The following summary was extracted from an extensive report on the coalbed methane resource potential of the Richmond Basin prepared by the Department of Mining and Minerals Engineering, Virginia Polytechnic Institute and State University.

THE METHANE POTENTIAL FROM COAL SEAMS IN THE RICHMOND BASIN OF VIRGINIA

Final Report

March 1981

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under

TRW Subcontract No. H12176JJ9S
DOE Contract No. DE-AC21-78MC08089

for

TRW Energy Systems Group
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McLean, Virginia 22102

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FOREWORD

This report is an evaluation of the coalbed methane resource potential of the Richmond Basin in east-central Virginia. The work was conducted and the report prepared by the Department of Mining and Minerals Engineering, Virginia Polytechnic Institute and State University under TRW/VPI & SU Subcontract H12176JJ9S, a subcontract under the U.S. Department of Energy (DOE) Methane Recovery from Coalbeds Project administered by the Morgantown Energy Technology Center.

The work develops the geologic framework and the coal and coalbed methane resources in a geologic basin from which very little recent subsurface exists. This report provides the background on which future coalbed methane exploration programs in this basin can be developed.

1. SUMMARY

The Richmond Coal basin, located about 12 miles west of the city of Richmond, Virginia, was the site of the first commercial coal mining in the United States. Mining activity continued there for a period of about 200 years. Despite this long history of mining activity, it is estimated that total production from the basin only amounted to about eight million tons of coal. Because very limited exploration work was done, the full extent of the coal resources of the basin are unknown and resource estimates are therefore imprecise, although they appear to range from two to four billion tons. The coal is chiefly medium volatile bituminous and in some areas has been altered to coke by igneous intrusions.

From the records, it appears that the coals contain significant quantities of methane. Although numerous reports of gas, gas explosions and disasters are recorded, accurate measurement of the gas content has never been attempted to establish the potential of this resource.

The city of Richmond, which currently consumes 13 billion cu. ft. per year of natural gas (Lordley, 1979), provides an excellent outlet and market for methane gas which may be produced from the basin.

Geologically, the coal occurs in an elongated basin 33 miles from north to south with a width that varies up to 9.5 miles. As stated, exploration has been minimal and the actual proportion of this area of approximately 170 square miles underlain by coal is not known. However, coal does outcrop or is known to occur over a distance of about 32.4 miles of a total perimeter of some 70 miles.

The coal seams dip steeply at 15° - 45° towards the center of the basin. The deepest part of the basin, at which coal is known to exist, was sampled at the Salisbury borehole which intercepted coal at 2320 feet (Jones, 1928). The depth in the center of the basin is not known, but could be 3,000 feet or greater. Whether or not the coal is continuous across the basin or continues around the perimeter cannot be determined from present evidence.

The coal seams mined, ranging from three to five in number, achieved great thicknesses especially where two or more of the seams merged. Thicknesses of 70 feet of coal, with some included shale bands, have been recorded.

As a result, assumptions have been made of the extent and thickness of the coals, upon which a coal resource has been estimated by computer contouring of available values, which results in a conservative estimate of 2.3 billion tons. The report of Shaler and Woodworth (1899) indicates the recoverable coal reserves at 1.152

billion tons, which when adjusted to include the unrecoverable coal gives a resource of 2.1 billion tons. Resource estimated by Heinrich (1878) range from 1.987 to 3.887 billion tons. In this report, however, a more conservative estimate of two billion tons has been used for the calculations of the methane content.

These resources were contoured for depth and thickness of coal, and an average quality of the coal was calculated. The results, based on the available data pertaining chiefly to the perimeter which was mined, are of varying credibility because of the quality dates and origin of some of the reports. For this reason, the gas content has been estimated using the method of Kim (1977), and the result has been evaluated for credibility with the reports of methane gas and found to have no conflict.

From this study it would appear that the potential resource methane may range from 700 billion cu. ft. to 1400 billion cu. ft. or enough to provide many years supply based upon the current total usage rate of Richmond.

Therefore, the drilling of a number of exploratory holes in the basin may have merit to establish the actual extent of the coal beds, the methane content of these beds, and the characteristics of desorption of the methane gas from the beds.

GUIDEBOOK TO THE GEOLOGY OF THE RICHMOND AND TAYLORSVILLE BASIN, EAST-CENTRAL VIRGINIA

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Eastern Section AAPG Meeting
Fieldtrip Number 4

10 November 1985

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The following guidebook, prepared by Dr. Bruce K. Goodwin and others in 1985 for the Eastern Section Meeting of AAPG, was available for many years from the Virginia Division of Mineral Resources in Charlottesville, VA. It is reproduced herein, with permission of the Division, to replace the now out-of-print version of the guidebook.

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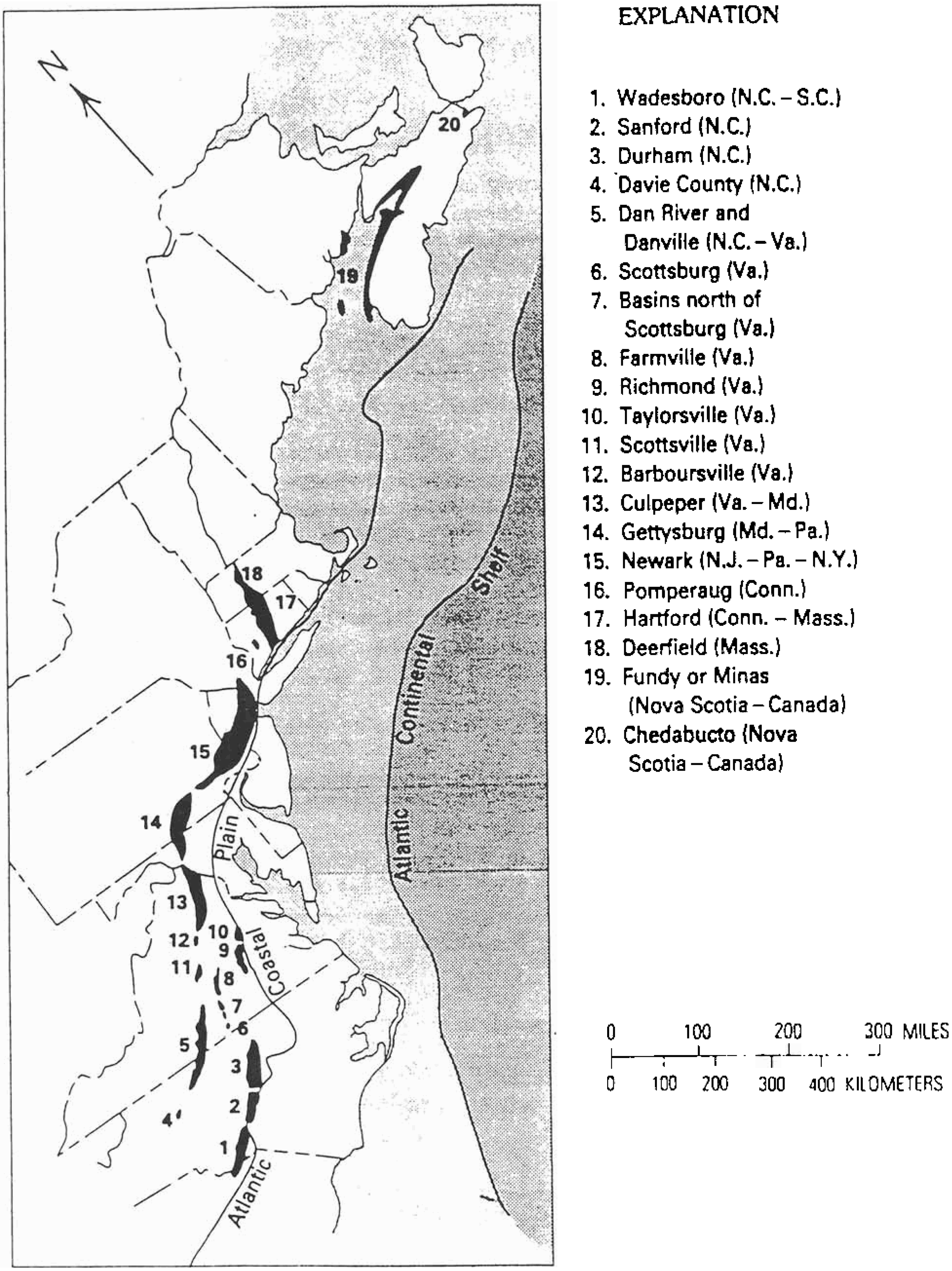
GUIDEBOOK TO THE GEOLOGY OF THE RICHMOND AND TAYLORSVILLE BASINS, EAST-CENTRAL, VIRGINIA

Introduction and regional setting

After the Appalachian orogeny, the long period from Permian through Early Triassic time was dominated by erosion and nondeposition in eastern North America. This interval was succeeded by an early Mesozoic rift regime, apparently controlled by extensional forces, that eventually would open up the Atlantic Ocean basin. One of the earliest signs of this profound change in tectonic regime was the commencement of deposition in the basins of the Newark Supergroup (fig. 1). The basal strata of the Fundy basin are Ladinian (Middle Triassic) in age and are the oldest known Newark beds (Froelich and Olsen, 1984), so this northernmost basin may have been the first to develop. Shortly after, probably in the middle Carnian, the Richmond and Taylorsville basins also began to subside and accumulate sediments. By late middle to late Carnian time, the other major rift-related basins had developed along inherited tectonic trends.

