wells are consistent with the types of crystalline rocks surrounding the Taylorsville basin (Bobyarchick and Glover 1979; Weems 1981, 1986).

Revised Stratigraphy of the Taylorsville Basin

The new subsurface information from the Taylorsville basin necessitates a reevaluation and revision of the stratigraphy of the outcropping part of the basin (figure 3.3). The earlier stratigraphic interpretations of Weems (1980a) and of Cornet and Olsen (1990) were based on observations in this outcrop area. The subsurface information presented here adds approximately 3 km to the known stratigraphic section of the basin. The revised stratigraphy provides a new perspective on the structure and evolution of the Taylorsville basin and facilitates comparison of the rocks with strata in the other Newark Supergroup rifts. It follows the guidelines established by the North American Commission on Stratigraphic Nomenclature in the 1983 North American Stratigraphic Code (NACSN 1983). The stratigraphic names that Weems (1980a) proposed for rocks in the outcrop area have been retained along with the type sections that Weems designated (NACSN 1983:arts. 7c and 19e), although the ranks of his stratigraphic divisions and stratigraphic correlations have been revised.

Details of designated type sections and nomenclature are presented in the appendix to this chapter, and a comparison of earlier stratigraphic schemes and my revised stratigraphy is shown in figure 3.3.

The most important revision is the recognition that the Taylorsville basin stratigraphic section consists of two unconformity-bound sequences (discussed later in the chapter), which I recognize in formal lithostratigraphic group names (figure 3.3). I designate the lower unconformity-bound sequence the Doswell Group by raising the rank of Weems's (1980a) Doswell Formation and revising it to include only the new basal unit (South Anna Formation) and an upper unit (Falling Creek Formation). The latter formation results from raising the rank of Weems's (1980a) Falling Creek Member. The Falling Creek Formation itself is now divided into three members: the basal, black, and gray Deer Creek Member; the middle, mostly gray Stagg

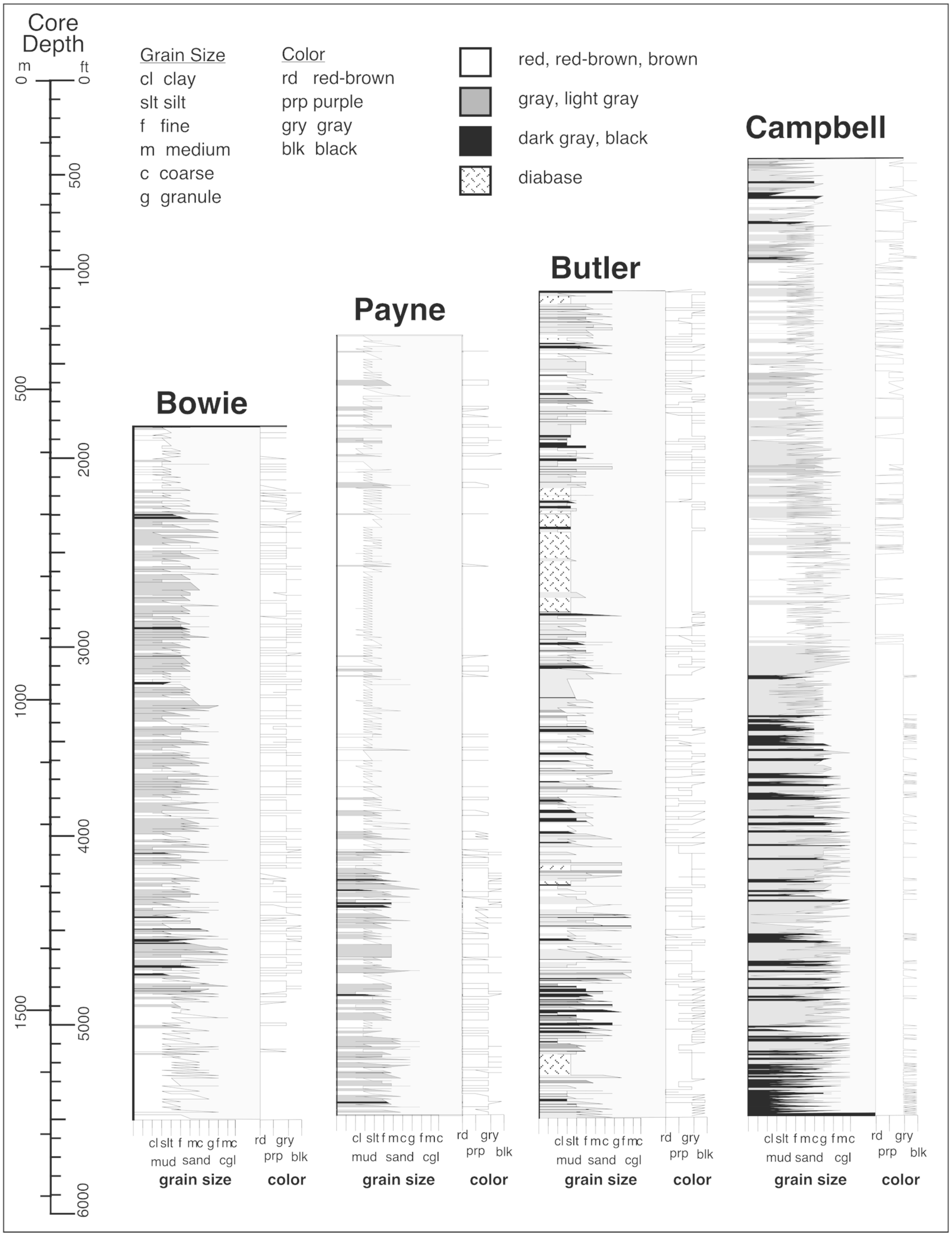

FIGURE 3.5 Grain size and color plots of Taylorsville basin coreholes evaluated in this study. Each core was drilled to 1,676 m (5,500 ft.) well depth. A fragment of dermal armor (scute) from *Aetosaurus arcuatus* (*Stegomus arcuatus*) was recovered from the Payne core at 666 m (2,184 ft.) well depth.

Creek Member; and the upper Poor Farm Member. The Deer Creek and Poor Farm Members are new and characterized by a predominance of black shale and gray sandstone, whereas the sandy Stagg Creek Member is a revision of Weems's (1980a) member. Based largely on the outcrops along Deer Creek, the predominantly gray sandstone and mudstone Stagg Creek Member, as reflected in the type section in adjacent Stagg Creek (Weems 1980a), is shown to lie between two black shale–dominated units (Deer Creek and Poor Farm Members), rather than between basement and a major black shale unit (Falling Creek Member of Weems 1980a). The newly designated South Anna Formation—consisting of black, gray, and red sandstone, mudstone, and conglomerate—demonstrably rests on basement and is overlain by the Falling Creek Formation.

The King George Group unconformably overlies the Doswell Group (for details, see the appendix). This new group consists of a basal, gray and red sandstone- and conglomerate-dominated unit, the Newfound Formation; a middle unit mostly of gray and black mudstone and sandstone, the new Port Royal Formation; and an upper red and gray mudstone- and sandstone-dominated interval, the new Leedstown Formation. The latter two formations are recognized only in the subsurface and comprise most of the thickness of the basin fill. The type sections of the Port Royal and Leedstown Formations are in the Wilkins and Gouldman wells, respectively (figure 3.4). The Newfound Formation derives from raising the rank of Weems's (1980a) Newfound Member and removing it from his Doswell Formation (now Doswell Group) because of the intervening unconformity and dramatic change in facies. In my revised stratigraphy, the Newfound Formation represents a coarse fluvial interval overlying the unconformity at the base of the King George Group tectonostratigraphic sequence. Therefore, it is logical to link it with the formations of the upper sequence rather than with the underlying Doswell Group of the lower tectonostratigraphic sequence.

The industry data, especially the deep test wells tied to the seismic sections and cores, show unequivocally the superposition of the units described here. The data show that far from being a tiny part of the Newark Supergroup, the Taylorsville basin section is one of the thickest basin-fill sections and spans one of the longest time intervals of any of the Newark rifts.

SEDIMENTOLOGY

The rocks of the Taylorsville basin, as observed in core and outcrop, consist of red, light- to dark-gray, and black conglomerate, sandstone, siltstone, and minor shale, which fall into several genetically related successions: red fluvial cycles (periodicity not implied), gray fluvial cycles, dark shale cycles, fluvial-shallow lacustrine beds, alluvial-fan conglomerates, and coal beds.

Red Fluvial Rocks

Fining-up red fluvial beds form most of the Leedstown Formation and part of the Newfound and South Anna Formations (figure 3.3). The base of the fining-up redbeds consists of either thick, cross-stratified sandstone or thin, ripple cross-laminated sandstone and silty sandstone (figure 3.6). The thick fining-up beds range between approximately 3 and 4.5 m (10 to 15 ft.) thick and have coarse intraformational mudstone and carbonate peloid conglomerate in trough and planar cross-stratified coarse to fine sandstone with scoured lower contacts. The thick beds fine up to current and climbing ripple cross-laminated medium to fine sandstone overlain by planar-laminated silty fine sandstone commonly containing burrows and root traces; soft sediment deformation is common in this middle interval of the cycle. The upper portion of the thick red cycles consist of silty fine sandstone and sandy siltstone with carbonate nodules and gray-green mottled horizons. The uppermost portion of the thick red cycles variably consists of massive, fine sandy siltstone and clayey siltstone with burrows, root traces, scarce desiccation cracks, soft sediment deformation, and brecciated zones (figure 3.6).

The thin red cycles range from approximately 0.5 to 3 m (10 ft.) thick and are recognized by the presence of ripple cross-laminated medium to fine sandstone and the absence of meter-scale cross-stratified coarse sandstone and intraformational conglomerate, which typify the thick red cycles (figure 3.6). In the thin red cycles, the basal sandstone is typically thin in comparison with the overlying fine sandy siltstone, which contains burrows, root traces, carbonate nodules, gray-green mottles, and scarce desiccation cracks (figure 3.6).

The upper portion of both the thick and thin red cycles consists of massive mudstone. Within the mas-

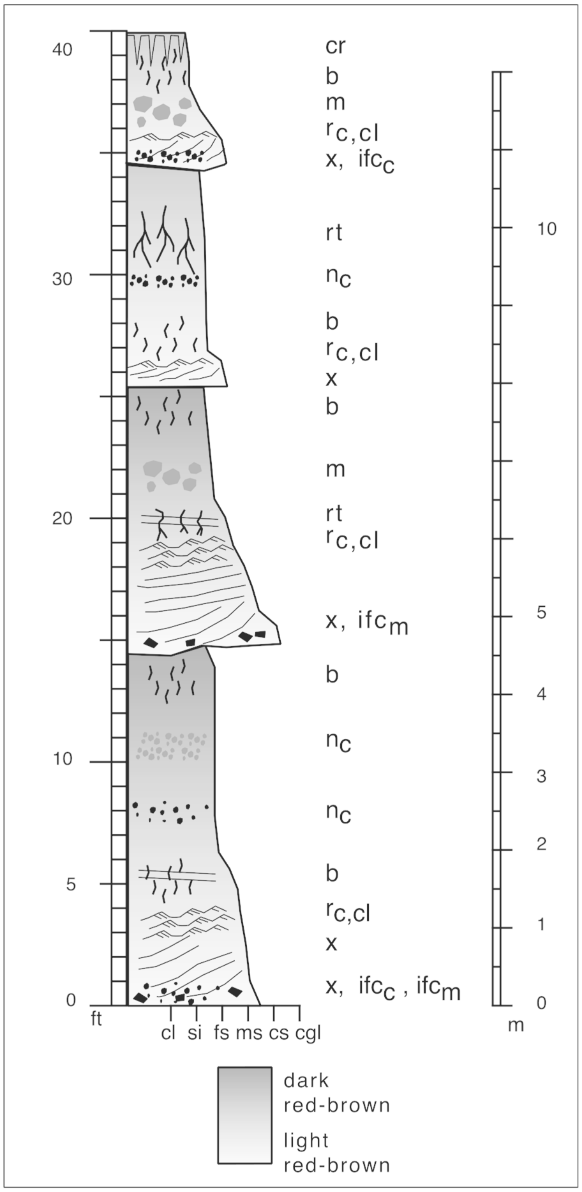

FIGURE 3.6 Schematic diagram of typical red fluvial cycles identified in Taylorsville basin coreholes, particularly the Payne core; *b,* burrows; *cr,* desiccation cracks; *ifc*$_c$, carbonate clast intraformational conglomerate; *ifc*$_m$, mudclast intraformational conglomerate; *m,* gray-green mottles; *n*$_c$, carbonate nodules; *r*$_c$, current ripples; *r*$_{cl}$, climbing ripples; *rt,* root casts; *x,* crossbedding.

sive mudstone, three divisions are recognized. The lower portion of the mudstone usually contains disseminated carbonate peloids (0.1 to 0.5 cm) and small nodules (0.5 to 3 cm) with variable quantities of root traces and burrows. The middle portion typically consists of greenish-gray to bluish-gray mottles or horizons, often with carbonate peloid accumulations, within the red and red-brown mudstone matrix. The upper zone is not always present but contains burrows, roots, and, less commonly, desiccation cracks. Faint and parallel horizontal lamination and ripple cross-lamination are often observed in portions of the massive mudstone not disrupted by burrows, roots, or brecciation (figure 3.6).

The red cycles were deposited in fluvial channel and floodplain environments. The thick red cycles are fluvial channel and floodplain deposits. The intraformational mudclast conglomerate commonly found at the base of the channel sandstone indicates the recycling of the floodplain areas during stream channel migration and avulsion. The thin red cycles are channel levee and crevasse splay sand deposited on floodplains adjacent to the main channels. The variability in thickness of the thin red cycles indicates the episodic deposition in variable bankfull discharge conditions. The channel margin levee environment is preserved as climbing-ripple and ripple cross-lamination and planar lamination. The upper portions of the red cycles are planar-and ripple-laminated floodplain mudstones that have undergone extensive postdepositional modification by biomechanical soil-forming processes, including burrowing, penetration by roots, and brecciation caused by repeated wetting and drying.

Gray Fluvial Rocks

The gray fluvial cycles typically are approximately 3 to 4.5 m (10 to 15 ft.) thick and fine upward from very coarse sandstone and conglomerate to organic-rich silty fine sandstone and dark clayey siltstone (figure 3.7). Gray fluvial rocks are found in the South Anna, Falling Creek, Newfound, and Leedstown Formations. The lower contacts of the gray cycles are erosional, scour into the underlying fine-grained beds, and commonly contain gray mudstone and siltstone intraclasts. The lower sandstone typically is crossbedded with both planar and tangential foresets and grades up to climbing and current ripple cross-lamination. Planar lamination dominates the middle portion of the gray sandstone cycles, and soft sediment deformation is common. The sandstone fines up to planar-laminated and ripple cross-laminated fine sandstone, silty fine sandstone, and fine sandy siltstone. The uppermost portion of the gray cycles consists of dark-gray fine sandstone and siltstone ranging from 10 to 50 cm

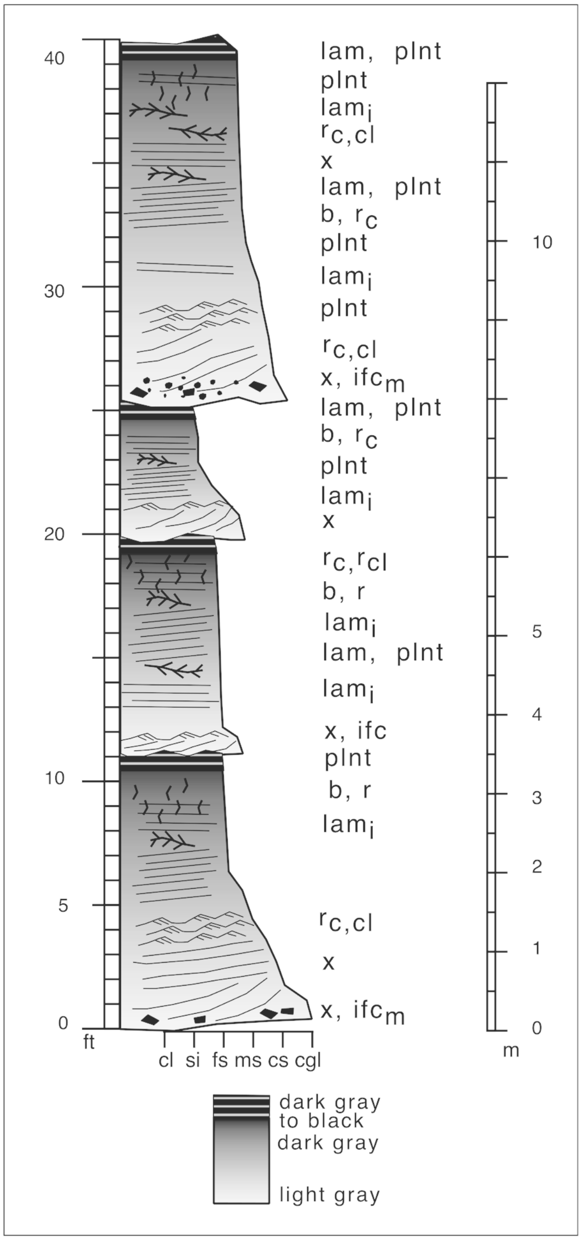

FIGURE 3.7 Schematic diagram of typical gray fluvial cycles identified in Taylorsville basin coreholes, particularly the Bowie core; *b,* burrows; *cr,* desiccation cracks; *ifc*$_c$, carbonate clast intraformational conglomerate; *ifc*$_m$, mudclast intraformational conglomerate; *lam,* planar lamination; *lami*$_i$, inclined lamination; *m,* gray-green mottles; *n*$_c$, carbonate nodules; *plnt,* megafossil plant remains; *r*$_c$, current ripples; *r*$_{c1}$, climbing ripples; *rt,* root casts; *x,* crossbedding.

thick. This upper division is typically thin in comparison with the lower sandstone portion of the cycle. Plant remains, including stems, branches, and leaves, are common throughout the coarser portions of the gray cycles. Layers of fine sandstone and siltstone found near the upper contact of the gray cycles contain a significant amount of plant debris. Near the margins of the basin, the gray cycles are predominantly coarse to fine conglomerate. In the Campbell core, for example, cobble and boulder conglomerate beds with obscure stratification are common (figure 3.5). As observed in the continuous cores (Bowie-Fogg, Butler, Payne) the gray fluvial cycles repeat throughout approximately 600 m (2,000 ft.) of vertical section (figures 3.5 and 3.7).