Diverse pollen and spore floras and the fluvial to lacustrine sedimentary fill of the various Newark basins in middle Carnian time suggest that these sediments were deposited under at least seasonally wet conditions. A trend toward increasing regional aridity is suggested by the alternating chemically precipitated and detritally accumulated sediments of the upper Carnian lake sequences in the Newark basin (Van Houten, 1964) and by upper Carnian floras in the Danville/Dan River basin (Cornet, 1977; Olsen and others, 1978; Robbins, 1982). By Norian time, the basins apparently became semiarid to intermittently arid, as indicated by reduced diversity among pollen and spores (Cornet, 1977). Dry conditions continued to prevail into earliest Jurassic time, but later during the Early Jurassic, conditions became more moist and equable, as indicated by the increased abundance of organic matter-rich lake deposits and stream deposits and by an increasing diversity of spores and pollen (Cornet, 1977). A second interval of aridity may have occurred near the end of Newark time, for pseudomorphs of evaporite minerals are found in the highest beds of the Newark and Hartford basins (J. P. Smoot, personal observation).

Depositional interludes in the Early Jurassic were punctuated by at least three major episodes of basaltic extrusion, which produced well-preserved flow sheets in all basins from the Culpeper north. Numerous diabase dikes, which cut the Triassic strata of the older southern basins, also may be associated with this volcanic activity. Subsequent



EXPLANATION

1. Wadesboro (N.C. – S.C.)
2. Sanford (N.C.)
3. Durham (N.C.)
4. Davie County (N.C.)
5. Dan River and Danville (N.C. – Va.)
6. Scottsburg (Va.)
7. Basins north of Scottsburg (Va.)
8. Farmville (Va.)
9. Richmond (Va.)
10. Taylorsville (Va.)
11. Scottsville (Va.)
12. Barboursville (Va.)
13. Culpeper (Va. – Md.)
14. Gettysburg (Md. – Pa.)
15. Newark (N.J. – Pa. – N.Y.)
16. Pomperaug (Conn.)
17. Hartford (Conn. – Mass.)
18. Deerfield (Mass.)
19. Fundy or Minas (Nova Scotia – Canada)
20. Chedabucto (Nova Scotia – Canada)

Figure 1. — Exposed basins of the Newark Supergroup in eastern North America (from Froelich and Olsen, 1984).

tectonism, which accompanied the opening of the Atlantic to the east, produced the tilted half-grabens that now characterize the Newark Supergroup of eastern North America.

This trip will be mainly concerned with sediments that accumulated during the early, relatively wet stage of this sequence, and with the subsequent diagenetic and tectonic changes that transformed them into the rocks that are now present in the preserved remnants of the Richmond and Taylorsville basins.

Areal extent and geologic setting

The Richmond and Taylorsville basins in east central Virginia (fig. 2) are north-northeast-trending fault-controlled troughs that contain regionally northwest-dipping Upper Triassic sedimentary rocks of the Newark Supergroup. The two basins are part of a series of half-grabens, all of early Mesozoic age, that are located east of the folded Appalachians (fig. 1). Locally, strata are cut and metamorphosed by narrow dikes of tholeiitic diabase which are probably of Early Jurassic age. Although all of the Newark basins possibly had similar depositional and early structural histories, they now are found in two very different geographic settings. The more westerly (exposed) basins are in subparallel belts in the Piedmont and equivalent terranes in New England and Maritime Canada from South Carolina to Nova Scotia (fig. 1), whereas more easterly basins are buried beneath Cretaceous to Quaternary sediments of the Atlantic Coastal Plain and Continental Shelf from Florida to Nova Scotia.

The Richmond basin (fig. 3) is located 12 miles (19 km) west of the Atlantic Coastal Plain and the City of Richmond; its approximate geographic center is just southeast of Hallsboro in Chesterfield County. The basin is 33 miles (53 km) long, with a maximum width of about 9.5 miles (15 km), and is exposed over an area of approximately 190 square miles (500 km^2). Five small outlying basins in proximity to the northeastern end of the Richmond basin were probably once continuous with the Richmond basin but have since been partially or completely isolated by erosion.

The Taylorsville basin (fig. 4) is located 16 miles (26 km) north of the City of Richmond and 7 miles (11 km) northeast of the Richmond basin. The exposed part of the Taylorsville basin is 12 miles (19 km) long and a maximum of 7 miles (11 km) wide, with an areal extent of about 50 square miles (130 km^2). The total area of this basin is larger, probably much larger, because the northeast edge of the exposed basin is overlapped by sediments of the Atlantic Coastal Plain. Subsurface control beneath the Coastal Plain is presently insufficient to delineate accurately the Taylorsville basin beneath it, but

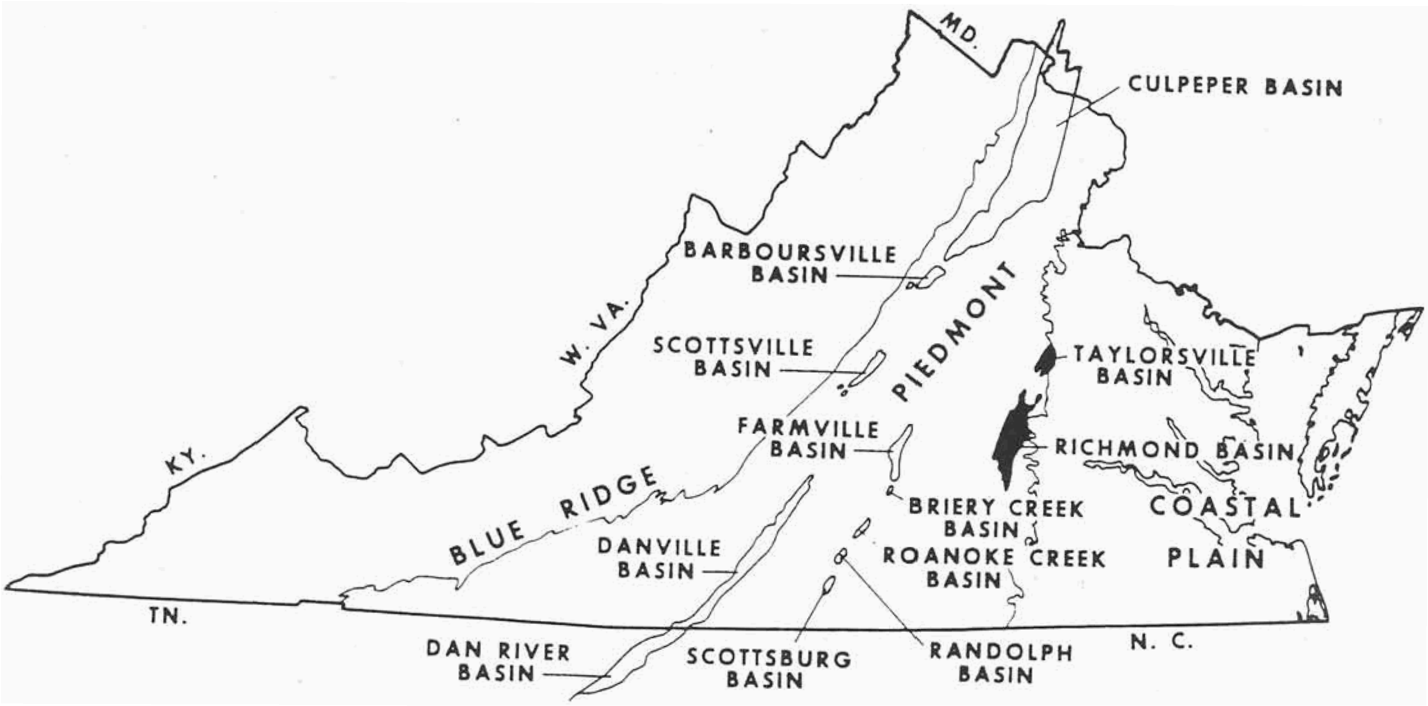


Figure 2. — Regional geologic setting of the Richmond and Taylorsville basins (modified from Johnson and others, 1985).