Gray fluvial deposits, including trough cross-stratified sandstone and conglomerate, and fining-up coarse sandstone through siltstone, are also observed in the outcrop area. The trough cross-stratified sandstone may contain thin discontinuous silt layers and lenses, significant quantities of megafossil plants, plant debris, and thin coaly lenses or layers. The trough cross-stratified sandstone was deposited in very sandy, high-energy braided rivers. The fining-up sandstone to siltstone beds are similar to the fining-up gray cycles observed in the Taylorsville basin cores. The depositional environments for the gray cycles are fluvial channels, are perennially saturated to flooded paludal environments (hydric paleosols) in heavily vegetated channel margin and floodplain areas, and are inferred to represent more humid conditions than that interpreted for the red fluvial cycles. The gray cycle overbank deposits represented by planar-laminated organic-rich siltstone in the cores are thin and typically form only the upper 5 to 20% of the cycle, in comparison with the red floodplain mudstone, which may form up to 75% of the red cycles.

Dark Lacustrine Shale

Dark shale beds form most of the Port Royal Formation and a large part of the Falling Creek Formation. Dark-gray and black shale was observed in outcrop in the Campbell and Butler cores (figure 3.5) and in cuttings from the Wilkins, Thorn Hill, and Gouldman test wells (figure 3.4). The Wilkins well encountered dark shale in the Falling Creek Formation at 2,900 to 3,050 m well depth and in the Port Royal Formation at 1,900 to 2,750 m well depth. The Thorn Hill well penetrated approximately 460 m of Falling Creek dark shale at depths below 2,740 m, and it penetrated approximately 150 m of Port Royal shale at 1,950 to 2,100 m well depth. The lower 300 m of the Gouldman well encountered sparse black shale cuttings and interbedded coal in the eastern facies of the Port Royal Formation.

A characteristic feature of the dark shale cycles is dark-gray to black, finely laminated, clayey siltstone and silty shale. Fossil fish, conchostracans, and ostracodes may be common within certain beds. Planar- to ripple cross-laminated coarse to fine sandstone occurs in thin beds that fine upward. The dark shale beds typically range from 1 to 3 m in thickness and are underlain by fining-up gray cross-stratified to ripple- and planar-laminated fine sandstone. The overlying beds are coarsening-up sandstone and conglomerate with—from bottom to top—oscillatory ripples, climbing ripples, planar lamination, and cross-stratification. The depositional environments of the dark shale cycles are marginal (littoral) to deep-water lacustrine (profundal) separated by coarse- to fine-grained fluvial and alluvial-fan environments.

An association of fluvial and shallow lacustrine rocks consists of gray coarse to fine sandstone and gray to green-gray sandy siltstone and silty claystone. Sedimentary structures include low-angle planar cross-stratification and ripple cross-lamination in the sandstone and ripple cross-lamination, planar lamination, and soft sediment deformation (slump folds, load and flame structures) in the finer-grained units. Fossils include well-preserved plants (Cornet and Olsen 1990), unionid clams, disarticulated fish remains, and scarce reptile bones and teeth. This association is best observed in the Butler core and in outcrops along Stagg Creek and the South Anna River in the exposed basin.

Conglomerates

Alluvial-fan conglomerates are present in Taylorsville basin core and outcrop. The coarse conglomerates in the Campbell core include fan and fan-delta deposits. Red-colored, poorly sorted, silty, commonly matrix-supported, fining-and coarsening-up conglomerate beds capped by thin silt drapes are indicative of subaerial fan deposition (Campbell, Roberts, Ellis cores). Gray, coarsening-and fining-up, clast-supported boulder and cobble conglomerate associated with dark shale lacustrine and lacustrine turbidite beds are interpreted as fan-delta deposits. These fan-delta beds are observed in the Campbell core and along Deer Creek in Hanover County, Virginia. Clasts in the Campbell core range up to more than 1 m in diameter. In the exposed basin, very coarse boulder conglomerates have been reported from the western margin of the exposed basin on the North Anna River (Rogers 1836).

Coal

Several thin (10 to 25 cm) coal beds are found in the Poor Farm Member of the Falling Creek Formation in Poor Farm Park, Hanover County, Virginia. Several coal prospect pits were excavated in the past in the Poor Farm Member, including a pit in Poor Farm Park (Weems 1981). Coal was encountered in cuttings from the lowest portion of the Gouldman well, from approximately 7,000 to 7,900 m well depth (figure 3.4). The presence of coal in the Gouldman well within the Port Royal Formation lacustrine interval indicates a transition from deep-water lacustrine depositional environments in western portions of the basin to paludal environments in eastern portions.

Structural Geology

The correlation of stratigraphic sections observed in rock cores and cuttings is in part dependent on the interpretation of basin structure. I present only a brief summary of the structural geology of the basin based on seismic profiles, borehole geophysics, and exposed strata to support the stratigraphic interpretation. The Potomac River line (seismic profiles 88SD9 and 88TG-1, figure 3.2) illustrates the major structural features of the Taylorsville basin (figure 3.8).

The lower part of the Potomac River line, from approximately 2 to 1.5 seconds two-way travel time (twtt), shows an irregular contact between basin sediments and the metamorphic and igneous basement rocks. The Wilkins well, located approximately 2 km southeast of the Potomac River seismic profile, encountered basement at approximately 3,000 m well depth. The seismic reflections outline three small half-graben lying above basement. The lower half-graben have seismic reflections that diverge toward the west, where they are truncated by east-dipping reflectors

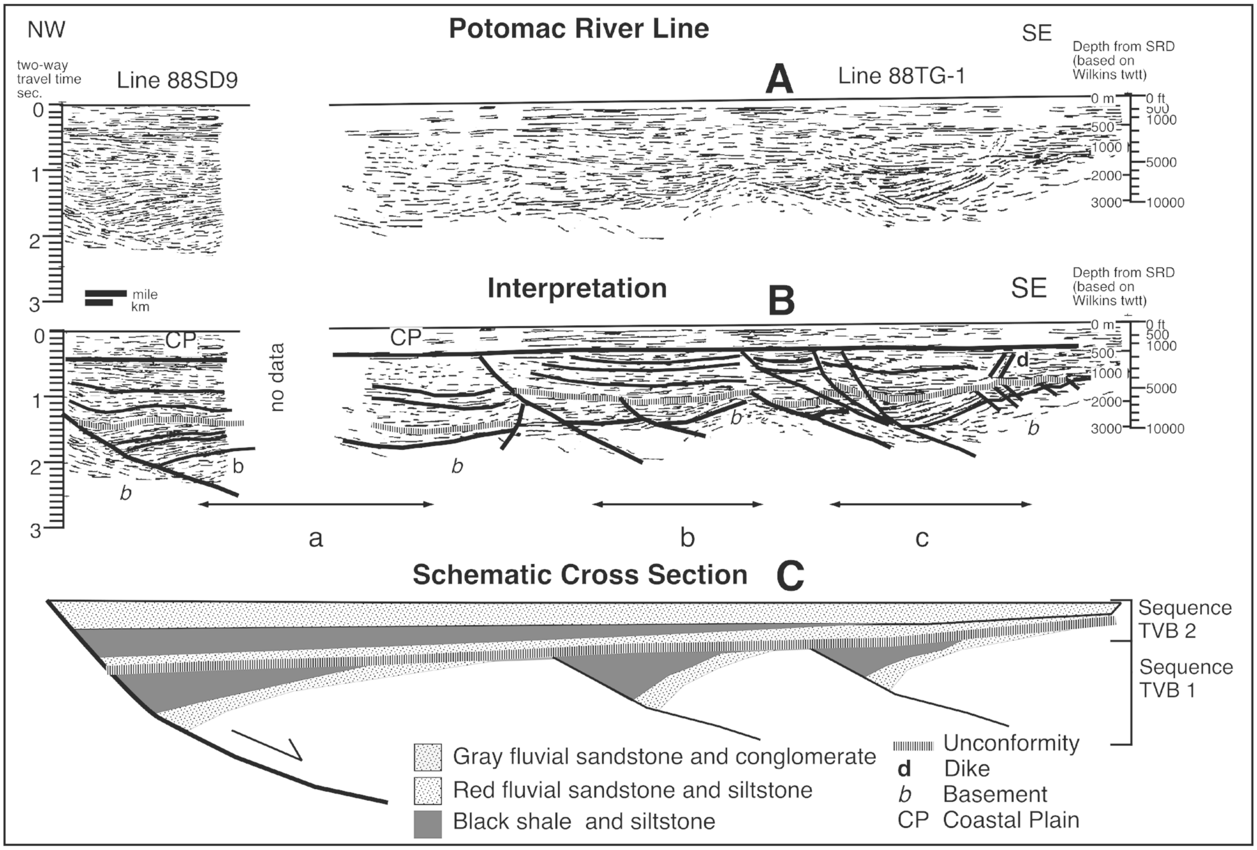

FIGURE 3.8 Drawing and interpretation of the Potomac River seismic line (lines 88SD9 and 88TG-1) with depth conversion of two-way travel time based on interval seismic velocity data from the Wilkins test well. (*A*) Line drawing of seismic lines. (*B*) Interpretation of seismic section tied to stratigraphic test well data; note that faults and folds show evidence of postrift inversion. (*C*) Schematic cross section restored to preinversion configuration. The schematic cross section illustrates the two-stage tectonic development of the rift, from a series of small, subregional half-graben in the lower part of the section to a regional-scale half-graben in the upper part of the section. Arrowed locations *a, b,* and *c* refer to the Sequence TVB 1 half-graben.

that are interpreted as the bounding faults of the small rift basins. The reflectors that define the small, lower half-graben are truncated by an unconformity that crosses the entire basin. The seismic reflections that are visible above the unconformity define the strata of the upper part of the Taylorsville basin, which were deposited in a large, regional-scale half-graben. The border fault for the upper half-graben is partially visible on the western side of the Potomac River profile. The strata within the basin dip toward both the west and the east as a result of folding and faulting that deformed the originally west-dipping strata of the half-graben border faults.

The interpretation of the Potomac River seismic profile indicates that the Taylorsville basin developed during two discrete episodes of rifting. The early stage of rifting formed a series of subregional half-graben that occupy the lower part of the Taylorsville basin. The upper part of the basin is a large half-graben that formed during the second stage of rifting. The upper and lower half-graben are separated by an unconformity defined by discontinuities in seismic reflections, abrupt lithologic changes observed in cores and cuttings, and changes in stratal attitude interpreted from dipmeter logs. Of the rift basins of the Newark Supergroup and the associated buried and offshore rifts, only the Taylorsville basin clearly shows the evolution from initial rifting in several small distributed half-graben to a single larger regional-scale half-graben. The two-stage tectonic development of the Taylorsville basin may be a result of the linkage of the small faults due to fault-tip propagation (Dawers and Anders 1995;

Ackermann and Schlische 1997; Gupta et al. 1998). As continental extension continued, the normal faults bordering the lower half-graben increased in length, and several of the faults linked to form the major basin-bounding fault for the upper, regional half-graben (Gupta et al. 1998). The smaller normal faults (and basins) were abandoned as the larger regional faults began to accommodate the extensional stresses (Ackermann and Schlische 1997).

The two-stage structural development of the Taylorsville basin formed two tectonically controlled depositional sequences in the Taylorsville basin. The basin-fill sequences are unconformity-bounded successions of strata. These sequences are defined by interpretation of the seismic reflection profiles, lithologic patterns, borehole logs, and observations and measurements of rocks in the exposed portion of the basin. The sediment deposited during subsidence of the lower half-graben form Taylorsville Basin (TVB) Sequence TVB 1. Sequence TVB 2 comprises the sediment deposited in the upper, regional half-graben. Sequences TVB 1 and TVB 2 in the Taylorsville basin correspond to the age-calibrated Carnian and Norian tectonostratigraphic sequences TS II and TS III identified by Olsen (1997) in the exposed basins of the Newark Supergroup and in related rifts of the CAM.

The exposed portion of the Taylorsville basin clearly exhibits evidence of relatively complex structure, including wide variations in bedding attitudes within small areas (Weems 1981, 1986), short-wavelength folds in the southwestern portion of the basin (Weems 1980a, 1981), and apparent map-view offsets in along-strike projections of dark shale marker beds. The bedding attitudes in the Sequence TVB 1 strata define a broad NW-plunging syncline (figure 3.9). The abrupt shift in bedding orientation and the lithologic change from deltaic-lacustrine rocks to coarse fluvial conglomerates define the unconformity between Sequence TVB 1 and Sequence TVB 2 (figures 3.9 and 3.10). The generally poor exposure and structural complexity resulted in some ambiguity regarding the basin stratigraphy—for example, the interpretations of Weems (1980a) versus that of Cornet and Olsen (1990) (figure 3.3). The continuous stratigraphic sections observed in the cores and cuttings provide constraints on possible interpretations of the stratigraphy of the exposed basin, as discussed later in the chapter.

CORRELATION OF BASIN STRATA AND TECTONOSTRATIGRAPHIC SEQUENCES

The correlation of strata within the basin is based on the structural interpretation, the comparison of similar rock types, the identification of depositional sequences, and the observations made in the exposed portion of the Taylorsville basin (figure 3.10) and was tested by paleomagnetic experiments. The lithologic log of the Wilkins well provides a stratigraphic framework for more than 2.5 km of the basin section. With the Wilkins stratigraphy as a starting point and in consideration of the structural position of the cores, the stratigraphic sections of the remaining test wells were arranged in vertical succession. A composite reference section was derived by summarizing the large-scale lithologic patterns observed in the correlated subsurface data (figure 3.10). The composite reference section and structural data reveal that the Taylorsville basin contains more than 4.5 km of vertical section. The correlation illustrates the vertical succession and lateral variability of rock types, and defines the lithologic components of the two basin-fill sequences.

Sequence TVB 1

Sequence TVB 1 (figures 3.10 and 3.11) primarily consists of lacustrine black shale and fluvial-deltaic sandstone, with a thin and variable basal conglomerate and sandstone overlying basement, and comprises the Doswell Group. The lower half-graben are not equally distributed, and the fill within the small rifts thins toward the hanging-wall sides of the basins. Therefore, depending on location and total depth, the stratigraphic test wells encountered variable portions of the total Sequence TVB 1 section.

The Campbell core, located on the western fault-bounded margin of the basin, is the only continuous corehole in this study that encountered Sequence TVB 1. It penetrated approximately 760 m (2,500 ft.) of Sequence TVB 1, consisting of lacustrine black shale and very coarse subaqueous and subaerial conglomerate below 910 m (3,000 ft.) core depth (figure 3.5). Although the Campbell core did not encounter the basal fluvial unit or basement, it did recover most of the estimated 760 to 910 m (2,500 to 3,000 ft.) thick Sequence TVB 1 lacustrine interval. The Sequence TVB

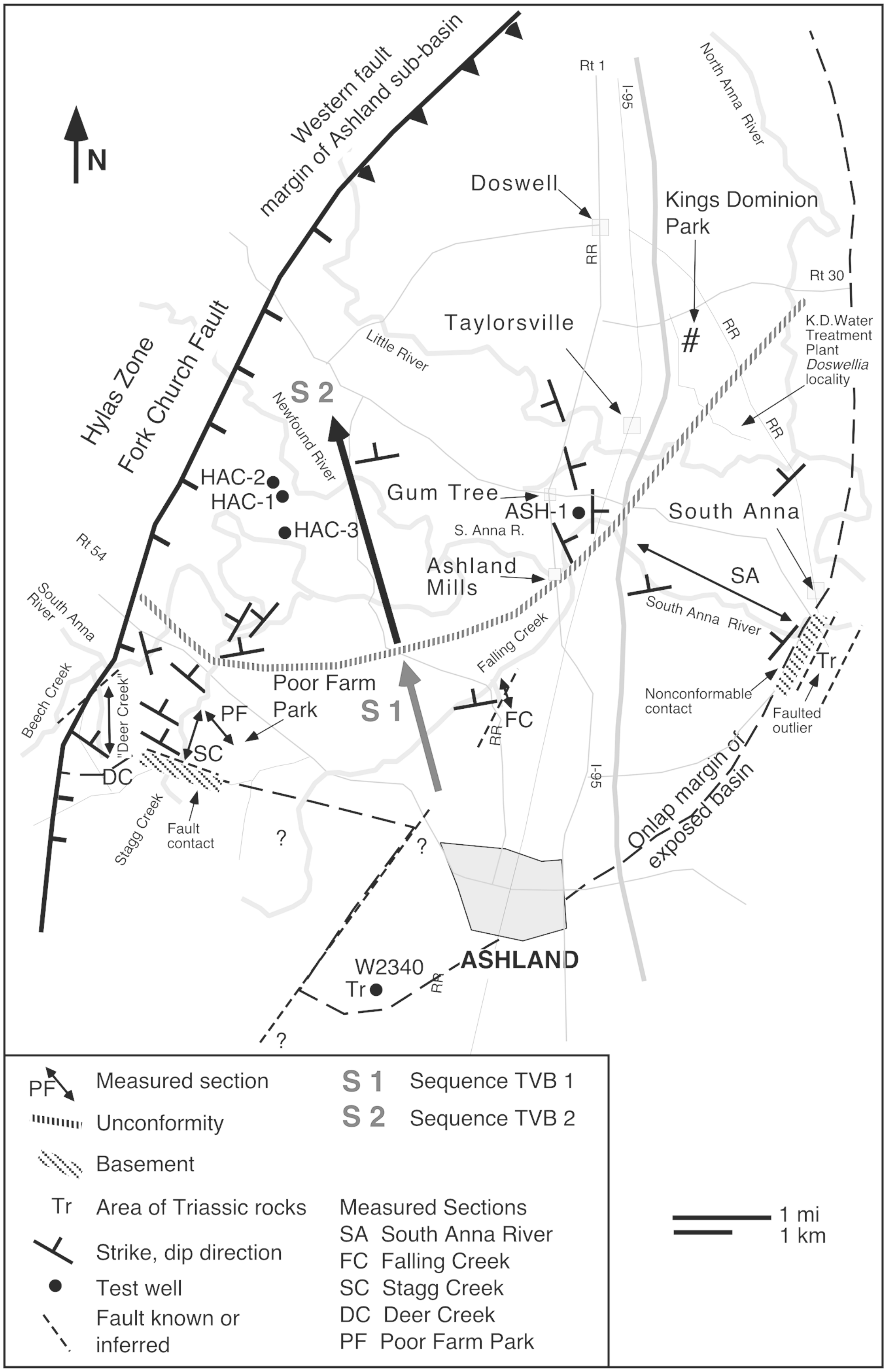

FIGURE 3.9 Simplified map of the exposed portion of the Ashland subbasin of the Taylorsville rift located near Ashland, Virginia, showing the locations of key geographic features, measured sections, structure, and tectonostratigraphic sequences. (Base map from DeLorme Atlas of Virginia [1995])