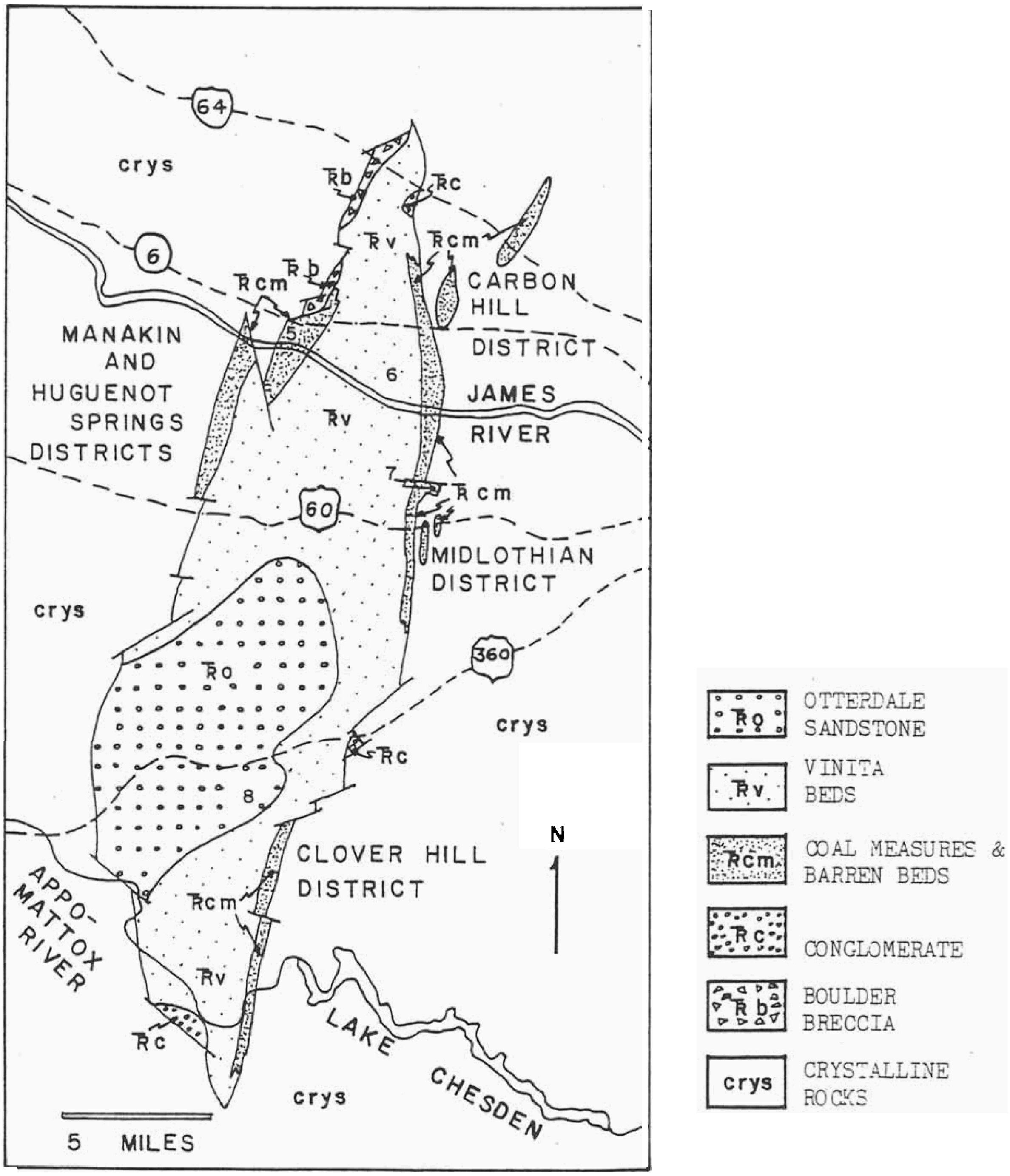


Figure 3. — Generalized geologic map of the Richmond basin and outlying basins (modified from Shaler and Woodworth, 1899; Roberts, 1928; Goodwin, 1970; and Goodwin and Farrell, 1979). Locations of field trip stops 5 through 8 are indicated.

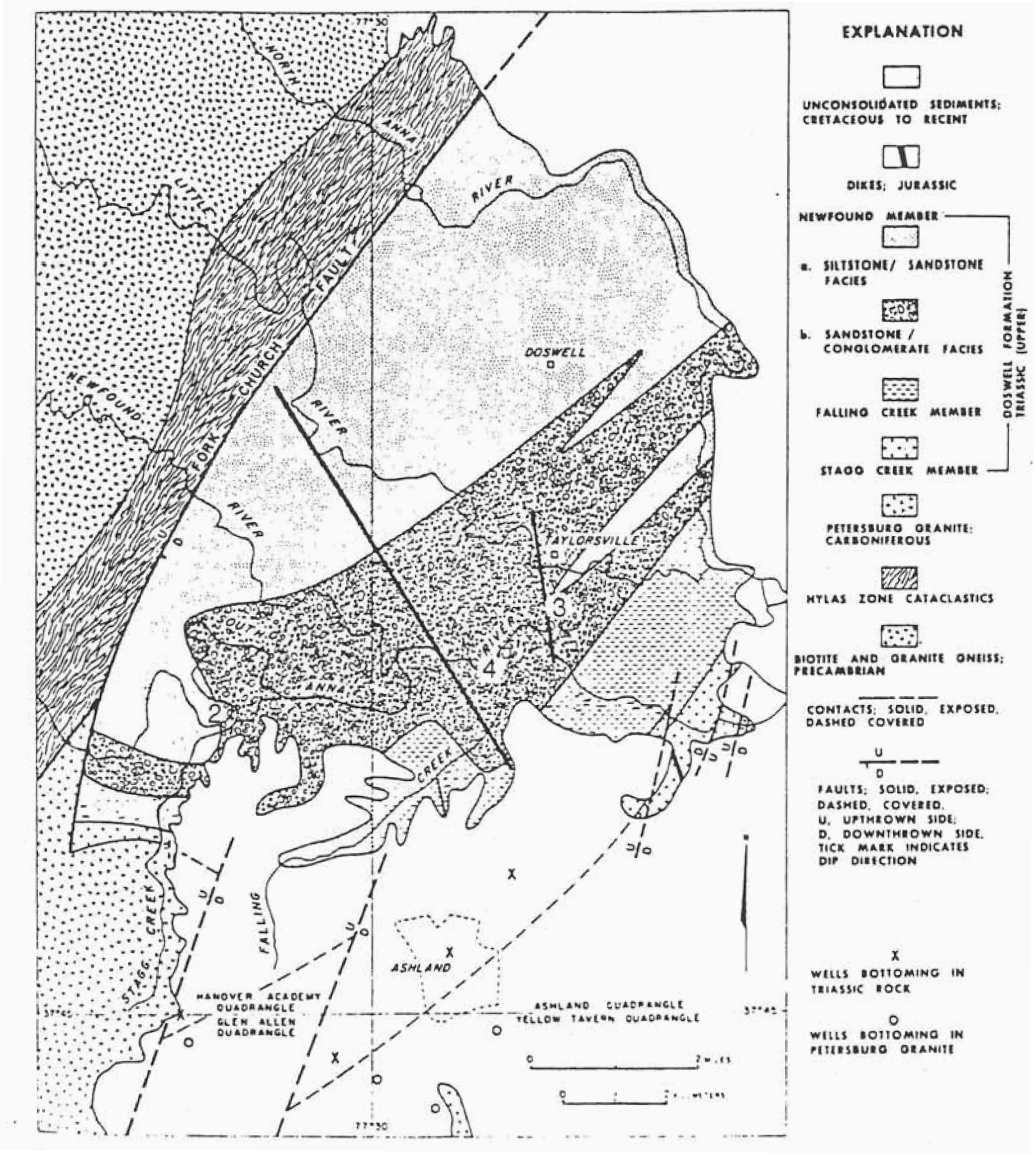


Figure 4. — Geologic map of the exposed portions of the Taylorsville basin (modified from Weems, 1980b). Locations of field trip stops 1 through 4 are indicated.

geophysical and sparse drill-hole data suggest that it could extend northeast into southern Maryland (Robbins and others, in press).

The Richmond basin is completely enclosed by older igneous and metamorphic rocks of the Piedmont Province (fig. 2). The exposed parts of the Taylorsville basin are similarly enclosed, as probably are the buried parts of the basin. Beds in both the Richmond and Taylorsville basins show a regional northwest tilt and both basins are bounded on their northwest sides by a common tectonic feature, the Hylas zone. This fault zone, composed mainly of cataclastic rocks, has been active in both late Paleozoic and early Mesozoic time (Bobyarchick and Glover, 1979), and in early to middle Tertiary time as well (Mixon and Powars, 1984). Most clasts in Triassic conglomerates along the northwest basin borders seem to represent fragments of the Hylas zone cataclastic rocks. Angular clasts are found in some of the Triassic conglomerates near the top of the sedimentary sequence in the Taylorsville basin (fig. 5), and along the western margin of the Richmond basin north of the James River. These may represent talus-slope deposits locally preserved at the base of the fault scarps from which they were derived. These observations suggest that the western margins of the basins, at least during the later stages of their development, were rooted in the intermittently active Hylas fault zone. Much of the sediment in both basins was derived by weathering and erosion of the gneiss, amphibolite, granodiorite, and granite of Proterozoic to possibly early Paleozoic age that are found immediately northwest of that zone.

The Petersburg Granite complex flanks both basins on the other exposed margins, except at the southern end of the Richmond basin where metasediments are exposed (fig. 3). The sedimentary deposits of the Richmond and Taylorsville basins unconformably overlie the Petersburg Granite, and the conglomerates exposed along the eastern basin margins contain numerous clasts of Petersburg Granite. This granite has been dated as 330±8 million years in age (Wright and others, 1975). The presence of two micas (biotite and muscovite) in at least some of the Petersburg facies indicates that the granite may have formed at a depth of at least 5 miles below the surface of the earth. Its presence directly below strata of the Richmond and Taylorsville basins therefore suggests that erosion may have stripped at least 5 miles of material from the complex of Petersburg batholiths during the 100 million years before the Late Triassic. Although small-scale faults are locally found along the eastern margins of the basins, the strata generally dip gently toward the west. Their structural and stratigraphic configuration, as well as the small erosional outliers of the Richmond basin, suggest that in the past both basins extended farther to the east.

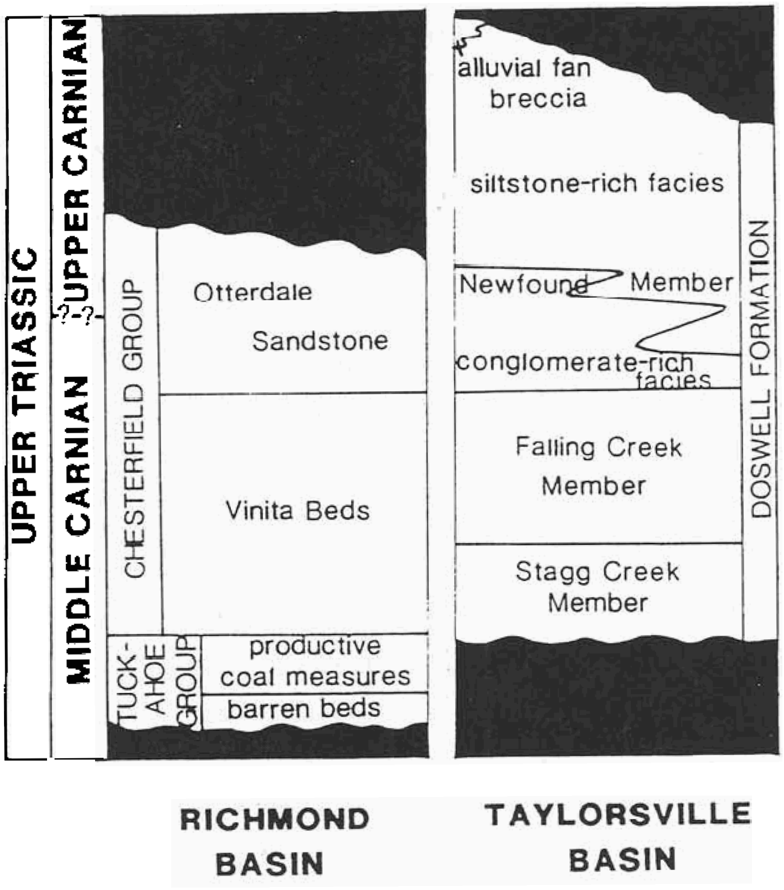


Figure 5. — Stratigraphic columns of the Richmond and Taylorsville basins (modified from Weems, 1980b).

Previous work

One of the earliest works on the Triassic rocks of the Richmond basin was by Sir Charles Lyell (1847). Other early publications on the coals, fossils, stratigraphy, and structure of this basin are by Heinrich (1878), Fontaine (1883), Ashburner (1888), Shaler and Woodworth (1899), Woodworth (1902), and Roberts (1928). The first geologic map of the basin was produced by Shaler and Woodworth (1899), reproduced by Roberts (1928) with no change, and provided the outline of the basin shown on the Geologic Map of Virginia (Milici and others, 1963). More recent studies of the Richmond basin and surrounding areas have been made by Goodwin (1970, 1980, 1981), and Goodwin and Farrell (1979). Studies of the paleontology and the age and correlation of the sedimentary rocks as revealed by spores, pollens, vertebrates, and other fossils have been made by Redfield (1841), Fontaine (1883), Cornet, Traverse, and McDonald (1973), Cornet (1977), Schaeffer and McDonald (1978), Olsen, McCune, and Thompson (1982), and Olsen (1984). Cornet (1977) assigned all of the Triassic strata in the Richmond and Taylorsville basins to his Chatham-Richmond-Taylorsville palynofloral zone of middle Carnian age (Late Triassic), and Olsen, McCune, and Thompson (1982) include these beds in the Dictyopyge fish zone. The approximate correlation of strata between the Richmond and Taylorsville basins is indicated in figure 5.

The sedimentary rocks in the Taylorsville basin were first studied and recognized as being Triassic or Jurassic in age by Rogers in the 1830's and 1840's (these reports are reprinted in Rogers,1884). Heinrich (1878) and Russell (1892) briefly discussed the strata in this basin, but after their time the sediments in the Taylorsville area were considered to be either mostly part of the Cretaceous Patuxent Formation (Clark and Miller, 1912) or to represent only a small outlying part of the Richmond basin (Roberts, 1928; Krynine, 1950). No detailed mapping was done in the Taylorsville basin until the work of Weems (1980b, 1981, 1985), who also introduced the present stratigraphic nomenclature for this basin (figs. 4, 5). Aspects of the paleontology of this basin have been studied or discussed by Fontaine (1883), Knowlton (1899), Cornet, Traverse, and McDonald (1973), Cornet (1977), Schaeffer and McDonald (1978), Weems (1980a), Olsen, McCune and Thompson (1982), and Olsen (1984).

Stratigraphy

The Triassic lithologies present in the two basins are similar, being dominantly sandstones with subordinate amounts of conglomerate, siltstone, shale, coal, and limestone. The sequence of these sediments in the two basins is somewhat different and the timing of sedimentation is not entirely synchronous (fig. 5), so the stratigraphic columns of the two basins have been named separately and are discussed separately below.

Stratigraphy of the Richmond basin:

Shaler and Woodworth (1899) divided the Triassic rocks in this basin into two groups: a lower, Tuckahoe Group and an upper, Chesterfield Group. Olsen and others (1978) have retained these two group names to refer specifically to the rocks of the Newark Supergroup in the Richmond basin. These two groups were subdivided by Shaler and Woodworth, who divided them, from bottom to top, into the Boscabel boulder beds, the lower barren beds, and the productive coal measures within the Tuckahoe Group, and the Vinita Beds and the Otterdale Sandstone within the Chesterfield Group. Variations on these names are still in common usage, but terminology for the Richmond basin has not stabilized. The major coal-mining districts in the Richmond basin are also indicated on figure 3. Since 1980, 15 exploratory test holes for oil and gas have been drilled to total depths ranging from 1,195 ft (362 m) to 7,443 ft (2,255 m). Most had gas and/or oil shows and only 4 penetrated the crystalline basement rocks.

The Boscabel boulder beds, as described by Shaler and Woodworth (1899), consist of large angular blocks of cataclastic rocks, as much as 2 by 3 feet (0.7 by 1 m) with some larger than 5 feet (1.7 m) in diameter, in a matrix of Triassic sandstone. They were referred to as a boulder breccia by Goodwin and Farrell (1979) and are found in a narrow outcrop belt (Fig. 3) along the faulted western margin of the basin west of Boscobel (which is a variant spelling of Boscabel) and north of the James River. They have not been recognized elsewhere along the basin margin, possibly because of the paucity of exposures within the basin. The angular nature, random orientation, and localized distribution of the Boscabel boulder beds suggest that they were deposited as talus piles at the base of a fault scarp along the western margin of the basin. It is probable that they are not a basal Triassic unit across the entire basin as envisioned by Shaler and Woodworth, but rather that they were deposited locally along the faulted northwest margin and proceed to grade eastward into finer grained sediments (Goodwin and Farrell, 1979). Conglomerates also are found locally along the eastern and southern margins of the Richmond basin (fig. 3).

The lower barren beds are so named because they lack coal and underlie the coal measures. The best section through the lower barren beds was presented by Heinrich (1878), who compiled a stratigraphic column from mine workings and drill holes in the

Midlothian area. He showed a thickness of 571 ft (173 m) for the lower barren beds including 36 ft (11 m) of basal conglomerate, but thicknesses are usually less than 400 ft (130 m). Heinrich described the rocks above the basal conglomerate and below the coal measures as being about 72 percent sandstone and 28 percent shale. The sandstones are light to dark gray, commonly carbonaceous and arkosic, whereas the shales are black or brownish black, and commonly rich in organic matter. Heinrich mentioned that about half of the shales in the upper part of the lower barren beds are calcareous, containing streaks and concretions of calcium carbonate. He also stated that the shales contain plant fossils, fish scales, and some reptilian teeth.

The productive coal measures constitute only a minor part of the stratigraphic column above the lower barren beds. Other coal beds locally occur at higher levels within the Vinita Beds and the Otterdale Sandstone. The base of the lowest minable coal marks the boundary between the lower barren beds and the productive coal measures, and the latter unit ranges from 0 to 400 ft (122 m) in thickness. Estimates of composite coal thickness within the productive coal measures have been: 32 ft (9.6 m) of coal in 90 ft (27 m) of section in the Midlothian area (Heinrich, 1878); 43 ft (13 m) of coal in 180 ft (54 m) of section at Winterpock (Fontaine, 1883); and 25 ft (7.5 m) of coal within 112 ft (34 m) of section at Gayton (Davis and Evans, 1938). The coal is usually a good-quality bituminous coal which is rich in methane. Black shales and fine- to medium-grained carbonaceous sandstones are present with the coal. Natural coke has been formed locally where Early Jurassic(?) dikes intrude coal seams.

The section described by Heinrich (1878) was composed of approximately 38 percent sandstone, 36 percent coal, and 26 percent shale (much of which is probably siltstone). The sandstone is gray and in places arkosic. It is generally poorly sorted, containing rounded grains that are bonded by silica or calcite cement. Coal bands, rafted coal, and plant debris have been noted in sections by Heinrich (1878) and Shaler and Woodworth (1899). The sandstone occurs as massive bodies or is interbedded with shale, siltstone, or coal. Shale occupies only a small part of the section. Locally, fossiliferous carbonaceous shale is found just above or below some coal seams which grade into other lithologies within a few feet. Rooted underclays underlie some coal seams.