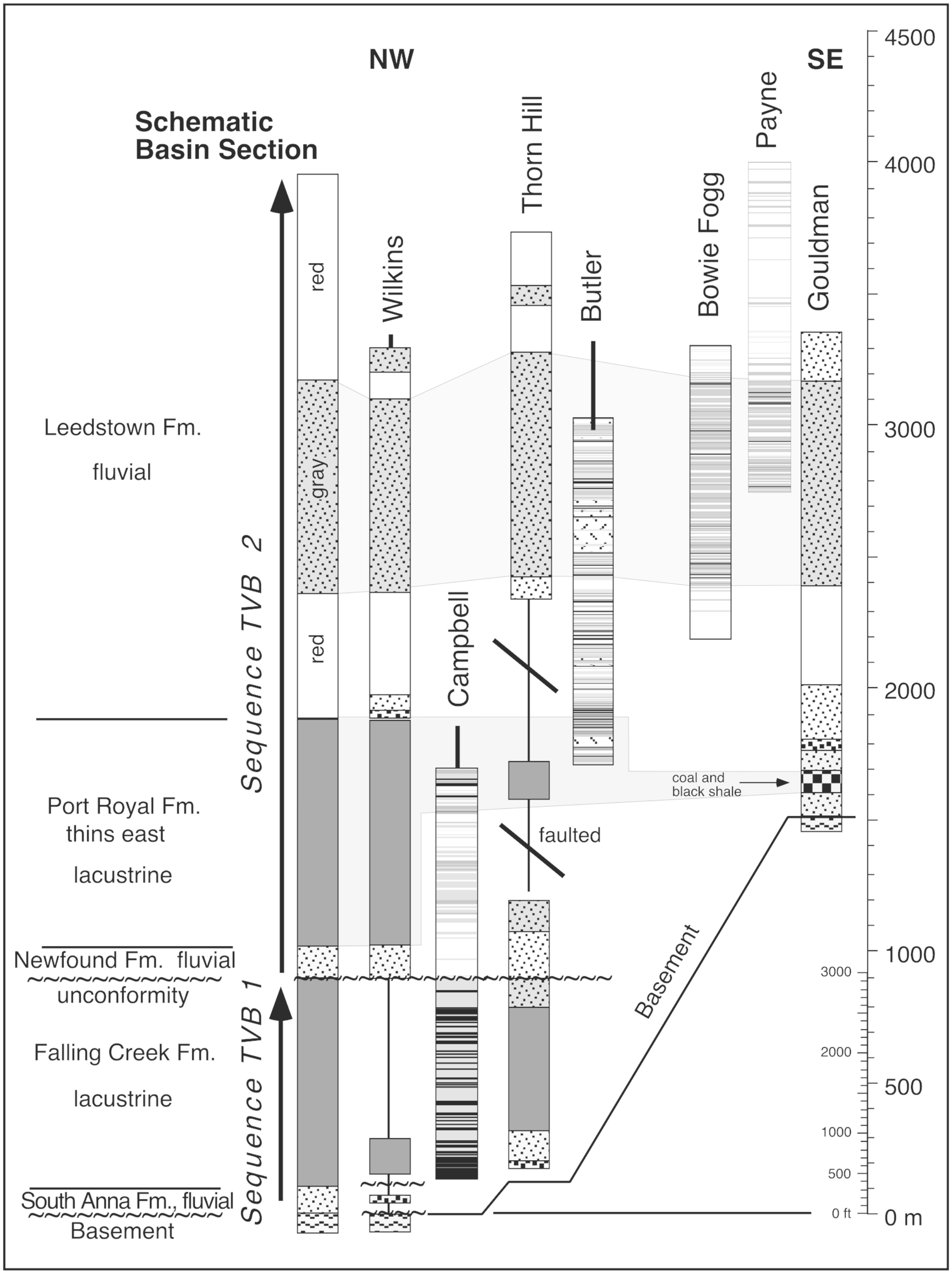

FIGURE 3.10 Lithostratigraphic correlation of cores and cuttings and schematic section of the Taylorsville basin. Relative stratigraphic position of cores is constrained by structural data from borehole logs and seismic interpretations. Schematic section shows tectonostratigraphic sequences and dominant style of sedimentation.

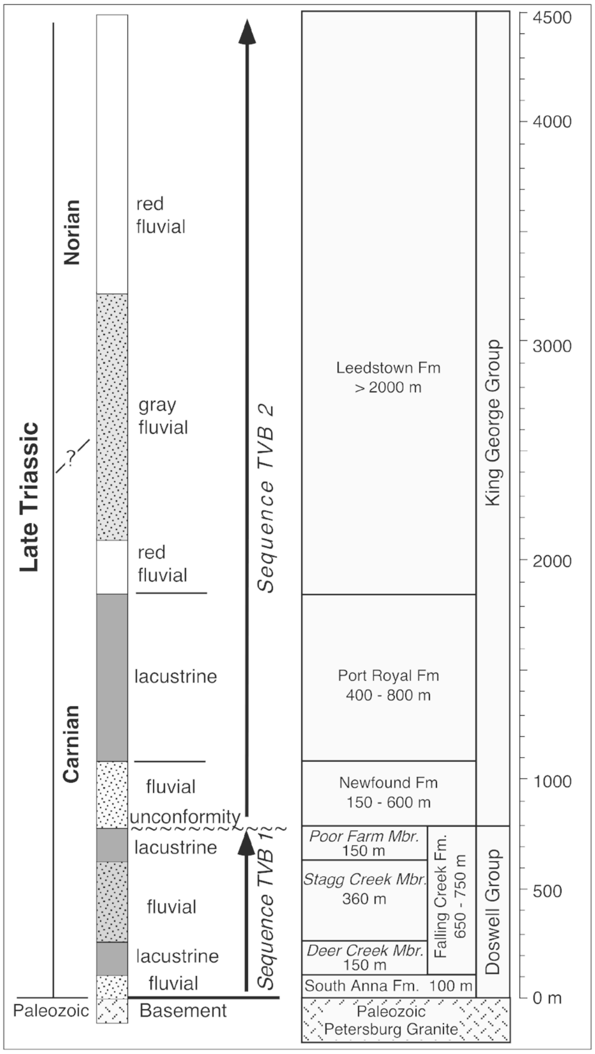

FIGURE 3.11 Lithostratigraphic sequences of the Taylorsville basin and revised and formalized stratigraphic nomenclature.

1 lacustrine interval thins east toward the Thorn Hill and Wilkins wells (figure 3.10).

The Thorn Hill well penetrated approximately 610 m (2,000 ft.) of Sequence TVB 1, including 150 m (500 ft.) of fluvial sandstone and conglomerate as well as approximately 460 m (1,500 ft.) of lacustrine black shale and gray sandstone and conglomerate below 2,740 m (8,000 ft.) core depth. Dipmeter data from the Thorn Hill well reveal that beds below 2,740 m (8,000 ft.) depth dip northwest and that beds at shallower depths dip southeast, further confirming the presence of an uncomformity separating upper and lower basin–fill sequences in the Thorn Hill well.

The Wilkins well penetrated approximately only 150 to 183 m (500 to 600 ft.) of Sequence TVB 1. The basal half-graben in the Taylorsville basin have a wedgelike shape, and strata gently thin to the east away from the western boundary faults. The Wilkins well penetrated only a relatively thin portion of the lower lacustrine interval in Sequence TVB 1. In down-dip portions of the basal half-graben, the Sequence TVB 1 lacustrine interval is substantially thicker than shown in the Wilkins well and may measure more than 750 m thick. The Gouldman well encountered basement at 2,390 m (7,840 ft.) on the eastern side of the Taylorsville basin, but, based on seismic data and rock types recovered, it did not penetrate Sequence TVB 1.

Sequence TVB 2

A pervasive unconformity—recognized by truncated seismic reflectors, bedding dip directions that vary by approximately 180°, and abrupt changes in grain size and facies—defines the surface separating Sequence TVB 1 and Sequence TVB 2. For example, dipmeter logs from the Wilkins well show an abrupt change in bedding dip direction corresponding to changes in rock type within the 2,740 to 2,896 m (9,000 to 9,500 ft.) interval. The coarse sandstone and conglomerate beds below 2,896 m dip toward the northwest, and the finer-grained fluvial to lacustrine beds above 2,740 m dip toward the southeast. The base of Sequence TVB 2 begins with an interval of coarse fluvial rocks that thins toward the east (figures 3.10 and 3.11). Sequence TVB 2 makes up the King George Group.

A 760 m (2,500 ft.) thick lacustrine interval overlies the coarse fluvial rocks that mark the transition from Sequence TVB 1 to Sequence TVB 2. This thick lacustrine interval is best defined in the cuttings from the Wilkins well, but the lowest portion of the lacustrine interval was cored in the Campbell well, and the uppermost part was recovered in the Butler core (figure 3.10). In the Thorn Hill well, the Sequence TVB 2 lacustrine interval is partially cut out by faults observed on one of the seismic lines (TX85T12). Cuttings from the Gouldman well indicate that on the eastern side of the Taylorsville basin the Sequence TVB 2 lacustrine interval thins dramatically and undergoes a facies change from black shale to black shale interbedded with coal.

Red sandstone, red siltstone, gray sandstone, and minor amounts of gray siltstone from the upper portion of Sequence TVB 2 were recovered in cores and cuttings. This interval is present in the Thorn Hill, Wilkins, and Gouldman wells, as well as in the Butler, Bowie-Fogg, and Payne cores (figure 3.10). This upper fluvial interval, which is well represented in the Gouldman cuttings, consists of three main divisions: an upper red division, a middle gray division, and a lower red division (figure 3.4). The Ellis and Roberts cores, which are located near the eastern margin of the Taylorsville basin (figure 3.2), contained coarse red and gray conglomerate and sandstone in the upper fluvial interval.

The fluvial and lacustrine rocks of Sequence TVB 1 are also found in the small exposed part of the Taylorsville basin. The rocks overlying crystalline basement on the eastern margin of the exposed basin include very coarse conglomerate and sandstone, which is in turn overlain by lacustrine black shale and interbedded fluvial and deltaic sandstone. This stratigraphic succession is traceable along the southern edge of the outcrop area to the western fault margin of the Taylorsville basin. The rocks of Sequence TVB 1 are overlain by the basal fluvial conglomerate and sandstone of Sequence TVB 2 in the central and northern parts of the outcrop area.

AGE OF THE TAYLORSVILLE BASIN

Pollen

Cornet (1977), Weems (1980a, 1980b), Cornet and Olsen (1985, 1990), Robbins and Weems (1988), Litwin and Weems (1992), and Fowell et al. (1996) found that pollen from the Taylorsville basin indicates a Late Triassic (Carnian–Norian) age. However, disagreement exists over stage assignments (e.g., Cornet and Olsen 1990; Litwin and Weems 1992; Cornet 1993) and substage definitions (e.g., the "mid-Carnian" of Cornet 1977). Pollen obtained from Sequence TVB 1 rocks has been assigned a Carnian age (Cornet and Olsen 1990). Pollen from Sequence TVB 2 indicates a late Carnian through Norian age for the upper part of the Taylorsville basin (S. J. Fowell, personal communication 1996).

Plants

A very well preserved conifer referable to *Pagiophyllum simpsonii* (Ash 1980; B. Axsmith, personal communication 1998) was recovered from gray, plant-rich, silty, fine sandstone at 852 m (2,796 ft.) depth in the Bowie-Fogg core (figure 3.12); an additional specimen was retrieved from 1,316 m (4,318 ft.) depth in the Payne core. Diagnostic marginal papillae described by Ash (1980) were observed on the Bowie-Fogg 852 m (2,796 ft.) specimen. *Pagiophyllum simpsonii* may be assigned a Carnian or early Norian age (Ash 1980; B. Axsmith, personal communication 1998).

Vertebrate Fossils

A single weakly ornamented osteoderm (figure 3.13)—likely referable to *Aetosaurus arcuatus* (*Stegomus arcuatus*), an armored herbivorous pseudosuchian aetosaur (Marsh 1896; Jepsen 1948; Lucas 1997, 1999)—was found at 666 m (2,184 ft.) depth (Leedstown Formation) in the Payne well (figure 3.13). Unlike the well-defined pitted sculpture of most other aetosaurs (Lucas 1997), *Aetosaurus arcuatus* osteoderm are nearly smooth and possess faint radial striae and grooves (Huber, Lucas, and Hunt 1993b; Lucas 1997, 1999). Huber, Lucas, and Hunt (1993a, 1993b) and Lucas (1997) consider *Aetosaurus arcuatus* the index fossil for the early to middle Norian Neshanician land-vertebrate faunachron (LVF). Therefore, the Leeds-

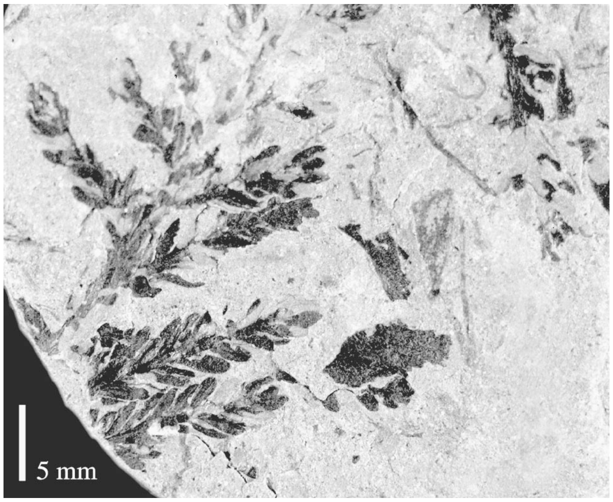

FIGURE 3.12 The age diagnostic Late Triassic *Pagiophyllum simpsonii* from the Bowie-Fogg core. Staple is approximately 12 mm long.

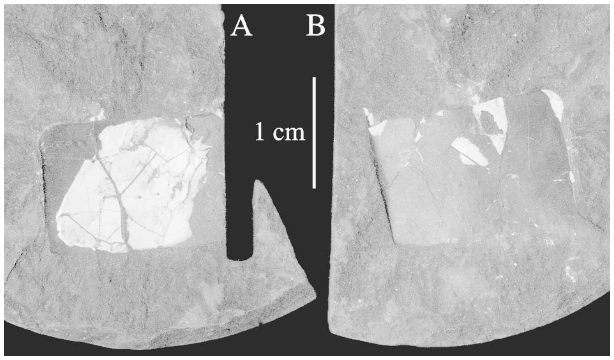

FIGURE 3.13 Fragment of scute (dermal armor) from the age diagnostic Late Triassic vertebrate *Aetosaurus* (*Stegomus*) *arcuatus* from 2,184 ft (666 m) well depth in the Payne core. Staple is approximately 12 mm long.

town Formation is, in part, early to middle Norian in age (Lucas 1999).

The fossil fishes of the Taylorsville, Richmond, Farmville, and Scottsville basins (figure 3.1) are dominated by the redfieldiid actinopteryigian *Dictyopyge macrurus,* which is unique to those basins (Cornet 1977; Olsen, McCune, and Thomson 1982; Cornet and Olsen 1990). Palynological data (Cornet and Olsen 1985; Cornet 1993; Fowell 1994), megafossil plant assemblages (Ash 1980), and vertebrate biostratigraphy (Huber, Lucas, and Hunt 1993b; Lucas 1997) point to a Carnian age for strata containing *Dictyopyge macrurus.* During the course of this study, specimens of *Dictyopyge macrurus* were found in lacustrine black shale beds from the Falling Creek Formation, including localities at Deer Creek, the Falling Creek type section, Little River, and the South Anna River.

The unique armored archosaur *Doswellia kaltenbachi* (Weems 1977, 1980b) occurs in the Poor Farm Member or the upper portion of the Falling Creek Formation. Huber, Lucas, and Hunt (1993b) included *Doswellia* in their late Carnian (Tuvalian) Sanfordian LVF.

Igneous Rocks

Diabase dikes and basalt flows are prominent features of the Central Atlantic Magmatic Province (CAMP), including the Newark Supergroup rifts (Manspeizer 1988; Marzoli et al. 1999). Diabase dikes crosscut the Taylorsville basin and the surrounding metamorphic terrain. The stratigraphic test wells and coreholes in the Taylorsville basin encountered mafic igneous rocks interpreted as dikes and sills based on coarse crystal size, the lack of lateral continuity between wells, steep to near-vertical contacts between igneous and sedimentary rocks observed in core samples, and the subvertical attitude of reflectors interpreted as dikes on seismic profiles. The diabase is unweathered, dark-green to black colored, and medium to coarsely crystalline. Diabase was encountered in the Gouldman well at approximately 760 m (2,500 ft.) and in the Bowie-Fogg core at approximately 1,067 m (3,500 ft.). The Butler core encountered approximately 240 m (800 ft.) of diabase at various depths in the 1,116 m (3,660 ft.) cored interval.