The Vinita Beds overlie the productive coal measures and consist dominantly of fine- to coarse-grained, gray sandstone (in part crossbedded), gray siltstone, and dark-gray to black shale. Some conglomerates, containing well-rounded pebbles of quartz, granite, and gneiss are present within the Vinita Beds, at the base of channels cut into underlying beds. Shaler and Woodworth (1899) considered the Vinita Beds to be about

2,000 ft (600 m) thick. However, recent drilling in the Richmond basin has shown that the Vinita Beds may be as much as 6,000 ft (1,800 m) thick. They were probably deposited in lacustrine, fluvial, and deltaic environments, with lacustrine sequences dominating the center of the basin and fluvio-deltaic sediments extending into the basin from the margins. The fluvio-deltaic deposits are apparently depositionally localized along the faulted western margin of the basin.

The overlying Otterdale Sandstone forms a large, lobate mass extending from the western border eastward toward the center of the basin (fig. 3). The predominant lithology is coarse-grained, arkosic sandstone that is commonly cross-bedded and contains well-rounded quartz granules and pebbles. Prominent channel scours are filled by coarse-grained, crossbedded, pebbly sandstone with basal cobble zones. Conglomeratic beds containing well-rounded pebbles and cobbles of quartz, gneiss, and granite, also are common. Fine-grained sandstones are locally interbedded with siltstones and shales. The conspicuous channels and their fill of coarse-grained, cross-bedded sandstones and conglomerates suggest that these sediments were deposited in a fluvial environment. A braided stream network that alternately cut and filled the surface of the area probably produced the numerous channels, and intermittent overbank deposits of silt produced the interfingering micaceous siltstones.

Shaler and Woodworth (1899) determined that the Otterdale Sandstone was more than 500 ft (150 m) thick, but they were unable to establish its full thickness. A well, drilled 0.5 mile from the basin's western border in 1978, penetrated 1,514 ft (454 m) of coarse sandstone and conglomerate comparable to the Otterdale before terminating in a diabase (Goodwin and Farrell, 1979). This suggests that the Otterdale Sandstone might continue down to basement near the northwestern edge of the basin, and that the lower strata of the unit may have been deposited in facies contact with lacustrine Vinita Beds, which were accumulating contemporaneously in the interior of the basin. The Otterdale thins to the northeast, becomes less conglomeratic, and there overlies the Vinita Beds. Locally, the Otterdale Sandstone and Vinita Beds appear to interfinger. This may have been caused by intermittant pulses of basin deepening, which would have affected the volume of coarse clastic sediments which could have been carried into the basin and deposited at the distal eastern end of the Otterdale sequence.

A brief history of coal mining in the Richmond basin:

The first coal mined in the United States came from the Richmond basin (Robbins and others, in press). Although coal was reported from this area as early as 1701, active mining did not commence until around 1750 (Nicholls, 1904) and only in 1795 did the annual production from the basin exceed 2,000 tons. Since then, three major mining centers developed on the eastern margin of the basin: (1) the Gayton District (Carbon Hill District) north of the James River; (2) the Midlothian District south of the James River; and (3) the Winterpock District (Clover Hill District) near the southern end of the basin. Two mining centers developed on the western margin of the basin: (4) the Manakin District north of the James River; and (5) the Huguenot Springs District south of the James River. Mining was nearly continuous along the eastern margin of the Richmond basin between the Gayton and Midlothian Districts, and on the western margin between the Manakin and Huguenot Springs areas. On the eastern margin, where Triassic rocks generally unconformably overlie basement, many mines began as open pits on the coal exposures and were later extended as inclines down the dip of the coals. Some shafts were driven down to the coals west of the exposures and inclines were then extended into the coals at the base of the shafts. The westward-dipping Triassic-basement contact and the overlying coal measures on the basin's eastern margin had many flexures (or "troubles" in the terminology of the miners). These caused the coal to thicken and thin rapidly, and even to pinch out locally. Adjacent to the faulted western margin of the basin, shaft mines were the rule. Although the coal in the Richmond basin is a high volatile bituminous coal of good quality, extracting it in this area has always been dangerous and frustrating. Roof control was difficult, violent methane explosions were common, and structural instabilities were difficult to predict.

At least 2,892,645 tons of coal were produced between 1780 and 1840 (Brown and others, 1952, Table 5). Most of this coal was used locally for domestic purposes, but some was shipped from Richmond to Philadelphia and New York. Mining activity was at its peak and flourished around Winterpock, Midlothian, and Gayton from 1842 to 1880. North of the James River, most of the mines around Manakin and Gayton finally closed around 1880 except for one deep, 2400-foot-long incline at Gayton which was open until 1912. Peak annual production was in 1835 with 201,000 tons of coal. This dropped to only 50,000 tons by 1923 (Roberts, 1928), when four mines were operating and only one was shipping coal. Since 1930, coal production has been negligible. Between 1935 and 1937 three small-scale coal mining ventures were reported in the newspapers: (1) a dragline operation in the Black Heath area; (2) a shallow incline near Winterpock; and (3) a shaft in the Huguenot Springs area.

It is unknown how much coal remains beneath the surface of the Richmond basin. Most of the former mining was confined to the basin's margins, and until the recent oil exploratory drilling activity nothing was known about the thickness, depth, or continuity of the coal measures across the basin. The old estimate by Shaler and Woodworth (1899) of 1,152,000,000 tons of coal remaining in the Richmond basin is probably reasonable, but the depth to the coal at the center of the basin is now known to be double their original estimate.

Stratigraphy of the Taylorsville basin:

The exposed parts of the Taylorsville basin are within the Ashland, Hanover Academy, and Ruther Glen quadrangles (fig. 6). The entire stratigraphic column of the Taylorsville basin (fig. 5) has been named the Doswell Formation, and it has been subdivided into three members (Weems, 1980b). The basal Stagg Creek Member consists of about 600 ft (180 m) of sandstone and conglomerate. Above the Stagg Creek are about 1200 ft (360 m) of paludal to lacustrine, interbedded flaggy sandstone, siltstone, shale, coal, and limestone which constitute the Falling Creek Member. Fossils of clams, branchiopods, fish, and reptiles are common locally. The coals probably occur in at least two horizons, one near the middle of the member and one near the top. Although they were mined on a small scale, there is no evidence that either of the coal-bearing intervals had much economic potential. The Falling Creek may be a potential hydrocarbon source bed, and for this reason it has received attention from oil exploration geologists in recent years. To date only four shallow coreholes, 145-225 ft (43-67 m) deep, have been drilled into the exposed basin, one of which was used in constructing one of the cross section lines for the Ashland quadrangle (Weems, 1985). Deeper holes drilled farther northeast through the Coastal Plain have penetrated similar strata which probably belong to this basin.

Above the Falling Creek, a thick (as much as 1,000 ft or 300 m) sequence of massive to crossbedded, mineralogically immature sandstone and conglomerate constitute the sandstone/conglomerate facies of the Newfound Member. This sequence is more conglomeratic toward the northwest border fault. The clasts are generally rounded to subrounded. The sandstones found farther into the basin typically consist of lenticular, 13-16 ft (4-5 m)-thick, fining-upward sequences with trough crossbedding; these are interpreted as braided river deposits. No exposed fine-grained beds are correlative to these river deposits within the basin, which suggests the possibility that 1) the paleodrainage was open to allow the finest fractions of sediment and dissolved materials to be transported out of the basin, or 2) that the depocenter of the basin is now buried beneath the Coastal Plain. Above this sandstone/conglomerate interval is a thick (as much as 2,000 ft or 600 m) sequence of siltstones and massive sandstones. These beds

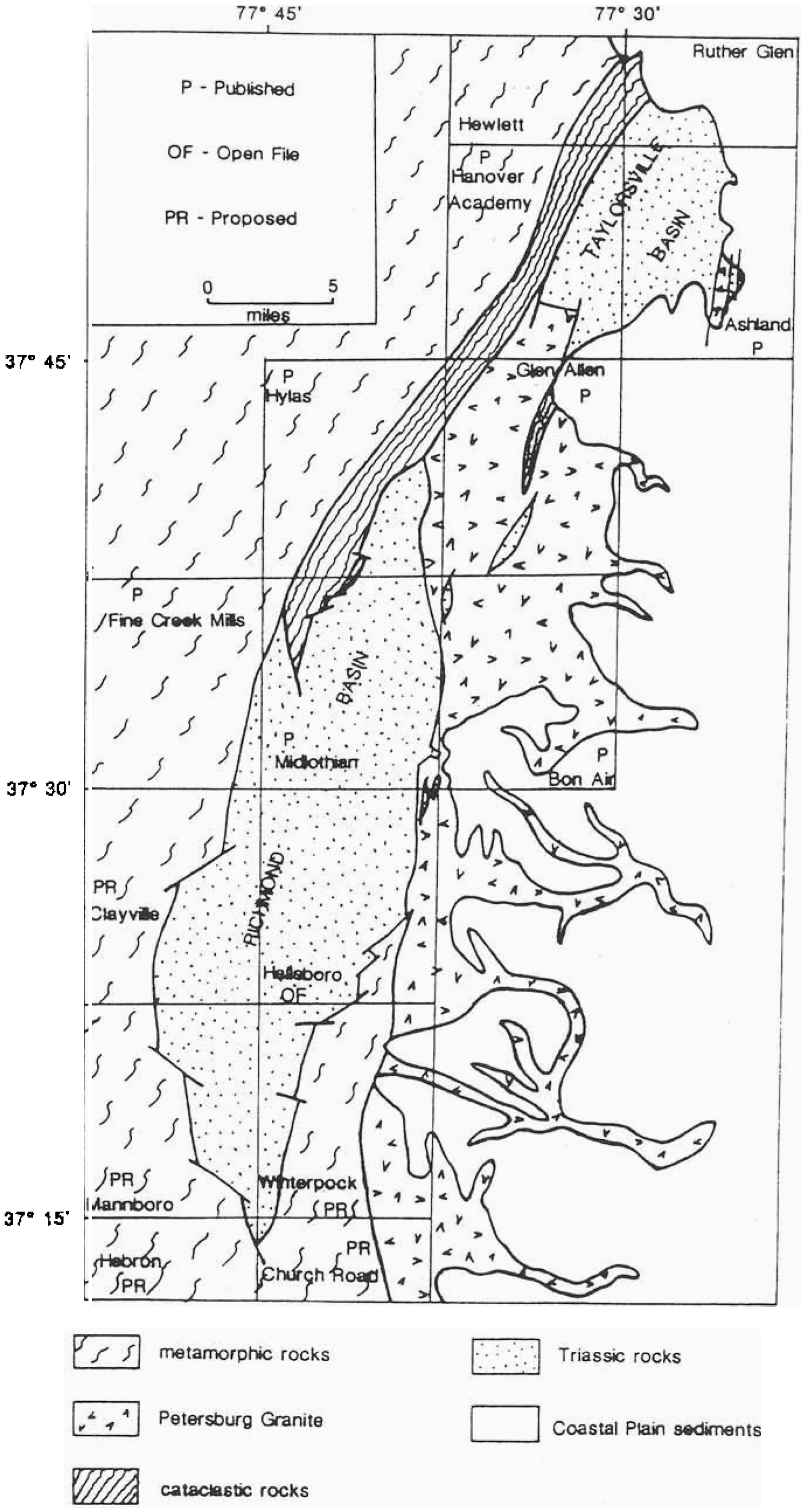


Figure 6. — Generalized map of the geology surrounding the Richmond and Taylorsville basins, also showing the status of 7.5-minute geologic quadrangle mapping in both basins.

are extensively bioturbated, probably by plant roots, so that most of their primary depositional structures have been obliterated; therefore these deposits are interpreted to have accumulated on vegetated flood plains or under submerged aquatic vegetation. Tectonically, they probably represent a period of slow deposition and uplift, analogous to the interval in which the Falling Creek Member was deposited, but without the development of a lake within the exposed part of the basin. In outcrop, these beds are poorly consolidated and crumbly. Local drillers have reported that below a depth of about 200 ft (60 m) this unit produces only salt water, and minor amounts of gypsum have been reported in the least weathered sediments of the basin (Weems, 1980a). A loss of gypsum and possibly carbonate cement would explain the anomalously soft, crumbly nature of these sediments in outcrop. Locally, at the top of the Newfound Member, angular cobble and boulder conglomerates along the northwest border of the basin suggest the former presence of talus slopes at the base of an exposed fault scarp.

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ROAD LOG

Begin Trip—Leave Williamsburg via chartered bus. Take Interstate 64 west to Interstate 295, bear right (northeast) to Interstate 95. Bear right (north) to "Va. 54: Hanover/Ashland" exit at milepoint 92.1 on Interstate 95. Take Ashland exit (Va. Route 54 West). This entire stretch of travel is through the Coastal Plain Province. Detailed road log commences.

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mileage		
total	increment	
00.0	0.0	Cross over Interstate 95 going west on Va. Route 54.
00.6	0.6	At U.S. Route 1 continue west through traffic light on Va. Route 54. The boundary between the Petersburg Granite and the strata of the Taylorsville basin (Stagg Creek Member) is in this vicinity. At this point both are buried beneath about 60 ft (18 m) of Coastal Plain sediments.
01.15	0.55	Cross Richmond, Fredericksburg, and Potomac Railroad tracks and continue west on Va. Route 54.
01.2	0.05	At Ashland Town Hall bear right and continue west on Va. Route 54.
01.7	0.5	Bear right and continue west on Va. Route 54.
03.6	1.9	Cross Falling Creek. This is the first point in our journey at which a stream has incised deeply enough to cut through the Coastal Plain section and exhume the underlying Triassic strata.
03.8	0.2	Turn left onto Va. Route 666.
04.5	0.7	Turn right onto Va. Route 696. Somewhere along this stretch of Va. Route 696 we cross from the Taylorsville basin back onto the Petersburg Granite.
05.3	0.8	Turn right into parking lot for Hanover County Dog Pound.

STOP 1: Doswell Formation, Stagg Creek Member and Falling Creek Member. Park and walk west (the same direction you were riding on Va. Route 696) about 100 ft (30 m) to bridge over Stagg Creek (fig. 7). On the near side of the bridge is a foot trail to the right which parallels the creek bank

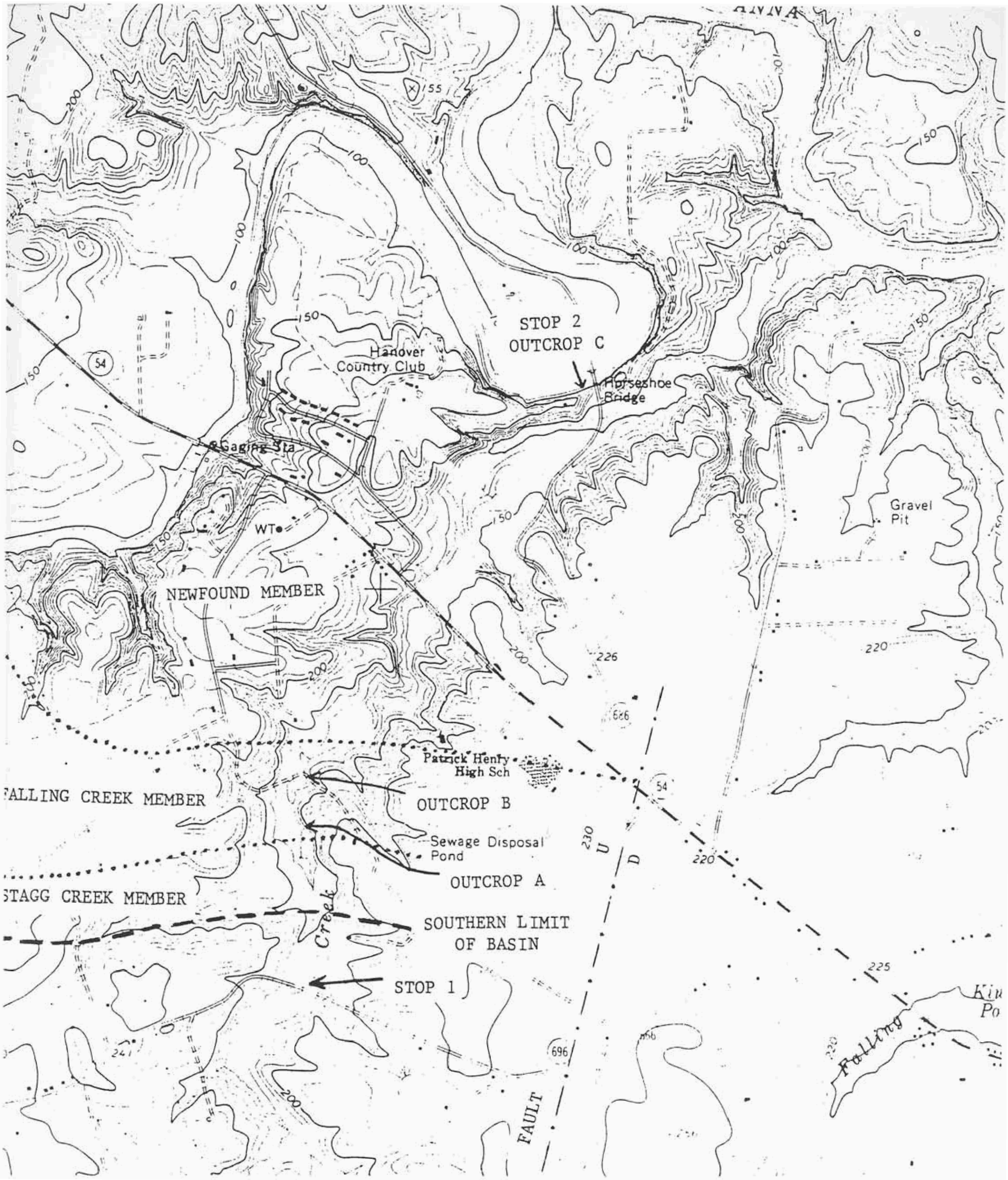

Figure 7. — Map showing detailed location of Stops 1 and 2 in the Hanover Academy 7.5-minute quadrangle.