Ragland, Cummins, and Arthur (1992) suggest a probable range of 195 to 205 Ma for the mafic igneous rocks of the Newark Supergroup based on a review of available dates. Isotopic dating of diabase from the Newark and Culpeper basins by Sutter (1988) using ^{40}Ar/^{39}Ar methods and from the Newark and Gettysburg basins by U/Pb methods (Dunning and Hodych 1990) have yielded Early Jurassic dates of approximately 201 Ma. Marzoli et al. (1999) report a mean age of 199.0 ± 2.4 Ma and a mode age of approximately 200 Ma for all CAMP basalts. Recent analyses of South Carolina diabase dikes and Newark basin basalt flows by Hames, Renne, and Ruppel (2000) using ^{40}Ar/^{39}Ar methods yielded dates ranging from approximately 199.5 ± 2.0 Ma for the dikes and 201.0 ± 2.1 Ma to 198.8.0 ± 2.0 Ma for the lower and upper basalt flows, respectively. A reasonable interpretation of these dates, constraints from paleomagnetic data (Kent, Olsen, and Witte 1995; Kent and Olsen 2000), and cyclostratigraphic interpretations (Olsen et al. 1996) suggest that the CAMP event occurred at approximately 201 Ma (see also McHone and Puffer, chapter 10 in volume 1 of *The Great Rift Valleys of Pangea*) with a duration of less than 600,000 years (Olsen et al. 1996).

Paleomagnetic analyses of the diabase dikes from the Taylorsville basin cores (figures 3.14–3.16) conducted for this study revealed normal paleomagnetic polarities consistent with the findings of Witte, Kent, and Olsen (1991) and of Kent, Olsen, and Witte (1995) for the extrusive basalts of the Newark basin. Therefore, if the correlation of the Taylorsville basin diabase dikes with the mafic igneous rocks of the CAMP is correct, then, based on the cross-cutting relationships, the Taylorsville strata are no younger than earliest Jurassic, or approximately 202 Ma (Kent, Olsen, and Witte 1995; Kent and Olsen 2000).

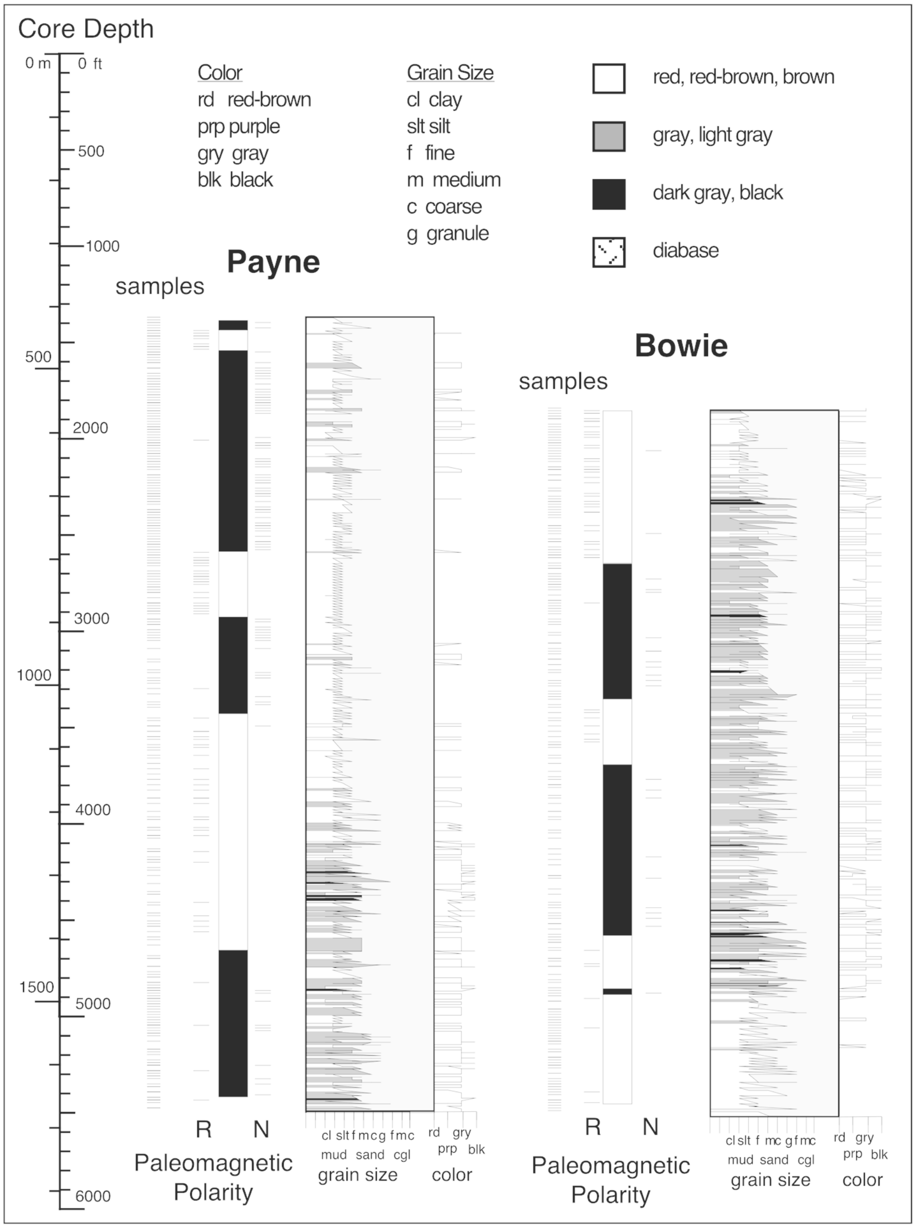

FIGURE 3.14 Geologic log and paleomagnetic polarity of the Payne and Bowie-Fogg cores. Thin horizontal lines show the location of all paleomagnetic samples and the locations of normal and reverse polarity samples that passed paleomagnetic reliability tests described in this chapter.

Paleomagnetic Correlation of the Taylorsville and Newark Basins

Paleomagnetic reversal stratigraphy was used to correlate strata within the Taylorsville basin and to compare its magnetostratigraphy with that of the Newark basin (figure 3.17). The paleomagnetic results summarized here are described in detail by LeTourneau (1999). The Newark basin magnetostratigraphic section is well constrained by lithostratigraphy and structural geology, and is age calibrated by cyclostratigraphy and paleontology (Olsen et al. 1996). Therefore, the Newark basin magnetostratigraphic section is the

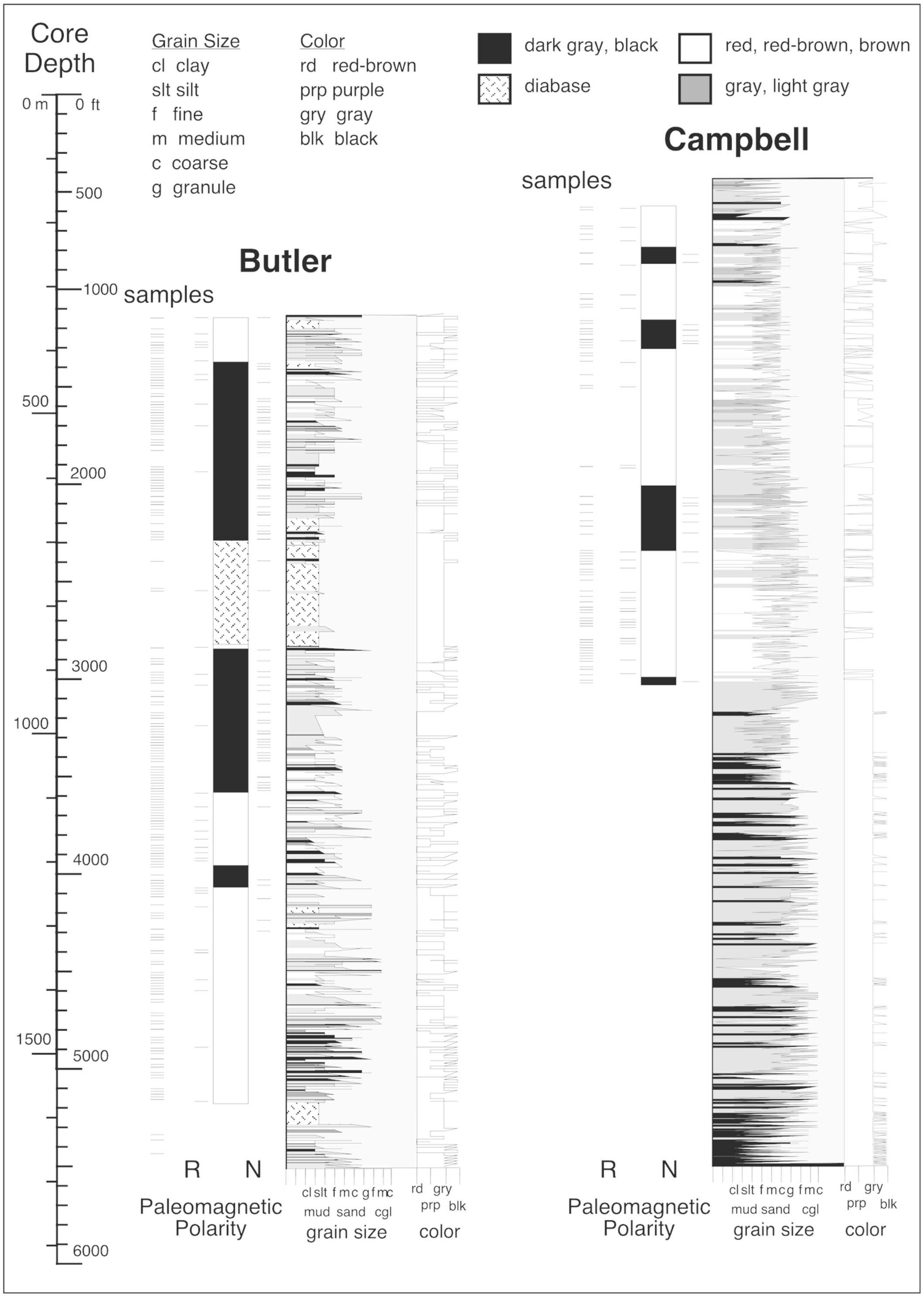

FIGURE 3.15 Geologic log and paleomagnetic polarity of the Butler and Campbell cores. Thin horizontal lines show the location of all paleomagnetic samples and the locations of normal and reverse polarity samples that passed paleomagnetic reliability tests described in this chapter.

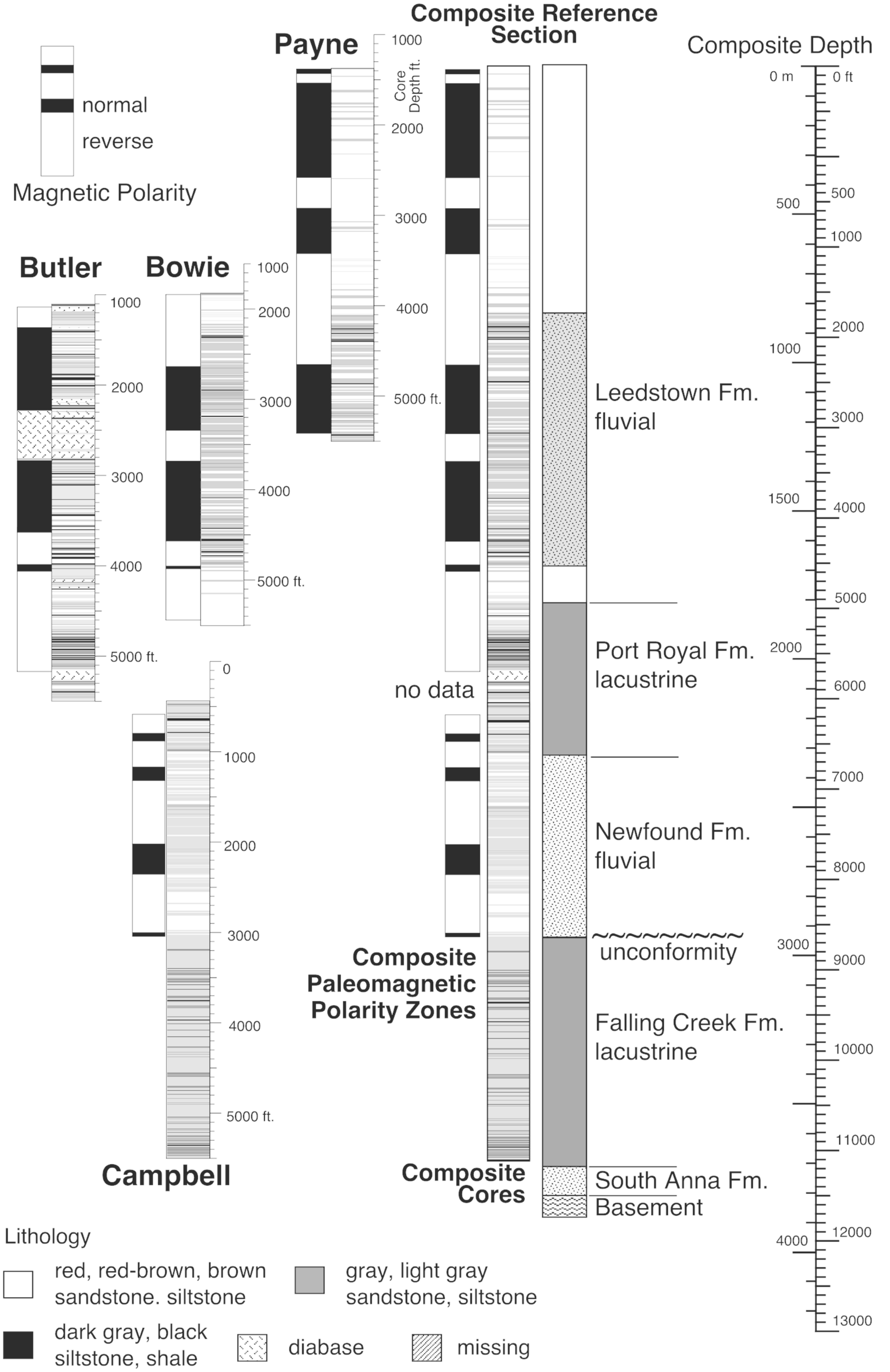

FIGURE 3.16 Geologic logs and paleomagnetic polarity of Taylorsville cores. Composite lithostratigraphic and magnetostratigraphic section is shown at right, along with a schematic reference section.

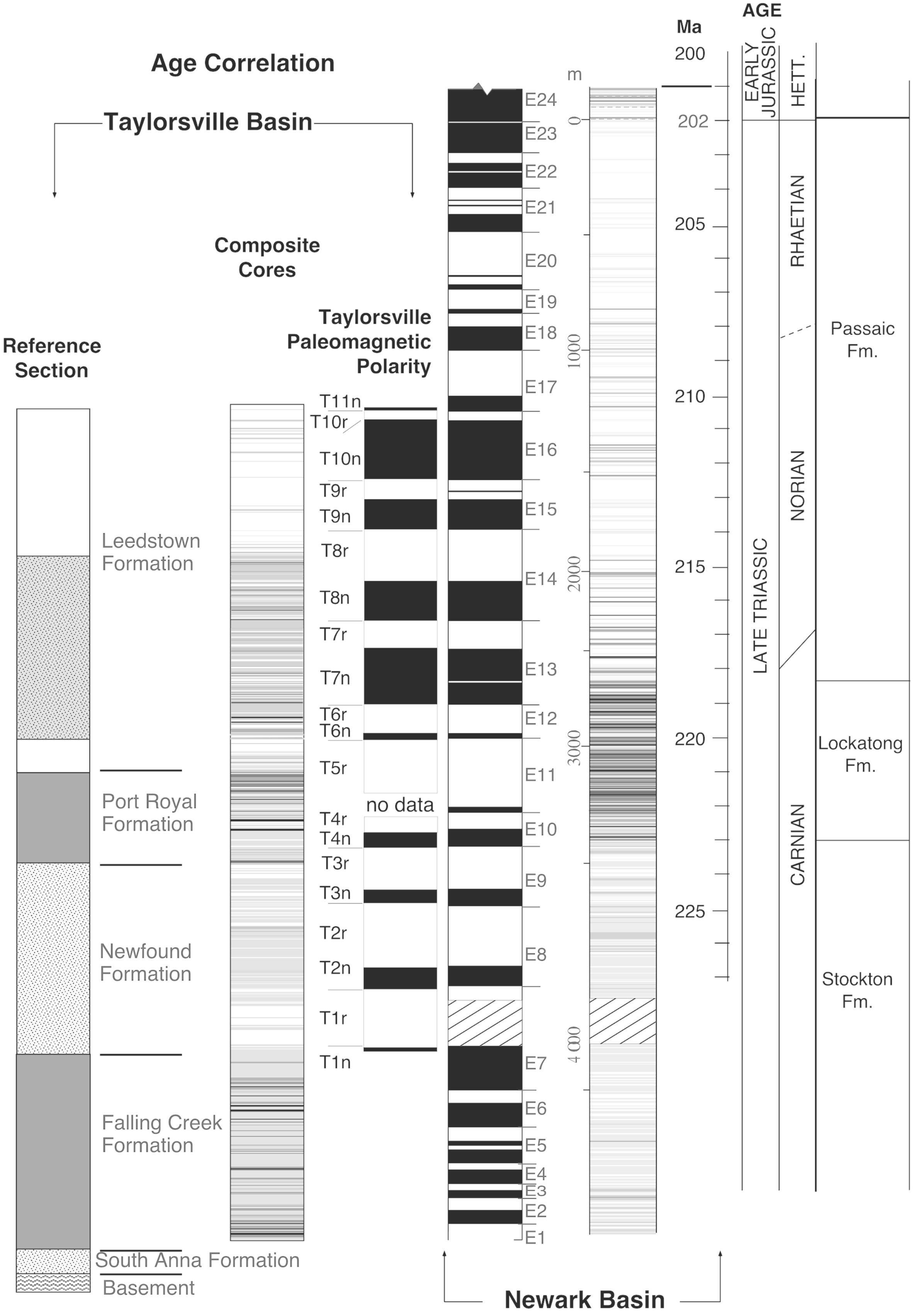

FIGURE 3.17 Correlation of the Taylorsville magnetostratigraphic section with the age-calibrated Newark basin reference section. The age-calibrated correlation indicates that deposition in the Taylorsville basin spanned more than 24 million years, ranging from approximately 234 Ma to approximately 210 Ma.

model used to test the completeness and probable age of the Taylorsville section.

Texaco recovered more than 6,800 m of continuous core (table 3.1) from six test wells in 1986 as part of its oil and gas exploration of the Taylorsville basin. More than 850 rock samples were obtained at vertical intervals of approximately 3 m for paleomagnetic analysis from the Payne, Bowie-Fogg, Butler, and Campbell cores (figures 3.2, 3.14, and 3.15). Samples were numbered according to corresponding core depth in feet, rounded to the nearest foot. Where mentioned in this chapter, the sample number is italicized (e.g., *1558* or *5328*).

The paleomagnetic samples were subjected to thermal demagnetization experiments to isolate the high-temperature characteristic remnant magnetization (ChRM). Other experiments, including isothermal remnant magnetization and alternating field demagnetization, were used to identify the magnetic carrier minerals and to explore the origin and stability of the ChRM.

Of the 858 samples analyzed, approximately 46% (396) passed tests for reliability of the data, including maximum angular deviation, paleomagnetic inclination, and paleomagnetic intensity tests (table 3.2). Approximately 54% (462) did not pass the reliability tests and were rejected. The 396 samples that passed reliability tests were subsequently screened for paleomagnetic polarity based on the inclination and character of the ChRM (table 3.3). Approximately 56% (222) of the accepted samples are of normal paleomagnetic polarity, and approximately 44% (174) are of reversed polarity. The screened data were used to determine stratigraphic intervals of normal and reverse paleomagnetic polarity and to evaluate the relationship between sample lithology and location (depth) of the samples (figures 3.14 and 3.15). The boundaries of the paleomagnetic polarity zones do not correspond to major lithologic boundaries, which strongly suggests that the ChRM of the rocks is not correlated with rock type. The independence of paleomagnetic polarity from lithology indicates that the rocks recorded the ambient geomagnetic field during deposition (detrital remnant magnetization [DRM]) or during early diagenesis (chemical remnant magnetization [CRM]), and that the magnetization is not a direct function of grain size, mineralogy, permeability, and thermal history.

The paleomagnetic polarity pattern of the individual cores (figures 3.14 and 3.15) was combined with the composite lithostratigraphic section to produce the paleomagnetic reversal stratigraphy of the Taylorsville basin section (figure 3.16). The composite lithostratigraphic reference section is based on the structural interpretation and the distinctive large-scale pattern of red, gray, and black lacustrine and fluvial rocks logged in the deep Wilkins, Thorn Hill, and Gouldman stratigraphic test wells, and on the logs of the Payne, Bowie-Fogg, Butler, and Campbell continuous cores.

The lithostratigraphic correlation and the paleomagnetic reversal correlation of the cores are in mutual agreement (figure 3.16). That is, the addition of the paleomagnetic reversal stratigraphy does not contradict or substantially revise the lithostratigraphic correlation (figure 3.10). The upper part of the Campbell core includes the base of the Port Royal Formation, and the base of the Butler core includes the top of the Port Royal Formation.

The age of the Taylorsville section is established roughly according to biostratigraphy, which provides constraints on possible paleomagnetic correlations. As described earlier in the chapter, the Taylorsville cores and outcrops have yielded Carnian and Norian age pollen, plants, and vertebrate fossils. The Payne core

TABLE 3.2 Results of Paleomagnetic Data Screening

Samples	*Payne*		*Bowie*		*Butler*		*Campbell*		*Total*	
	Count (*n*)	%	Count (*n*)	%	Count (*n*)	%	Count (*n*)	%	Count (*n*)	%
Pass	154	52.6	75	33.8	118	47.4	49	52.1	396	46.2
Rejected	139	47.4	147	66.2	131	52.6	45	47.9	462	53.8
All	293	100.0	222	100.0	249	100.0	94	100.0	858	100.0

TABLE 3.3 Results of Paleomagnetic Polarity Screening

Samples	*Payne*		*Bowie*		*Butler*		*Campbell*		*Total*	
	Count (*n*)	%	Count (*n*)	%	Count (*n*)	%	Count (*n*)	%	Count (*n*)	%
Normal	87	29.7	23	10.4	81	32.5	31	33.0	222	25.9
Reverse	67	22.9	52	23.4	37	14.9	18	19.1	174	20.3
Rejected	139	47.4	147	66.2	131	52.6	45	47.9	462	53.8
All	293	100.0	222	100.0	249	100.0	94	100.0	858	100.0
Pass all									396	100
Normal pass									222	56
Reverse pass									174	44

produced an osteoderm (dermal armor) at 666 m (2,184 ft.) core depth identifiable as *Aetosaurus arcuatus* (*Stegomus arcuatus*), the Norian age index fossil for the Neshanician LVF of Huber et al. (1993a). The Neshanician LVF includes the Warford through Neshanic Members of the Passaic Formation in the Newark basin (Olsen et al. 1996). Therefore, the paleomagnetic reversal pattern in the upper part of the Taylorsville section should match the reversal pattern found in the lower half of the Newark basin Passaic Formation. The distinctive paleomagnetic polarity pattern shown from Newark magnetozone E17 through E11 compares favorably with the reversal pattern found in the Payne, Bowie, and Butler cores (figure 3.17). The overall fit of the Taylorsville and Newark Basin Coring Project (NBCP) magnetopolarity zones is remarkably good. The paleomagnetic polarity correlation of the Taylorsville and Newark basins (figure 3.17) interestingly places the *Aetosaurus* scute in the same interval as the Neshanic Member (Chron E14r) of the Passaic Formation, where Jepsen (1948) originally found a specimen of *Aetosaurus arcuatus.*

Comparison of the Taylorsville magnetostratigraphic section and the cyclostratigraphically calibrated age section for the Newark basin (Kent, Olsen, and Witte 1995) shows that the resulting age correlation of the Taylorsville section is consistent with the biostratigraphic correlation based on vertebrate fossils, plants, and pollen (figure 3.17). The Taylorsville basin spans approximately 23 million years in the mid-Carnian through the late Norian, based on comparison with the NBCP reference section. Sedimentation in the Taylorsville basin began at approximately 234 Ma and continued at least until 211 Ma. An additional core (Roberts) that overlaps the Payne core and includes the youngest Taylorsville strata may provide the opportunity to extend the section above 210 Ma.

The paleomagnetic polarity zones for the Taylorsville basin are numbered from base to top according to normal–reverse pairs (e.g., Kent, Olsen, and Witte 1995). The base of the polarity section begins with T1n and T1r, defining the first Taylorsville (T) magnetic reversal zone, and the numbering proceeds upward to T11n, a normal interval. The missing section is interpreted to contain a normal interval, T5n, but there are no data from that interval. If, however, T4r and T5r represent the same reversed polarity zone, then the interval T4r–T5r represents an unusually long reversal in comparison with the Newark paleomagnetic reversal pattern. Therefore, the reverse polarity zones below and above the missing section are numbered separately.

The paleomagnetic reversal pattern of the Campbell core presents several options for correlation with the Newark section. The magnetopolarity zones T2, T3, and T4 may correlate with the NBCP zones E8, E9, E10, and E11. If the T2-E9, T3-E10, T4-E11 fit is used, then the Port Royal Formation becomes less than 200 m thick, and that possibility is not supported by the deep stratigraphic test well or core data. In fact, the T2-E9, T3-E10, T4-E11 correlation forces the Port Royal Formation to become thinner than the 300 m thickness of the Port Royal observed in the Butler core alone. Furthermore, this correlation is not supported by lithostratigraphic patterns in the Taylorsville and Newark basin sections. Therefore, the T2-E9, T3-E10, T4-E11 paleomagnetic polarity correlation is not tenable.

A T1-E7, T2-E8, T3-E9, T4-E10 correlation is my favored solution (figure 3.17). In this arrangement, the deep-water lacustrine rocks of the upper Port Royal Formation correlate with the base of the lacustrine Lockatong Formation in the Newark basin. The gray rocks of the Leedstown Formation also correlate with the gray and black rocks of the lower Passiac Formation in this arrangement. Finally, the lithologic patterns of the Newfound Formation also correlate well with those of the upper Stockton Formation. When compared with the NBCP interval E7r, the Taylorsville interval T1r appears anomalously thick. The T1r interval occurs within a thick interval of very coarse conglomerate and sandstone in the Campbell core, which was drilled near the western margin of the Taylorsville basin. Thus the anomalous thickness of T1r may be due in part to the high sedimentation rates expected in alluvial-fan and fan-delta conglomerates at the basin margin in comparison with the correlative NBCP interval, which was drilled in the central portion of the Newark basin. Alternatively, as shown in figure 3.17, an unconformity has been identified at the base of the Newfound Formation, and a similar unconformity is postulated to exist in the Newark Stockton Formation (P. E. Olsen, personal communication 1999).

Comparison of the paleomagnetically correlated composite sections from the Taylorsville and Newark basins reveals striking similarities between "wetter" and "drier" intervals. In the Taylorsville composite core section, black lacustrine shale in the upper part of the mostly lacustrine Port Royal Formation correlate with the Lockatong Formation in the Newark basin. The upper Leedstown Formation of the Taylorsville basin is dominated by red fluvial and shallow lacustrine rocks similar to the lower part of the Newark Passaic Formation. The Taylorsville cores and cuttings also show evidence of lateral facies variability (figure 3.10). In particular, the cores show mostly shallow lacustrine and fluvial rocks in the lower Port Royal, whereas the cuttings from the Wilkins well show black lacustrine shale predominating (figures 3.4, 3.5, and 3.10). Similarly, the Newark cores were drilled in the eastern part of the Stockton Formation, where fluvial strata predominate, but the Stockton Formation contains substantial lacustrine rocks in the western (and deeper) parts of the basin (Reynolds 1993; P. E. Olsen, personal communication 1999). Comparison of the two basins shows that in the Newark basin composite section the eastern facies of the Stockton Formation appears mostly fluvial, whereas the correlative Taylorsville Falling Creek Formation is mostly lacustrine. The correspondence between fluvial and lacustrine strata in the Taylorsville and Newark basins apparently reveals the influence of regional or global paleoclimate on the depositional history of the basins. The relative shifts from "drier" to "wetter" facies is in remarkably good agreement between the two basins, particularly when facies variability is recognized. Although the tectonic history of the two basins differs, the overriding effect of orbitally induced climate change on the relative amount of water available to the separate depositional basins appears quite similar.

The paleomagnetic reversal stratigraphy for the Taylorsville basin is also useful for direct correlations with other Triassic rifts of the CAM (figure 3.18). Continental Late Triassic age magnetostratigraphic sections are available from the Dan River–Danville, Culpeper, and Fundy basins (figure 3.18), and from the Jameson Land basin in East Greenland (Kent and Clemmensen 1996; Kent and Olsen 1997). The lacustrine interval in the lower part of the Taylorsville and Richmond basins correlates with the mostly fluvial strata in the lowest portion of the Newark basin section. The Dan River–Danville basin contains two lacustrine intervals that only partially overlap with the lower and upper lacustrine intervals in the Taylorsville basin. The upper part of the Taylorsville basin contains repetitive, fining-up, fluvial cycles that correlate with coarse fluvial rocks in the Culpeper and Fundy basins. The high-resolution paleomagnetic correlations are useful for determining the influence of local and regional paleoclimate on deposition and for placing the tectonic evolution of the rifts into a proper stratigraphic context.

DISCUSSION

Tectonic and Climatic Controls on Deposition

The correlation matrix (figure 3.18) reveals possible tectonic, climatic, and paleolatitudinal controls on sedimentation (Olsen 1997; Kent and Olsen 2000). The basin-fill model of Schlische and Olsen (1990) predicts

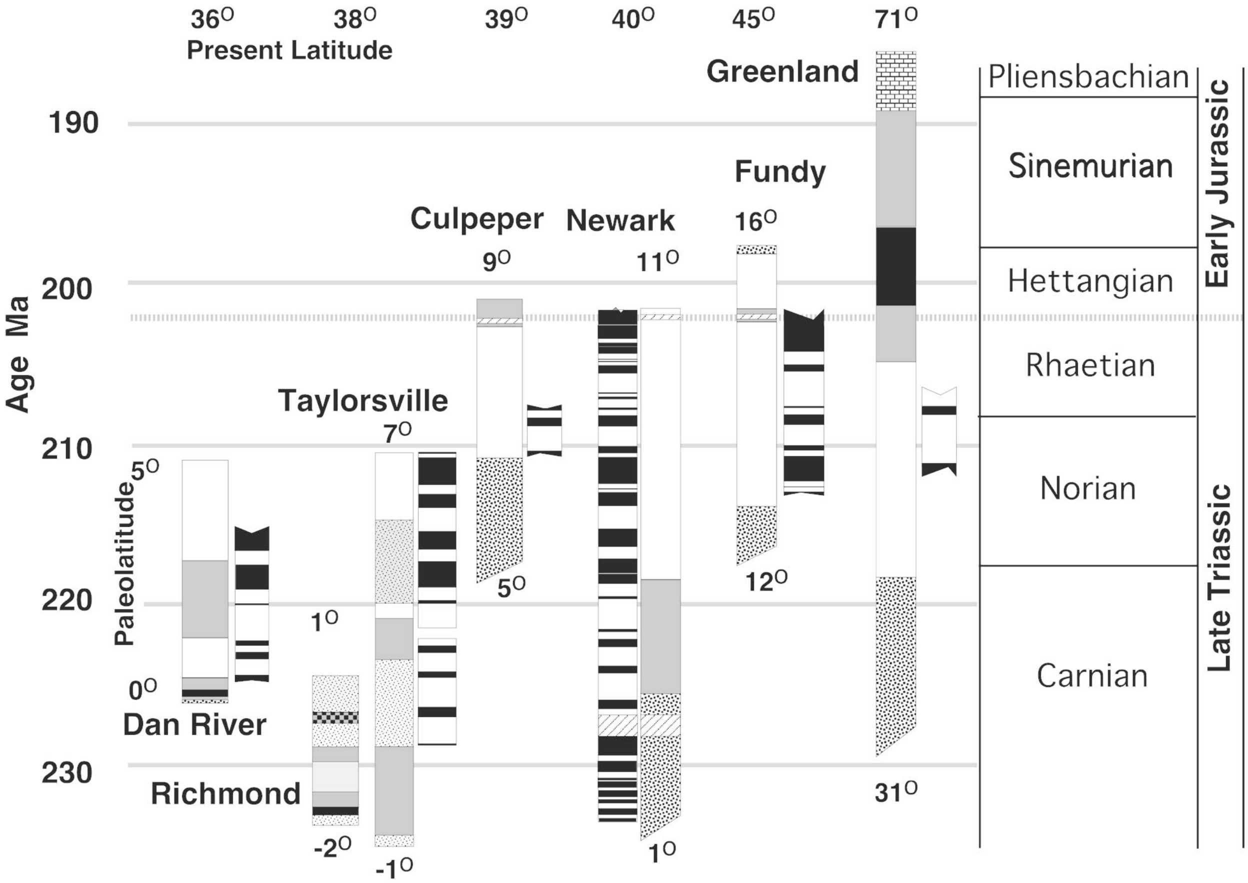

FIGURE 3.18 Correlation matrix of selected Triassic–Jurassic rifts in eastern North America and Greenland. (Data sources: Dan River [Kent and Olsen 1997]; Culpeper [P. E. Olsen and P. M. LeTourneau, unpublished studies]; Newark [Olsen et al. 1996]; Fundy [Kent and Olsen 2000]; Greenland [Kent and Clemmenson 1996])

that single-tectonic-cycle basins should contain a basal fluvial interval followed by a deep-water lacustrine interval that gradually tapers to a shallow lacustrine and fluvial interval. The stratigraphy of the Culpeper, Newark, and Fundy basins and the upper part of the Taylorsville basin agrees with the model predictions. Coarse fluvial rocks in one basin may correlate with deep-water lacustrine rocks in another basin, depending on the age of the initial rifting, as seen in a comparison of the Culpeper and Dan River basins, for example (figure 3.18). In the Taylorsville basin, the large-scale stratigraphic pattern of two unconformity-bounded sequences with a predictable succession of facies is in good agreement with rift-fill models based on tectonic controls.

Climatic controls on basin fill are revealed in cycles that correlate with periodic astronomical forcing (Olsen 1986) and in patterns of mainly arid or mainly humid depositional environments that correspond to paleolatitude (Olsen 1990). The Taylorsville, Richmond, and Dan River–Danville rifts were located at equatorial paleolatitudes throughout their depositional history, and they contain rocks indicative of persistently humid climate conditions such as coal, organic-rich paludal mudstones, and black lacustrine shale. However, the rifts located at higher paleolatitudes contain rocks indicative of arid and semiarid conditions, including playa and eolian deposits. Therefore, for a selected time-equivalent interval, the rifts show a northward trend of increasing aridity (figure 3.18). Small-scale variability within the large-scale patterns produced by tectonic and paleolatitude controls on basin filling are due to periodic, astronomically forced climate change.

The Newark basin also conforms to the model and contains three tectonostratigraphic sequences overprinted by variable, astronomically forced climate change (Olsen 1986, 1997; Olsen et al. 1996). The Doswell Group of the Taylorsville basin corresponds to the lower three-quarters of the Stockton Formation (TS II of Olsen 1997), which in outcrop and available core and industry drill holes is predominately fluvial (figure 3.18). Thus the Taylorsville Falling Creek Formation more faithfully records the influence of variable climate on sedimentation, whereas tectonic controls on sedimentation prevail in the time-equivalent Stockton Formation in the Newark basin. The King George Group of the Taylorsville basin correlates with the upper Stockton Formation (Raven Rock Member), the Lockatong Formation, and the lower three-quarters of the Passaic Formation of the Newark basin. The upper Stockton, Lockatong, and Passaic Formations comprise TS III of the Newark basin (Olsen 1997). However, the Taylorsville basin lacks any strata equivalent to the succeeding tectonostratigraphic sequence in the Newark basin (TS IV of Olsen 1997), which is composed of basalt flows and interbedded and overlying largely lacustrine rocks.