downstream (north). Follow this path along the edge of Stagg Creek, which flows to your left across fault-sheared Petersburg Granite. At 900 ft (270 m), cross a small gully and begin ascending a steep ridge. At the base of the ridge, Petersburg Granite crops out 20 ft (6 m) to your right. At 960 ft (290 m) along the trail, cross over an outcrop of Petersburg Granite on the ridge. Trail crosses the top of the ridge, then descends to a wooden foot bridge crossing a steep-sided ravine at 1,100 ft (330 m). This gully roughly marks the south border of the Taylorsville basin. Immediately beyond the bridge the trail forks; bear left at trash barrel and stay beside creek. At 1,200 ft (360 m), trail skirts creek edge and Stagg Creek Member sandstone and conglomerate are visible along the creek floor. This material is a micaceous, very poorly sorted, silty sandstone with pebbles 0.2-2.4 in. (0.5 to 6.0 cm) in diameter scattered throughout. Pebbles are composed mostly of sheared and foliated Petersburg Granite and vein quartz. Because this material is so poorly sorted, it probably was deposited very rapidly. The closest source for this material would have been from an upland developed immediately to the south, above the eroded stump of Petersburg Granite which we crossed to get here. Continue along trail; massive to poorly bedded Stagg Creek Member is exposed intermittently along the stream bottom, especially around 1,550 ft (465 m). At 1,750 ft (525 m) a large outcrop of Stagg Creek sandstone and conglomerate is visible on the bluff that is near the creek on your right. It is similar to the previous outcrops except that the pebbles are slightly smaller (less than 1.6 in. or 4 cm). At 1,770 ft (530 m) the trail forks again, bear left and continue beside the creek. At 1,910 ft (573 m) pass a "No Hunting" sign on tree to right of trail. At 1,960 ft (588 m) the Stagg Creek Member again crops out in the creek bottom. It is poorly sorted, medium- to very coarse grained sandstone, with mica flakes to 1 mm in diameter scattered throughout. It weathers into irregular humps and has no distinct bedding. At 2,080 ft (625 m) cross a small gulley, and at 2,100 ft (630 m) the first exposure of well-bedded Falling Creek Member sandstone of the Doswell Formation crops out along the creek bed. This exposure is a moderately well sorted, fine-grained, light yellowish-brown silty sandstone bedded at 0.1-0.4 in. (0.5-1.0 cm) intervals; bedding planes are defined by an abundance of mica flakes. The bedding strikes N80^{0}W and dips about 60^{0}N. At 2,150 ft (645 m) cross

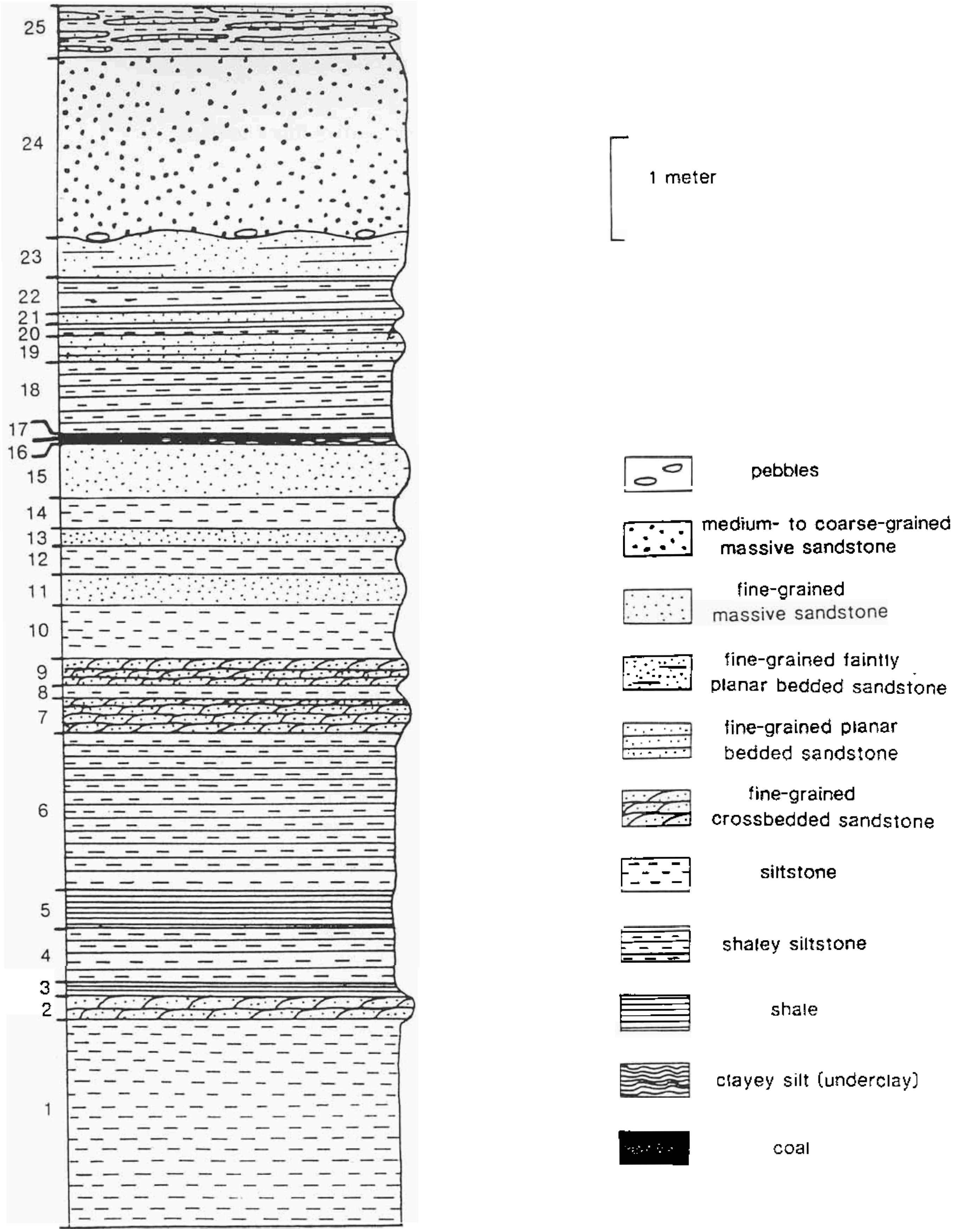

Figure 8. — Columnar section of Outcrop A at Stop 1.

another small gulley, and at 2,170 ft (651 m) come to the base of a second steep bluff. A good outcrop of the Falling Creek Member is present 70 ft (21 m) to your left where the creek impinges against the base of the bluff. This outcrop is shown diagramatically in figure 8 and is described as follows:

Outcrop A: Bedding strikes N75°W, dips 45°N; section represents parts of generalized intervals 38-40 of section 1 in Weems (1980b). Description of intervals begins at the top of the outcrop (see fig. 8).

Interval	meters	description
25	0.53	SILTSTONE, dark-gray to medium-gray, with 0.25 to 1.0 cm bedding, interbedded with SANDSTONE, fine-grained, light-brown, with 0.5 to 2.5 cm bedding, flaggy, very micaceous, bedding planes defined by mica flakes; gradational contact with:
24	1.73	SANDSTONE, medium- to coarse-grained, light-brown, micaceous, massive, fines upward, scattered 2.5 cm diameter pebbles at base and sharp contact with bed below.
23	0.41	SANDSTONE, fine-grained, light-brown, small mica flakes scattered throughout, poorly bedded; gradational contact with:
22	0.33	SILTSTONE, light-brown, sandy, interbedded with SHALE, dark-gray, silty, with mm to cm bedding, well bedded; gradational contact with:
21	0.11	SANDSTONE, fine-grained, light-brown, slightly micaceous, well cemented, with mm to cm bedding with mica flakes defining bedding planes; gradational contact with:
20	0.13	SILTSTONE, light-brown, sandy, and SHALE, dark-gray, silty, interbedded at mm to cm intervals, well bedded; gradational contact with:
19	0.28	SANDSTONE, fine-grained, light-brown, slightly micaceous, well cemented, mm to cm bedding with mica flakes defining bedding planes; gradational contact with:
18	0.74	SILTSTONE, clayey, to SHALE, silty, dark-gray, bedding poorly defined, fissile; gradational contact with:

17	0.03	COAL, black, greasy; gradational contact with:
16	0.02	SILT, light-gray and light-yellow mottled, clayey, massive; "underclay"; gradational contact with:
15	0.53	SANDSTONE, fine-grained, medium-brownish-gray, massive; gradational contact with:
14	0.31	SILTSTONE, dark-gray, bedding poorly defined, blocky, includes a single 1 cm-thick dark-gray clay layer; gradational contact with:
13	0.15	SANDSTONE, fine-grained, dark-gray, silty, micaceous, massive; gradational contact with:
12	0.28	SILTSTONE, dark-gray, sandy, micaceous, massive soft; gradational contact with:
11	0.31	SANDSTONE, fine-grained, medium-gray, silty, micaceous, massive; gradational contact with:
10	0.53	SILTSTONE, dark-gray, bedding poorly defined, weakly fissile; gradational contact with:
9	0.25	SANDSTONE, fine-grained, medium-brownish-gray, cross-bedded at cm scale, mica flakes define bedding planes; gradational contact with:
8	0.13	SILTSTONE, medium-brownish-gray, micaceous; gradational contact with:
7	0.33	SANDSTONE, fine-grained, medium-brown, crossbedded with partings developed at cm scale, mica flakes define bedding planes; gradational contact with:
6	1.55	SILTSTONE, dark-gray, shaly, bedded at cm intervals, slightly blocky; gradational contact with:
5	0.36	SHALE, black, very fissile, parts at mm to cm intervals, pervasively slickensided; gradational contact with:
4	0.53	SILTSTONE, dark-gray, shaly, parts at cm intervals, slightly blocky, moderately well banded; gradational contact with:
3	0.15	SHALE, dark-gray to black, very fissile, parts at mm to cm intervals; gradational contact with:
2	0.23	SANDSTONE, fine-grained, medium-gray, micaceous, mica flakes define bedding planes, crossbedded with partings developed at mm scale; gradational contact with:

1	2.05	RESIDUUM, mostly developed from siltstone but includes possible bed of COAL (2 cm thick) and SANDSTONE (8-10 cm thick), poorly exposed.
	12.00 m	Total thickness

Return to trail and ascend bluff. At 2,200 ft (660 m) pass red barrel on right. Trail rises for a distance of 2,330 ft (700 m), then starts to descend. To left is a ledge of Falling Creek sandstone (fine-grained, reddish-gray, well sorted, micaceous, crossbedded) which probably holds up the crest of this bluff. At 2,440 ft (732 m) pass another ledge on your left (coarse- to very coarse grained, light-yellowish-brown sandstone). More sandstone ledges crop out on left to 2,490 ft (747 m); these are coarse-grained. Descend bluff to creek bottom at 2,580 ft (774 m). Tree to left is hollow and has a beehive — PASS WITH CARE! From 2,580 to 2,910 ft (774 to 873 m) trail parallels a deep and murky stretch of Stagg Creek (Falling Creek Member, interval 59, in Section 1 of Weems, 1980b). This interval probably is composed mostly of soft shales and coals, as a coal mine once was located about 0.25 mile (0.4 km) to the right along strike. At 2,910 ft (873 m) trail swings right around the head of a gulley and exits at 2,960 ft (888 m) onto a dirt road that descends from the hill on your right. To your left the creek again impinges against the edge of its valley and exposes the following section of the Falling Creek Member (see also figs. 7 and 9):

Outcrop B: Bedding strikes N80^0E, dips 50^0N; section represents intervals 61-63 in generalized Section 1 of Weems (1980b).