Recent models of rift basin subsidence and sedimentation suggest that tectonic controls, overprinted by periodic climatic fluctuations, produce predictable sequences of basin fill (Olsen 1990; Schlische 1991, 1993; Schlische and Anders 1996; Contreras, Scholz, and King 1997). Half-graben rift basins ideally contain a tripartite sequence of fill, beginning with initial fluvial sedimentation, progressing relatively early in the basin history to deep-water lacustrine deposition, followed by a relatively slow transition to shallow lacustrine and fluvial sedimentation (Schlische and Olsen 1990; Schlische 1991; Olsen et al. 1996; Contreras, Scholz, and King 1997; Gupta et al. 1998). I refer to the tripartite basin-fill divisions as A, initial fluvial sedimentation; B, deep lacustrine; and C, late-stage fluvial and lacustrine. The complete basin-fill succession is named here a *Schlische cycle* in recognition of Roy Schlische's (Rutgers University) model of tectonic controls on rift basin sedimentation (Schlische and Olsen 1990; Schlische 1991, 1993; Schlische and Anders 1996) (figure 3.19). Astronomical forcing of climate modulates the tectonic controls on sedimentation by influencing the relative quantity of water available to the rift basin, and rift basin strata may contain periodic cycles of lacustrine and fluvial strata (Olsen 1986). The combination of tectonic and climatic controls result in predictable large-scale and small-scale patterns of sedimentation.

I identified two tectonically controlled basin-filling sequences for the Taylorsville basin (figure 3.19) based on my structural and stratigraphic interpretation. Sequence TVB 2 shows divisions A, B, and C, or a complete Schlische cycle, predicted by Schlishe and Olsen's (1990) basin-fill model and similar to the cycle observed in the Newark basin (Schlische and Olsen 1990; Schlische 1992). In the Taylorsville basin, the coarse sandstone and conglomerate Newfound Formation is division A in Sequence TVB 2, which corresponds to the predicted interval of initial fluvial sedimentation in Schlishe and Olsen's (1990) rift basin model. The lacustrine Port Royal Formation is division B, and the overlying fluvial Leedstown Formation is division C.

Basin-fill Sequence TVB 1 in the Taylorsville basin consists of a partial Schlische cycle (figure 3.19). Division A is represented by the coarse fluvial South Anna Formation, and division B is the overlying lacustrine Falling Creek Formation. The lacustrine division B in Sequence TVB 1 shallows upward and has a middle deltaic-lacustrine interval (figure 3.19). The tectonic model predicts that the deep lacustrine interval will shallow upward and undergo a transition to fluvial sedimentation. This simple relationship does not occur in Sequence TVB 1. The deep lacustrine strata are overlain by fluvial strata, which are in turn overlain by shallow lacustrine deposits. This departure from the stratigraphic succession predicted by the basin-fill model may be the result of climatic fluctuations that promoted less-humid depositional environments. Sequence TVB 2 shows a similar deviation from the model Schlische cycle. In the Leedstown Formation (figure 3.19), the overall shallowing upward trend is interrupted by a thick interval of gray, plant-rich fluvial sedimentation that indicates a return to more humid depositional conditions.

The first-order basin-fill pattern for the Taylorsville basin, particularly in Sequence TVB 2, is predicted by the tectonic model of Schlische and Olsen (1990). Therefore, tectonics controlled the formation of the small, lower half-graben; the upper, regional half-graben; and the large-scale basin-fill patterns within the lower and upper half-graben. Deviations from the overall tectonically controlled basin-fill pattern is likely

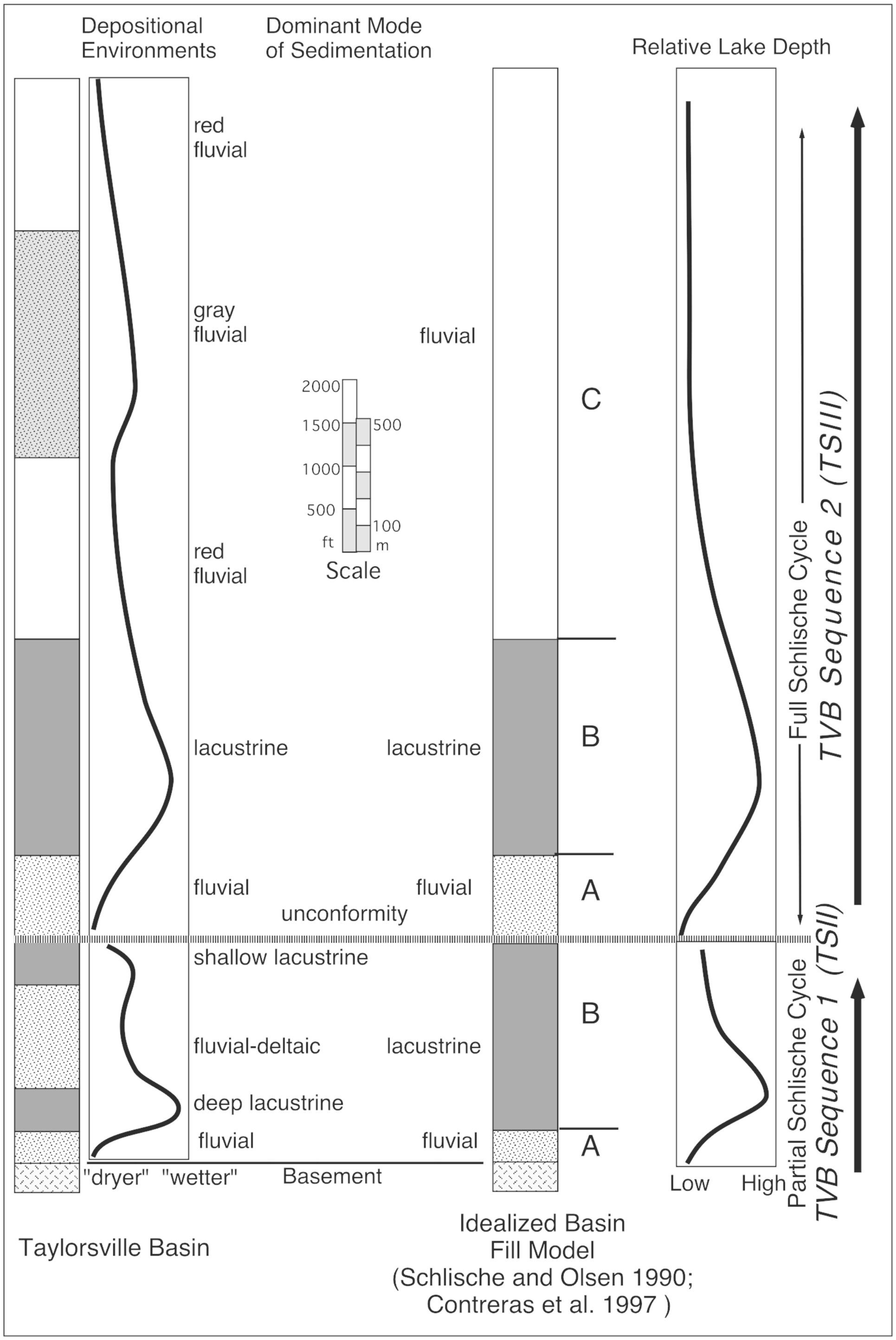

FIGURE 3.19 Comparison of tectonostratigraphic sequences of the Taylorsville basin with the idealized basin-fill models of Schlishe and Olsen (1990) and Contreras et al. (1997). TS II and TS III refer to Olsen's (1997) tectonostratigraphic sequences for the CAM rift system.

controlled by periodic climatic fluctuations (Olsen 1986; Olsen et al. 1996). Climatic controls on sedimentation include the regional hydrologic regime imposed by latitude—in this case near the Late Triassic paleoequator for the Carnian–Norian age Taylorsville basin (Kent, Olsen, and Witte 1995; Kent and Olsen 1997)—and by astronomically forced fluctuations predicted by Milankovitch periodicities (Olsen 1986). Therefore, in the tectonically controlled division B lacustrine depositional sequence, the presence or absence of lacustrine shale may be the result of periodic high-frequency modulations in the relative availability of moisture to the depositional system. The tectonic basin-fill model of Schlische (1991, 1993) provides the framework for the overall basin-fill pattern, but variations in regional hydrology controlled by latitude and astronomical forcing exert a strong control on sedimentation in specific intervals. For example, in the division B lacustrine sequences of the Taylorsville basin, both fluvial and lacustrine deposits are interbedded, and some lacustrine beds occur in the dominantly fluvial division C as a result of climatic variability.

Rock from the cores and from cuttings examined in my study reveals a far wider variety of sedimentary rocks and depositional environments than those based on only outcrop data (Weems 1980a; Goodwin et al. 1985; Ressetar and Taylor 1988; Cornet and Olsen 1990). Outcrops in the Taylorsville basin reveal the fluvial and lacustrine rocks of Sequence TVB 1 and only the lower fluvial portion of Sequence TVB 2. In the subsurface, the upper portion of Sequence TVB 2 consists of thick intervals of fine-grained fluvial and shallow to ephemeral lacustrine redbeds that are not present in the exposed basin. The humid "Richmond-type" model of rift basin deposition proposed by Olsen (1990) applies to the Sequence TVB 1 deposits, but the Sequence TVB 2 deposits correspond more closely to a model intermediate between the "Richmond and Newark types."

The "Richmond-type" model (Olsen 1990) describes rift sedimentation under persistently humid depositional conditions based on the presence of thick black shale beds and of coal and on the absence of evidence of subaerial exposure. In the "Richmond-type" model, water inflow to the basin exceeded evaporation, and the lake level equaled the outlet elevation much of the time. Fossiliferous lacustrine black shale, intercalated black shale and gray sandstone deposited as lacustrine turbidites, limestone beds, abundant plant fossils, coal beds, common unionid clam fossils, and lack of desiccation features argue strongly for humid depositional conditions that produced lakes, swamps, and perennial rivers and streams during the Sequence TVB 1 interval in the Taylorsville basin. The tectonic evolution of the basin was the primary control on basin morphology that favored the establishment of deep lakes in Sequence TVB 1. The basin was located in a near-equatorial position (Kent and Olsen 1997), and climate was the primary control on the amount of water available to the basin. Humid equatorial climate resulted in perennially wet depositional environments.

In the "Newark-type" model of Olsen (1990), water inflow closely matches outflow and changes in precipitation result in lake-level fluctuations of hundreds of meters. Dark-colored rocks deposited under deep lacustrine water alternate with red-brown–colored rocks, showing evidence of subaerial exposure and desiccation. Depositional cycles in "Newark-type" basins are largely controlled by periodic climatic fluctuations (Olsen 1986). The rocks of Taylorsville basin Sequence TVB 2, observed mostly in cores and cuttings, have a greater variability than the rocks of Sequence TVB 1. In Sequence TVB 2, laminated lacustrine black shale is commonly interbedded with red-brown– or gray-colored conglomerate, sandstone, and siltstone. The fine-grained redbeds may show evidence of exposure (desiccation cracks) or pedogenic profiles (caliche horizons). Again, tectonic evolution controlled the overall morphology of the depositional basin in Sequence TVB 2, with periodic climatic variability controlling the depositional environments. The deep lacustrine environments established early in the Sequence TVB 2 interval were gradually replaced by shallow lacustrine and fluvial environments in good agreement with the model predictions of Schlische and Olsen (1990) and Schlische (1991). During this later stage of rift basin development, periodic climatic fluctuations exerted a greater influence on deposition. Changes in basin configuration increased the total depositional area, resulting in alternations between open and closed basin conditions as lake depths fluctuated above and below the basin outlet level. Furthermore, northward drift of the North American plate moved the Taylorsville basin farther from the equator and into subequatorial climatic zones (Kent and Olsen 1997; Olsen 1997).

Tectonostatigraphic Sequences

The recent recognition of tectonostratigraphic sequences in the Triassic–Jurassic rifts of the CAM is a result both of the availability of seismic reflection profiles from the Taylorsville (LeTourneau 1999), Newark (Costain and Coruh 1989; Olsen 1997), Fundy (Withjack, Olsen, and Schlische 1995), and offshore rifts (Klitgord and Hutchinson 1985) and of the reinterpretation of outcrops in the Fundy basin and Argana basin of Morocco (Olsen 1997; Olsen et al. 2000). The presence of tectonostratigraphic sequences in the CAM rifts reveals that the tectonic history of the rifts is not one of constant subsidence, but one of punctuated episodes of subsidence and tectonic reorganization as the basin-bounding faults increase in size and interact with other normal faults (Dawers and Anders 1995; Withjack, Olsen, and Schlische 1995; Schlische and Anders 1996; Ackermann and Schlische 1997; Withjack, Schlische, and Olsen 1998). This study reveals that the large-scale stratigraphic architecture of the Taylorsville basin is defined by two unconformity-bounded tectonostratigraphic sequences. The stratigraphic interpretation of the CAM rifts is strongly dependent on the recognition of the tectonostratigraphic sequences and their attendant unconformities. The presence of tectonostratigraphic sequences explains some of the seemingly anomalous changes in depositional style or structural attitudes within some vertical sequences (figure 3.9).

The Taylorsville basin tectonostratigraphic sequences TVB 1 and TVB 2 correspond to the CAM tectonostratigraphic sequences TSII and TSIII of Olsen (1997). The tectonostratigraphic sequence concept provides a framework for understanding the timing and duration of rifting in individual basins and the regional tectonic history of the CAM (Withjack, Schlische, and Olsen 1998).

My study also has implications for the origin and age of the small Triassic rift basins scattered throughout the southern portion of the Newark Supergroup, including the Deep Run, Scottsville, and Briery Creek basins in Virginia. If the model for the origin and evolution of the Taylorsville basin can be extrapolated to these small outliers, it appears likely that the basins are remnants of the basal half-graben formed during the early stages of extension in the Late Triassic. These small basins may be comparable to the Sequence TVB 1 half-graben in the Taylorsville basin. My study suggests that small half-graben may have proliferated throughout the eastern flank of the southern Appalachians during distributed extension in the initial stages of rifting, only to be replaced by regional-scale half-graben as the basin-bounding faults increased in length and linked with neighboring faults during later phases of extension (Schlische and Anders 1996).

In addition, my findings suggest that the nearby Richmond basin has a related tectonostratigraphic history. Rocks in the lower portion of the Richmond basin are typified by dark lacustrine shale, coal, and gray sandstone, whereas the upper portion consists of fluvial sandstone (e.g., Otterdale Sandstone) and shallow lacustrine beds. These two major divisions of the Richmond basin are broadly comparable to Sequence TVB 1 and Sequence TVB 2 as defined in the Taylorsville basin. If this is the case, then most of the Richmond basin was deposited in a small, isolated, half-graben that later became part of a larger regional basin. In this interpretation, the upper stratigraphic levels of the Richmond basin once may have been connected to the Sequence TVB 2 strata of the Taylorsville basin.

Many of the numerous small Triassic basins known or inferred to exist beneath the Atlantic Coastal Plain cover, particularly those in the southern and central United States, may be related to Sequence TVB 1 half-graben indicated in this study, although some of the larger buried basins likely contain some Sequence TVB 2 deposits as well. The numerous subsurface, onshore, and offshore early Mesozoic age rift basins in eastern North America constitute an important record of the breakup of Pangea, but these basins are largely unexplored. Future seismic and drill hole explorations of the intriguing array of onshore and offshore buried early Mesozoic rift basins may reveal the sedimentological, paleontological, and perhaps economic riches that have lain undisturbed since the Late Triassic.

CONCLUSIONS

The Taylorsville basin, located in eastern Virginia and Maryland, is buried mostly beneath Cretaceous and younger passive margin deposits, although a small area of the southern part of the basin is exposed. Prior to oil and gas explorations conducted in the subsurface part of the basin in the 1980s and 1990s, only the outcrop area was used for stratigraphic, structural, and paleontological studies. Formerly thought to be one of the smallest of the early Mesozoic rifts in eastern North America, the Taylorsville basin is now known as one of the largest of the rifts, which has implications for the size of possible oil and gas reserves. Biostratigraphic data from vertebrate and plant fossils recovered in cores indicate that the subsurface portion of the basin is of Late Triassic, Carnian–Norian age. The age of the subsurface part of the basin is consistent with the Carnian and Norian age of strata in the outcrop area.

The Taylorsville basin contains the record of two main stages of rift subsidence. In the early stage of tectonic development, the basin consisted of a series of small, subregional-scale half-graben. The small, lower half-graben eventually were superseded in the later stage of development by a large, regional-scale half-graben. The lower half-graben are separated from the upper half-graben by a basinwide unconformity.

The sedimentary fill of the Taylorsville basin occurs in two unconformity-bounded sequences. Sequence TVB 1 was deposited in the small, lower half-graben, and Sequence TVB 2 was deposited in the large upper half-graben. Sequence TVB 1 rocks form the Carnian age Doswell Group, which includes, from base to top, the red and gray coarse, fluvial South Anna Formation and the dark-gray and black lacustrine shale, siltstone, and sandstone Falling Creek Formation. Strata deposited during Sequence TVB 2 form the Carnian–Norian age King George Group, consisting of, from base to top, the red coarse, fluvial Newfound Formation; the dark-gray and black lacustrine shale, siltstone, and sandstone of the Port Royal Formation; and the red and gray siltstone and sandstone of the Leedstown Formation. The composite stratigraphic section of the Taylorsville basin includes more than 4.5 km of strata.

Paleomagnetic analysis of the Taylorsville basin rocks produced a coherent paleomagnetic reversal stratigraphy that supports the lithostratigraphic interpretation. Furthermore, the paleomagnetic reversal stratigraphy correlates well with the Late Triassic magnetostratigraphy of the Newark basin. Paleomagnetic reversal stratigraphy provides the opportunity for high-resolution correlation of the Taylorsville basin with other Late Triassic rift sections of the CAM. The high-resolution correlations of rift sections reveal profound differences in the timing and duration of rifting and strong similarities in the paleoclimate record of the rifts once paleolatidudinal trends are recognized.

The large-scale stratigraphic patterns of coarse fluvial-lacustrine-fluvial rocks are in good agreement with the vertical arrangement of strata predicted by the tectonically controlled half-graben-fill model of Schlische and Olsen (1990) and of Schlische (1991). The rocks overlying both the basal and the middle unconformity are coarse-grained sandstone and conglomerate similar to the model predictions. The lower coarse-grained interval in both of the unconformity-bounded sequences is overlain by fine-grained, organic-rich lacustrine strata consistent with the tectonic basin-fill model. The lower sequence is truncated above the lacustrine interval by the midbasin unconformity, but the upper sequence continues up to a thick interval of interbedded fine and coarse fluvial strata, completing the model-predicted succession of strata. Small-scale variability within the large-scale pattern—for example, fluvial rocks interbedded in the lacustrine interval—is a result of climate-controlled changes in the hydrologic regime. A combination of tectonic and climatic influences on sedimentation produced the stratigraphic patterns observed in the Taylorsville basin.

The evaluation of the Taylorsville basin stratigraphy and structure based on test well and seismic data has yielded insights into the evolution of continental rifts that would be difficult to achieve by outcrop studies alone. The Taylorsville basin clearly shows two tectonically controlled stages of development. Evolution from small, isolated half-graben to a larger, regional-scale half-graben is controlled by the growth and linkage of basin-bounding normal faults. The tectonostratigraphic sequences are a first-order component of the rift stratigraphic architecture.

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APPENDIX

Revised Stratigraphic Nomenclature of the Taylorsville Basin

This appendix formalizes the stratigraphy of the Taylorsville basin. Where the earlier stratigraphic interpretations of Weems (1980a) and of Cornet and Olsen (1990) were based on observations in the outcrop area, this revised stratigraphy is based on the extensive subsurface data and a reevaluation of the relatively small area of outcrops in the vicinity of Ashland, Virginia. My reinterpretation adds approximately 3 km to the known stratigraphic section of the basin. This revised stratigraphy follows the guidelines established by the North American Commission on Stratigraphic Nomenclature in the 1983 North American Stratigraphic Code (NACSN 1983). I have retained the stratigraphic names proposed by Weems (1980a) for rocks in the outcrop area, along with the type sections designated by that author (NACSN 1983:arts. 7c and 19e), but I have revised the ranks of his stratigraphic divisions and stratigraphic correlations.

Sequence TVB 1: The Doswell Group

I raise the Doswell Formation of Weems (1980a) to group rank (NACSN 1983:arts. 28a and 28c). The Doswell Group, as herein defined, contains the strata within the unconformity-bounded Sequence TVB 1, deposited in the small half-graben in the lower part of the Taylorsville basin section. The Doswell Group represents a natural tectonostratigraphic unit bounded at the bottom by Paleozoic and Precambrian basement rocks and at the top by a basinwide unconformity (figures 3.10 and 3.11). The rocks of the Doswell Group are recognizable in the subsurface in well cuttings (figure 3.4) and cores (figure 3.5). The unconformity-bounded sequence that is formed of Doswell Group rocks is recognizable in seismic reflection profiles (figure 3.8). The Doswell Group includes two formations: the lower, fluvial South Anna Formation and the upper, predominantly lacustrine Falling Creek Formation (figure 3.11).

Sequence TVB 1 Lower Fluvial Deposits: The South Anna Formation

Cornet and Olsen (1990) and Milici et al. (1995) suggested that the stratigraphy of Weems (1980a, 1981, 1986) may not describe fully the lithologic relationships in the Taylorsville basin. In particular, the correlation of a basal, sandstone, and conglomerate fluvial unit observed in Stagg Creek and the South Anna River (figure 3.9) is equivocal, based on palynology (Cornet and Olsen 1990) and on the thickness of the overlying Falling Creek Formation. New data from the Campbell core and detailed observations along Stagg Creek, Deer Creek, and the South Anna River for this study reveal that the Stagg Creek Sandstone (Member) on Stagg Creek is not the same lithostratigraphic unit as the basal coarse fluvial unit that unconformably overlies basement along the South Anna River near the eastern margin of the basin, as identified in Weems (1981, 1986). The Stagg Creek Member, as defined by Weems (1980a) along Stagg Creek, Hanover County, Virginia, remains a valid lithostratigraphic unit within the revised stratigraphy proposed here, but, *contra* Weems (1980a), it is not the basal unit of the Taylorsville basin. The South Anna Formation, defined here, is the basal formation in the basin (figures 3.11 and 3A.1).

The South Anna Formation is named for the exposures on the South Anna River (Ashland Quadrangle, Virginia) that begin approximately 400 m upstream (south and west) of the Virginia Route 738 bridge over the South Anna River and for the nearby district of South Anna, Virginia, located on the Chesapeake and Ohio railroad line approximately 400 m northeast of Virginia Route 738 (figure 3.9). The exposures along the South Anna River unambiguously overlie the Paleozoic Petersburg Granite at this locality, and at least 107 m (350 ft.) of the basal coarse sandstone and conglomerate may be observed in a vertical section along the east and south banks of the river (figures 3.9, 3A.1, and 3A.2). This section is the proposed type section of the South Anna Formation (NACSN 1983:arts. 8e and 22b) (figure 3A.2).

The South Anna Formation forms the base of Sequence TVB 1 and consists of coarse fluvial conglomerate and sandstone ranging in thickness from 31 to 150 m (100 to 500 ft.). At the type locality (figures 3.9, 3A.1, and 3A.2), the South Anna Formation is approximately 107 m (350 ft.) thick. Only 4.6 to 6.1 m

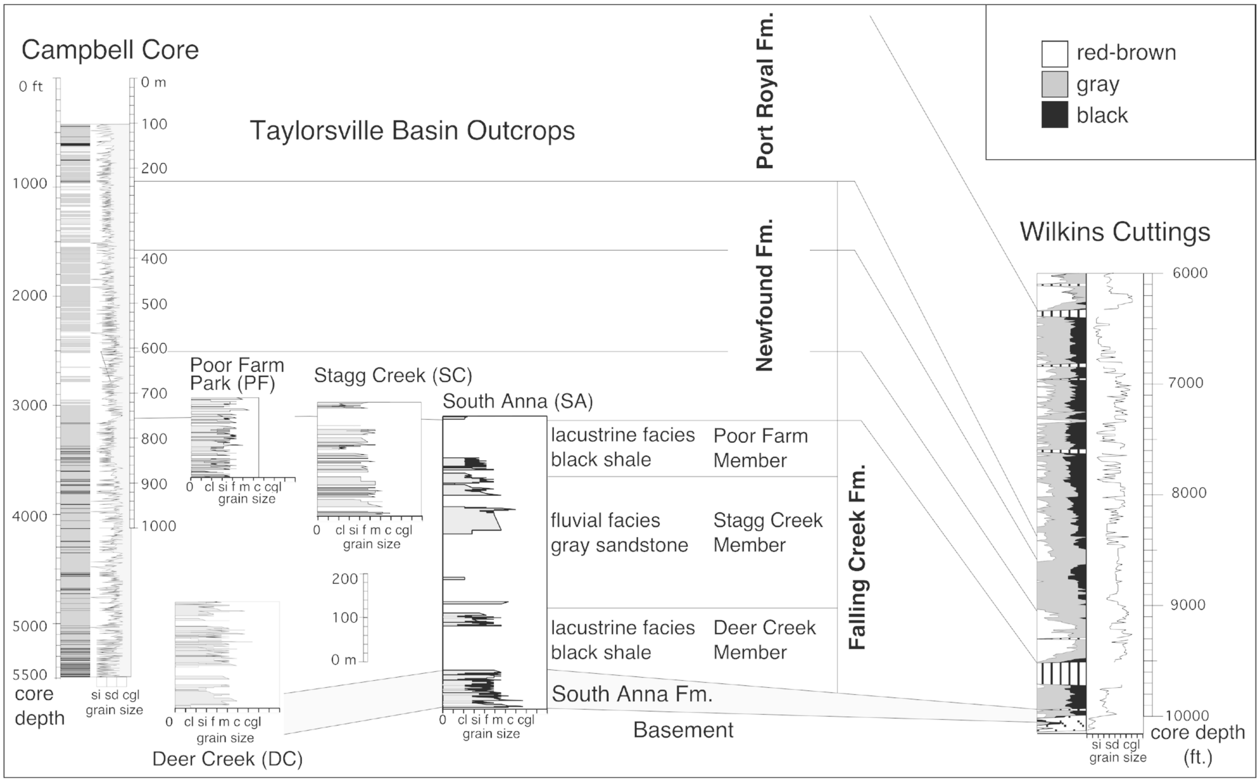

FIGURE 3.A1 Correlation of key measured sections from outcrops in the Ashland subbasin with the Campbell and Wilkins stratigraphic test wells from the subsurface part of the Taylorsville basin.

(15 to 20 ft.) of covered interval separates the fluvial section from the underlying basement. The lowest beds in the South Anna Formation are red, red-brown, and red mottled with green-gray very coarse sandstone and cobble and boulder conglomerate. Several thin, 0.9 to 1.5 m (3 to 5 ft.) thick sandy siltstone and silty, coarse to fine sandstone interbeds mark the tops of fining-up fluvial units.

Approximately 38 m (125 ft.) above basement at the type section, the fluvial deposits become organized into a repetitive succession of fining-up beds consisting of light-gray, channel-form, cross-stratified pebbly and very coarse sandstone overlain by dark-gray to black, organic-rich, ripple-and planar-laminated very silty, coarse to fine sandstone and sandy siltstone comprising overbank or floodplain deposits similar to the gray fluvial cycles. The overlying channel sandstones have bases scoured into the dark-colored, finer-grained floodplain deposits. Therefore, the finer-grained units are variable in thickness. The dark-gray to black color of the finer-grained fluvial beds is a result of the extraordinarily high percentage of coarse to fine macerated plant material preserved under reducing depositional conditions. In places, these units contain thin, coaly lenses and layers.

The coarse fluvial sandstone and organic-rich fine sandstone and siltstone of the basal South Anna Formation is also found in the exposed basin along Deer Creek (Hanover Academy Quadrangle, Virginia), where it underlies the Sequence TVB 1 fossiliferous lacustrine black shales of the Falling Creek Formation. The basal sandstone and conglomerate is approximately 150 m (500 ft.) thick in the Thorn Hill well but only about 30 to 60 m (100 to 200 ft.) thick in the Wilkins well, indicating that the South Anna Formation thins to the east as it onlaps the hanging-wall margin of the basin (figure 3.10).

Sequence TVB 1 Lacustrine Interval: The Falling Creek Formation

A lacustrine interval averaging approximately 610 m (2,000 ft.) thick overlies the coarse-grained rocks at the base of Sequence TVB 1 (figures 3.10 and 3.11). The lacustrine interval is characterized by organic-rich,

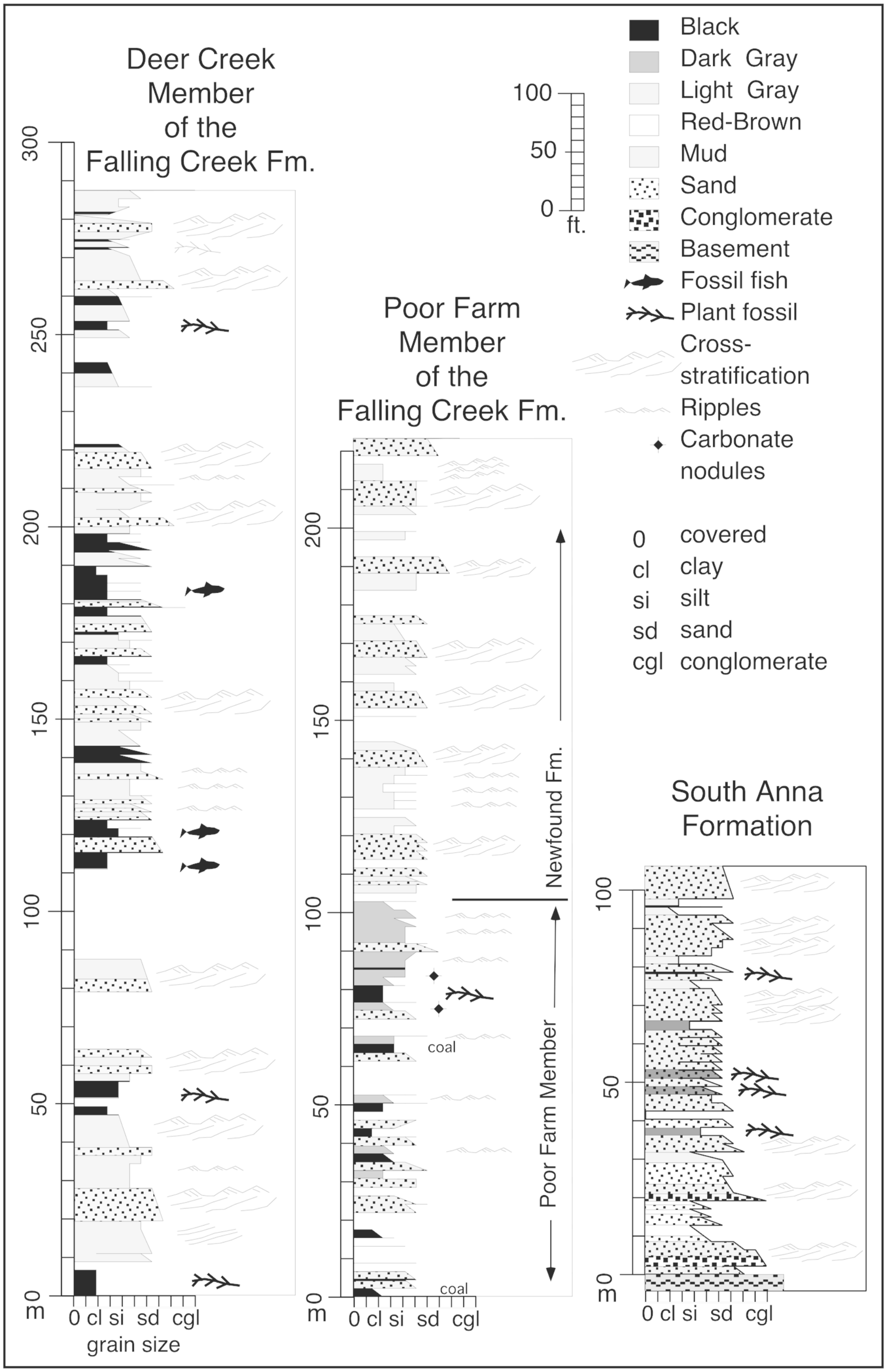

FIGURE 3.A2 Type sections of redefined stratigraphic intervals in the Taylorsville basin. For location, see figure 3.9; for the stratigraphic context, see figure 3A.1.

laminated, fossiliferous black shale and is important for biostratigraphic (pollen and vertebrates) interpretation and as a potential source rock for petroleum or natural gas. This interval is relatively well represented in the outcrop area of Taylorsville basin (e.g., Weems 1980a, 1981, 1986; Goodwin et al. 1985; Cornet and Olsen 1990) and was penetrated by the Campbell core and by the Thorn Hill and Wilkins wells. The Sequence TVB 1 lacustrine interval thickens toward the fault-bounded footwall margins of the lower half-graben. The Campbell core penetrated 760 m (2,500 ft.) near the thicker border fault margin of one of the basal half-graben (figure 3.10). The Thorn Hill well encountered approximately 366 m (1,200 ft.) of the Sequence TVB 1 lacustrine interval, and the Wilkins well penetrated about 150 m (500 ft.) of lacustrine strata near the thin hanging-wall side of one of the basal half-graben.

In the outcrop area, the lacustrine interval in Sequence TVB 1 was defined originally by Weems (1980a) as the Falling Creek Member of the Doswell Formation (figure 3.3). The type section of the Falling Creek (Member) described by Weems (1980a) is retained, but additional reference sections described here (figures 3A.1 and 3A.2) define three members that fully characterize the Falling Creek interval (NACSN 1983). The Falling Creek Formation contains fossiliferous black and dark-gray lacustrine shale interbedded with gray coarse to fine sandstone, gray siltstone, and minor discontinuous beds of dense, dark-gray to black limestone approximately 0.15 to 0.3 m (0.5 to 1.0 ft.) thick (figures 3.10, 3.11, and 3A.1). The lower portion of the Falling Creek Formation contains the most well developed lacustrine shales and also produces abundant fish fossils, particularly at the type section on Falling Creek (Weems 1980a, 1981), in exposures on the South Anna River, and in beds found in Deer Creek. Lacustrine shales are laminated and often contain thin, fining-up beds of sand to silty clay interpreted as turbidites based on the repetitive vertical arrangement of sedimentary structures as has been described in other Newark basins (Sanders 1965; Hentz 1985; Gore 1988; LeTourneau and McDonald 1997).

I raise the Falling Creek Member of the Doswell Formation (Weems 1980a) to the stratigraphic rank of a formation (NACSN 1983:arts. 24b–d). In my revised stratigraphy (figures 3.3, 3.11, and 3A.1), the Falling Creek Formation contains three members: a lower, deep-water lacustrine member; a middle fluvial member; and an upper, shallow lacustrine and fluvial-deltaic member.

The Deer Creek Member of the Falling Creek Formation. The reference section of the lower lacustrine member of the Falling Creek Formation is found in Deer Creek, a tributary of Beech Creek that flows into the South Anna River, northwest of Ashland, Virginia (figure 3.9). Deer Creek is located east of Deer Creek Road, north of Virginia Route 696; it is approximately 1 km to the east of and roughly parallel to Stagg Creek. The lower lacustrine division of the Falling Creek Formation is named the Deer Creek Member (figures 3.11 and 3A.1) after the type section (figure 3A.2) on Deer Creek. Here, fossiliferous lake beds are intercalated with fluvial-deltaic sandstone and minor conglomerate indicative of the position of the section near the western edge of the basin. Lacustrine turbidite beds—consisting of thin fining-up beds of coarse to fine sandstone, climbing ripple cross-laminated fine sandstone, and laminated silt and clay—are common throughout the section.

The Deer Creek Member of the Falling Creek Formation has the most well developed lake beds within Sequence TVB 1, consisting of finely laminated black shale often containing well-preserved fossil fishes, including *Dictyopyge macrurus, Cionychthis* sp., *Semionotus* sp., and Coelocanthidae indet. Outcrops of the Deer Creek Member of the Falling Creek Formation are found on Deer Creek, on the South Anna River, at the Falling Creek type section (Weems 1980a 1986), and on Little River near its confluence with the North Anna River (figure 3.9).

Along the South Anna River (figures 3.9 and 3A.1), the Deer Creek Member contains black, laminated lake shales; dark-gray to black limestone beds 0.15 to 0.3 m (0.5 to 1.0 ft.) thick; interbedded, light-to dark-gray, cross-stratified, coarse to fine sandstone; and organic-rich sandy siltstone. Two well-exposed black shale lake beds on the South Anna River have produced abundant and well-preserved fossil fish, as well as isolated reptile teeth, conchostracans, and ostracodes. A comparable and correlative section of the Deer Creek Member is observed in the Falling Creek type section of Weems (1980a, 1986) adjacent to Virginia Route 667 (Ashland Quadrangle, Hanover County, Virginia).

Here, two of four lake beds also produce abundant, well-preserved fossil fish. Thin, decimeter-scale lacustrine limestones are found also in the Deer Creek Member on the South Anna River and in Falling Creek. Two lacustrine, black shale beds of the Deer Creek Member containing fossil fish are found on the south bank of the Little River approximately 200 m west of the Chesapeake and Ohio railroad bridge near the confluence with the Little and North Anna Rivers (figure 3.9).

Approximately 293 m (960 ft.) of the Deer Creek Member is observed in the Campbell core from 1,384 to 1,676 m (4,540 to 5,500 ft.) depth (figures 3.4 and 3.9). The finely laminated, organic-rich, black shale beds are interbedded with very coarse conglomerate, and sandstone and lacustrine turbidite beds are common.

The Stagg Creek Member of the Falling Creek Formation. The middle division of the Falling Creek Formation consists of 366 to 460 m (1,200 to 1,500 ft.) of 0.9 to 3.1 m (3 to 10 ft.) thick, gray- to drab-brown–colored, fining-up fluvial, crossbedded, coarse channel-fill sandstone overlain by 0.15 to 0.9 m (0.5 to 3.0 ft.) thick silty sandstone and sandy siltstone overbank deposits. Similar to the fluvial deposits of the South Anna Formation, these overbank fines often contain a very high percentage of fine plant debris that imparts a very dark color to the beds (figures 3.11 and 3A.1).

I revise the Stagg Creek Member of Weems (1980a) to refer to the middle fluvial division of the Falling Creek Formation based on lithostratigraphic relationships observed in outcrop on Stagg Creek and the South Anna River and in the Campbell core (figure 3A.1). Weems (1980a, 1981) defined the coarse fluvial deposits on Stagg Creek in Poor Farm Park (Hanover County, Virginia) as the type Stagg Creek Member of the Doswell Formation. At this locality, approximately 183 m (600 ft.) of cross-stratified coarse sandstone and interbedded silty sandstone and siltstone arranged in fining-up beds occur above a faulted lower contact with the Petersburg Granite basement (figure 3A.1).

Along the South Anna River, approximately 366 m (1,200 ft.) of vertical section consisting of extensive bluffs of fining-up coarse to fine sandstone, pebbly sandstone, and minor conglomerate are observed above the fossiliferous lacustrine black shale of the Deer Creek Member and below overlying shallow lacustrine strata (figure 3A.1). These coarse-grained rocks are in the Stagg Creek Member of the Falling Creek Formation.

The Stagg Creek Member of the Falling Creek Formation is observed also from 1,079 to 1,533 m (3,540 to 5,029 ft.) depth in the Campbell core (figure 3A.1). This approximately 460 m (1,500 ft.) interval is dominated by coarse boulder-and-cobble conglomerate and coarse sandstone, with subordinate medium to fine sandstone and siltstone. The massive to cross-stratified beds range from 0.9 to 3.1 m (3 to 10 ft.) thick fine-up and frequently are capped by dark-gray to black, plant-rich, laminated, silty fine sandstone and sandy siltstone.

The Poor Farm Member of the Falling Creek Formation. The upper division of the Falling Creek Formation is named the Poor Farm Member for the excellent exposures in a tributary, herein referred to as Poor Farm Creek, flowing into Stagg Creek from the vicinity of the former sewage-disposal pond in Poor Farm Park, Hanover County, Virginia (figures 3.9 and 3A.2). Here, several thin coal beds are found along with an abandoned coal prospect pit (Weems 1981). It is noteworthy that one other abandoned coal prospect located north of Ashland, Virginia (Weems 1986), is also in the upper lacustrine division.

The Poor Farm Member of the Falling Creek Formation (figure 3A.2) is characterized by gray-, green-gray–, dark-gray–, and black-colored sandstone, silty sandstone, siltstone, calcareous sandstone and siltstone, and thin coaly beds indicative of shallow lacustrine, paludal, and fluvial deltaic depositional environments. The finely laminated, fossiliferous, lacustrine black shales that typify the lower division of the Falling Creek Formation are scarce in the Poor Farm Member. The dark-gray and black siltstone beds in the upper division often contain abundant burrows, carbonate nodules, a diverse assemblage of well-preserved plant fossils (e.g., Cornet and Olsen 1990), common and abundant clamshell casts referable to *Unio* sp. (Weems 1977), and disseminated fossil fish scales. To date, this division has not produced articulated fish remains, but vertebrate fossils—including isolated reptile teeth and bones and the unique armored archosaur *Doswellia kaltenbachi* (Weems 1977, 1980b)—have been found there.

The Poor Farm Member also contains thin (0.25 to 1 m) silty coal beds and lenses. The coal beds typically are surrounded by plant-rich, dark-gray to black siltstone and silty sandstone. Two abandoned coal prospect pits are found in the upper shallow division of the Falling Creek Formation; one is adjacent to thin coal beds in Poor Farm Creek, and the other is approximately 2 km west of Elletts Crossing north of Ashland, Virginia (Ashland Quadrangle, Virginia) (Weems 1980a, 1986). No coal prospects have been identified in the Deer Creek Member—the lower lacustrine division of the Falling Creek Formation.

The Poor Farm Member is exposed along Stagg Creek in Poor Farm Park (figure 3.9). The lacustrine rocks exposed here were described by Weems (1980a, 1981) and by Cornet and Olsen (1990) and in a field trip guide by Goodwin et al. (1985). The Poor Farm Member is also exposed along the South Anna River west of the power lines that cross the river and east of the Interstate 95 overpass (figure 3.9). Weems (1980a) described temporary exposures of lacustrine and fluvial rocks that produced *Doswellia* during the construction of the King's Dominion Amusement Park sewage-treatment plant. This interval is in the Poor Farm Member and is located near the confluence of the Little River and the North Anna River (figure 3.9). Weems (1980a) described an additional *Doswellia*-producing interval of the Poor Farm Member, located in a drainage cut beneath the Richmond, Fredricksburg, and Potomac railroad line approximately 1 km south and west of Elletts Crossing and U.S. Route 1 (Ashland Quadrangle, Virginia). This locality also occurs high within the Falling Creek Formation and is therefore in the Poor Farm Park Member. A temporary excavation of brownish-gray, clayey siltstone of the Poor Farm Member at Elletts Crossing produced abundant *Unio* casts (Cornet 1977) typical of the Poor Farm Member of the Falling Creek Formation.

The Poor Farm Member of the Falling Creek Formation is observed also from 963 to 1,079 m (3,160 to 3,540 ft.) depth in the Campbell core (figure 3A.1). This interval is dominated by coarse sandstone and conglomerate indicative of a change to coarse-grained facies near the western fault margin of the Taylorsville basin. Dark-gray to black, laminated, lacustrine shale beds and silty fine sandstone and siltstone beds are intercalated with the coarse fluvial and alluvial deposits.

SEQUENCE TVB 2: THE KING GEORGE GROUP

The fluvial and lacustrine strata in depositional Sequence TVB 2 comprise the King George Group, named for the town of King George in King George County, Virginia, located near the Taylorsville basin subsurface explorations (figure 3.11). The King George Group includes the Newfound Formation, the Port Royal Formation, and the Leedstown Formation. The fluvial South Anna Formation and the lacustrine Falling Creek Formation of Sequence TVB 1 are overlain unconformably by the lacustrine and fluvial strata of Sequence TVB 2. The unconformity between the two sequences is interpreted from seismic reflection profiles, borehole geophysical logs, abrupt lithologic changes, and changes in bedding attitudes.

The Newfound Formation

I raise the Newfound Member of the Doswell Formation of Weems (1980a) to formation rank (NACSN 1983:arts. 24b–d). The Newfound Formation consists of red and gray conglomerate, coarse sandstone, and sandy siltstone (figure 3.10). The exposures on Stagg Creek in Poor Farm Park south of Virginia Route 54 and in the Hanover Country Club north of Route 54 are included in Weems's (1980a) type section of the Newfound Formation. Additional exposures in the vicinity of Horseshoe Bridge on the South Anna River (Hanover Academy Quadrangle, Virginia) also typify the formation. Solite Corporation test holes on record with the Virginia Division of Mineral Resources (Charlottesville, Virginia) indicate the presence of red- and red-brown–colored conglomerate, sandstone, and siltstone in three wells (HAC-1, HAC-2, HAC-3) located between the South Anna River and Newfound River in the area north of Horseshoe Bridge, and in an additional well (ASH-1) located north of the South Anna River (figure 3.9). The ASH-1 well penetrates approximately 162 m (530 ft.) of the Newfound Formation and, at the bottom of the test hole, encountered approximately 9 m (30 ft.) of gray sandstone and dark-gray siltstone interpreted as the uppermost portion of the Falling Creek Formation.

Weems (1980a) stated that the Newfound Formation is up to 900 m (3,000 ft.) thick and consists of two facies: a sandstone-conglomerate facies and a siltstone-sandstone facies. However, due to poor exposures and the lack of deep stratigraphic test wells in the region of Newfound Formation exposures, the full stratigraphic thickness of the formation in the outcrop area is unknown. Based on data from cores, cuttings, and outcrops, the Newfound Formation is estimated to be approximately 600 m (2,000 ft.) thick. Comparison with the subsurface correlative of the Newfound Formation observed in the Campbell core and in the Wilkins and Thorn Hill wells sheds light on the lateral variability in the basal fluvial strata of Sequence TVB 2.

As traced in the subsurface, the Newfound Formation extends 16 km northeast to the Campbell corehole and more than 60 km northeast to the Wilkins and Thorn Hill wells (figure 3.10). In the Campbell core, the Newfound Formation is more than 650 m (2,100 ft.) thick and is encountered from 305 to 963 m (1,000 to 3,160 ft.) core depth (figures 3.10, 3.11, and 3A.1). This interval contains interbedded red-, red-brown–, and gray-colored conglomerate, coarse to fine sandstone, and siltstone. Fine-grained redbeds are common and have abundant root traces and burrows; coarser beds typically fine up and contain cross-stratification and ripple cross-laminae. A few dark-gray, laminated, plant-rich silty, fine sandstone beds are interbedded with the generally organic-poor red and gray beds. The Newfound Formation thins to approximately 150 m (500 ft.) thick toward the central portion of the Taylorsville basin as observed in the Wilkins and Thorn Hill wells (figure 3.10). Cuttings from the two wells reveal that in the center of the basin, the Newfound Formation consists primarily of red- and red-brown–colored conglomerate, sandstone, and siltstone, with subordinate quantities of gray sandstone and siltstone. Therefore, the character of the formation is consistent in the subsurface, although the thickness changes dramatically from approximately 610 m (2,000 ft.) near the western fault margin of the basin to approximately 150 m (500 ft.) near the basin center. This thickness change is largely a result of lateral facies change from predominately gray sandstone and minor gray and black mudstone in the area of the Campbell well to predominately gray and black mudstone and lesser sandstone toward the axis of the basin.

The Port Royal Formation

A thick lacustrine interval overlies the fluvial Newfound Formation. This interval measures up to 760 m (2,500 ft.) thick and is typified by dark-gray to black, finely laminated, fossiliferous shale, siltstone, and coarse to fine sandstone. Black shale cuttings from the Wilkins well contain isolated fish scales, conchostracans, and darwinulid ostracodes. The Sequence TVB 2 lacustrine interval is recognized in the Wilkins, Thorn Hill, and Gouldman wells and in limited portions of the Campbell and Butler cores (figure 3.10).

This lithologically distinct interval is named the Port Royal Formation for the municipality of Port Royal, Virginia, which is located near the center of the area of stratigraphic test wells and coreholes that reveal and define the lacustrine formation in the subsurface. This unit is mappable in the subsurface over a horizontal distance of approximately 40 km from the Campbell corehole on the western margin of the basin north-northeast to the Wilkins and Thorn Hill wells, and approximately 36 km from Campbell northeast to the Gouldman well (NACSN 1983:arts. 7a, 16a, 16b, 24a–c).

The Port Royal Formation (figures 3.4, 3.10, and 3.11) is defined as the predominantly dark shale and gray sandstone strata found between 1,920 and 2,740 m (6,300 and 9,000 ft.) depth in the Texaco Wilkins No. 1 stratigraphic test well, drilled at 38° 14′ 29′′ north latitude and 77° 00′ 45′′ west longitude, Westmoreland County, Virginia (Dahlgren Quadrangle, Virginia). Cuttings from this well are archived at the Lamont-Doherty Earth Observatory of Columbia University, Palisades, New York (NACSN 1983:art. 16b).

The Port Royal Formation has been recognized only in the subsurface portion of the Taylorsville basin in the Wilkins, Thorn Hill, and Gouldman wells and in the Campbell and Butler cores. As described earlier, the best expression of the deep-water lacustrine Port Royal Formation is found in the Wilkins well (figure 3.4). In the Thorn Hill well, the Port Royal Formation is approximately 460 m (1,500 ft.) thick and contains a larger percentage of gray conglomerate than the comparable interval in the Wilkins well. The Gouldman cuttings come from a location near the eastern margin of the basin and contain less black shale and more gray siltstone and sandstone than the cuttings from the basin-central Wilkins and Thorn Hill wells (figure 3.4). In addition, the Gouldman well contains coal suggestive of paludal and shallow lacustrine depositional environments near the eastern basin margin in contrast to the persistent, deep-water lacustrine environments that predominate in the central and western portions of the basin.

Only limited portions of the Port Royal Formation are observed in the Campbell and Butler cores (figure 3.10). In the Campbell core, an approximately 174 m (570 ft.) thick lacustrine formation occurs from 130 to 305 m (430 to 1,000 ft.) depth. Here, well-developed lacustrine black shales are interbedded with predominantly gray, coarse to fine sand and siltstone, with subordinate red- and red-brown–colored sandstone and with burrowed and rooted siltstone. The lowest portion of the Butler core, from 1,646 to 1,676 m (5,400 to 5,500 ft.) depth, is interpreted as the uppermost portion of the Port Royal Formation based on the occurrence of dark-gray to black silty fine sandstone and clayey siltstone exhibiting planar laminations, soft sediment deformation (slump folds), and the projected position of the Port Royal beds relative to the Butler core on seismic profiles. Overall, the Butler core contains finer-grained rocks than those recovered from the Payne and Bowie-Fogg coreholes located to the east, which indicates a large-scale, west-fining facies trend.

Due to generally poor exposures in the central and northern portions of the exposed part of the Taylorsville basin, it is possible that subsurface explorations in that region may eventually reveal part of the Port Royal Formation, although dark-shale beds have not been noted from the north-central and west-central portions of the outcrop area. I predict that only the lower portion of the Port Royal Formation occurs in the outcrop area.

The Leedstown Formation

The upper portion of depositional Sequence TVB 2 consists of more than 2,740 m (8,000 ft.) of red, red-brown, and light- to dark-gray sandstone, siltstone, and minor shale (figures 3.10 and 3.11). This distinct unit is named the Leedstown Formation for the nearby village of Leedstown, Virginia, which is located approximately 4 km west of the Gouldman well. The Leedstown Formation is defined as the predominantly red, red-brown, and gray sandstone and siltstone strata found between 552 and 2,134 m (1,810 to 7,000 ft.) depth in the Texaco P. H. Gouldman Jr. et al. No. 1 stratigraphic test well (figure 3.4), drilled at 38° 06′ 15′′ north latitude and 76° 57′ 20′′ west longitude, and located approximately 1 km southwest of Horners, Westmoreland County, Virginia (Champlain Quadrangle, Virginia and Maryland) (NACSN 1983:arts. 9, 22b, 23b). Cuttings from this well are archived at the Lamont-Doherty Earth Observatory of Columbia University, Palisades, New York (NACSN 1983:art. 16b).

This Leedstown Formation is present in all the cores and test wells used in my study, except for the Campbell core (figures 3.4, 3.5, and 3.10), and is thus the best-represented stratigraphic interval in the Taylorsville basin. The upper stratigraphic division of Sequence TVB 2 consists of three subdivisions: a 610 m (2,000 ft.) thick lower interval of red sandstone and siltstone; a 760 m (2,500 ft.) thick middle interval of gray sandstone; and a 760 m (2,500 ft.) thick upper interval of red sandstone and siltstone (figures 3.10 and 3.11). Cuttings from the Gouldman well and continuous core from the Bowie-Fogg test well best illustrate the three main lithologic divisions of the Leedstown Formation (figures 3.4, 3.5, and 3.10). The Leedstown Formation is traceable in the subsurface over an east–west distance of approximately 17 km from the Butler corehole to the Gouldman well, and over a north–south distance of approximately 20 km between the Payne corehole and the Thorn Hill well. Additional information provided in Texaco well logs indicates that the Leedstown Formation is also traceable from the coreholes in the central basin to the Ellis and Roberts coreholes on the eastern margin of the basin. The lower contact of the Leedstown Formation with the underlying Port Royal Formation is noted by an abrupt change from dark lacustrine shale in the Port Royal to red and red-brown sandstone and conglomerate. The upper boundary of the Leedstown Formation is not observed; it is overlain unconformably by Cretaceous Coastal Plain deposits that thin to the west.