Interval	meters	description
16	0.31^+	SILTSTONE, medium-gray, blocky, faintly bedded at mm scale, very weathered at top; gradational contact with:
15	0.15	SANDSTONE, fine-grained, medium-brownish-gray, massive, contains disseminated fine mica flakes; gradational contact with:
14	0.23	SILTSTONE, medium-brownish-gray, soft, bedded at 0.25-0.50 cm intervals; gradational contact with:

13	0.03	COAL, black, shaley, fissile; gradational contact with:
12	0.02	CLAY, light-gray, unbedded; gradational contact with:
11	0.23	SILTSTONE, dark-brownish-gray, soft, faintly bedded at mm scale; gradational contact with:
10	0.15	SANDSTONE, very fine grained, light-brown, micaceous, poorly bedded; gradational contact with:
9	0.13	SILTSTONE, light-brownish-gray, sandy, micaceous, blocky; gradational contact with:
8	0.94	SANDSTONE, fine grained, light- to medium-brownish-gray, bedded at 0.25-1.00 cm intervals, crossbedded; bottom bedding plane contains leaf impressions, some higher bedding planes have invertebrate trails; prominently jointed with vertical offsets up to 8 cm; gradational contact with:
7	0.33	SANDSTONE, fine-grained, and SILTSTONE interbedded, medium-brownish-gray, bedding planar but faintly developed; gradational contact with:
6	0.15	SANDSTONE, fine-grained, medium-brownish-gray, massive, micaceous; gradational contact with:
5	0.99	SILTSTONE, ranges from dark-gray, clayey and well bedded to medium-brownish-gray, faintly bedded and blocky; gradational contact with:
4	0.41	SANDSTONE, very fine grained, light-brownish-gray, massive, very finely micaceous; gradational contact with:
3	0.94	SILTSTONE, medium-brownish-gray to medium-gray, poorly bedded, blocky, very finely micaceous; gradational contact with:
2	2.46	SANDSTONE, fine-grained, light- to medium-brownish-gray, crossbedded, parts mostly at 0.25-1.00 cm intervals but at up to 8 cm intervals, micaceous, mica flakes define bedding planes; gradational contact with:
1	0.53	SILTSTONE, medium-brownish-gray, sandy, micaceous, prominently bedded at 0.5-1.0 cm intervals, breaks into flaggy slabs, contains plant impressions.
	8.00+ m	Total thickness

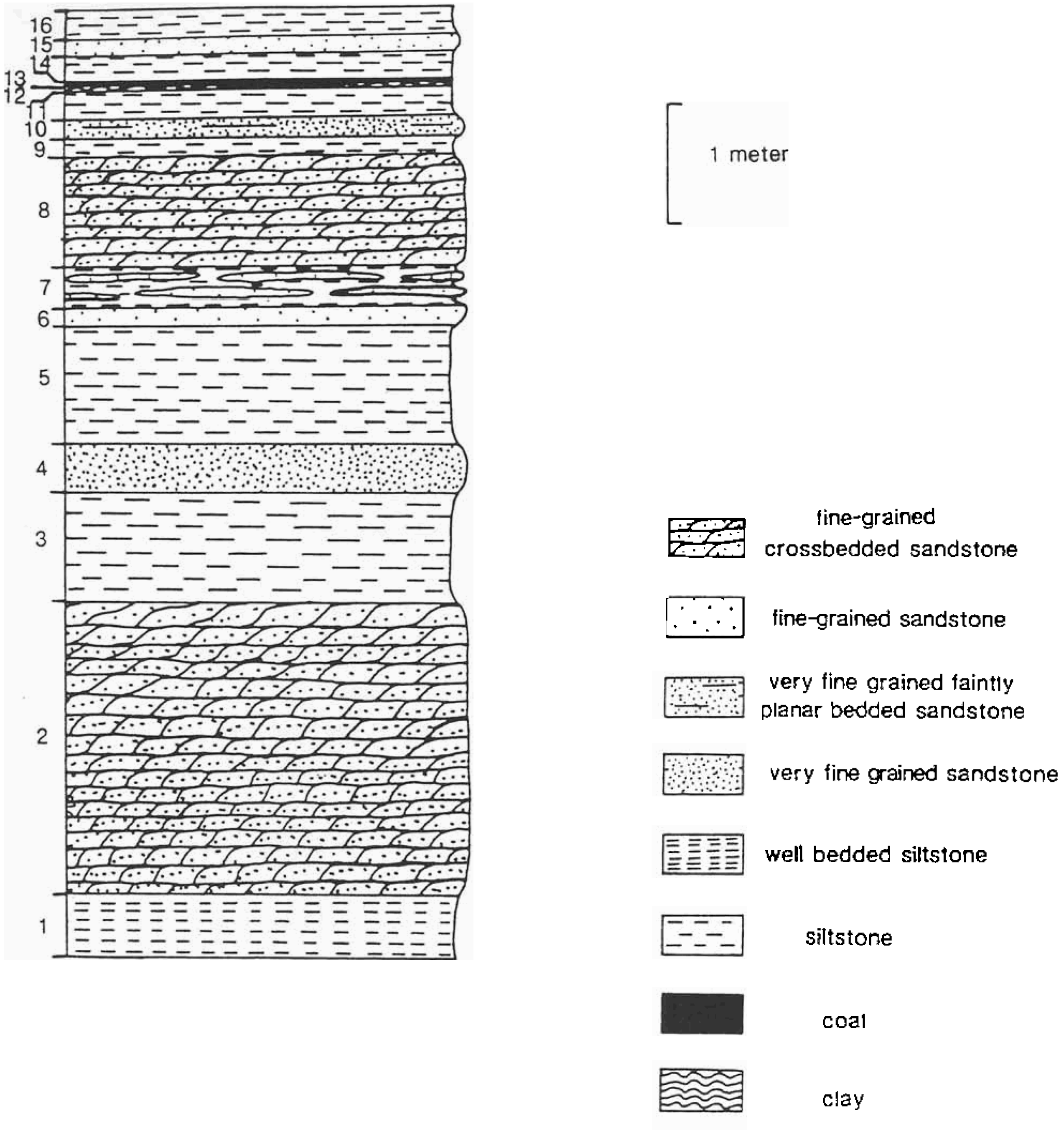

Figure 9. — Columnar section of Outcrop B at Stop 1.

Return to vehicle by the same path.

05.3	——	Turn left onto Va. Route 696.
06.1	0.8	At stop sign turn left on Va. Route 666.
06.8	0.7	At stop sign turn left on Va. Route 54.
07.6	0.8	Turn right on Va. Route 686.
08.5	0.9	Cross Stagg Creek.
08.6	0.1	Pull over at near end of Horseshoe Bridge.

STOP 2: Doswell Formation, Newfound Member, sandstone/siltstone facies. Park and cross road to left side of bridge abutment (fig. 7). Descend slope of reddish-gray siltstone. At river go upstream 300 ft (100 m) to exposure on left. This section is at the base of the sandstone/siltstone facies of the Newfound Member of the Doswell Formation. The basal bed in this area is the massive siltstone over which you descended at the south end of the bridge. The topmost bed of the sandstone/conglomerate facies of the Newfound Member is visible downstream beneath the bridge about 300 ft (100 m) distant. The soft basal siltstone bed of the upper facies is apparently responsible for the small wind gap through which the road runs to the bridge. The following section is exposed (see also fig. 10):

Outcrop C: Bedding strikes N25^{0}E, dips 27^{0}NW.

Interval	meters	description
3	±2	SANDSTONE, medium- to very coarse grained, light-brownish-gray, sparsely micaceous, trough crossbedded, contains clay lumps and rock pebbles to 3 cm in diameter, carbonized wood fragments, and rare bone impressions; channeled into bed below.
2	0.2-0.8	SANDSTONE, fine-grained, light-brownish-gray, cross-bedded, layers developed at mm scale, slightly micaceous, well sorted; gradational contact with:
1	±7	SILTSTONE, dark-reddish-gray, sandy, micaceous, blocky, burrowed and rooted.
	±9.5 m	Total thickness.

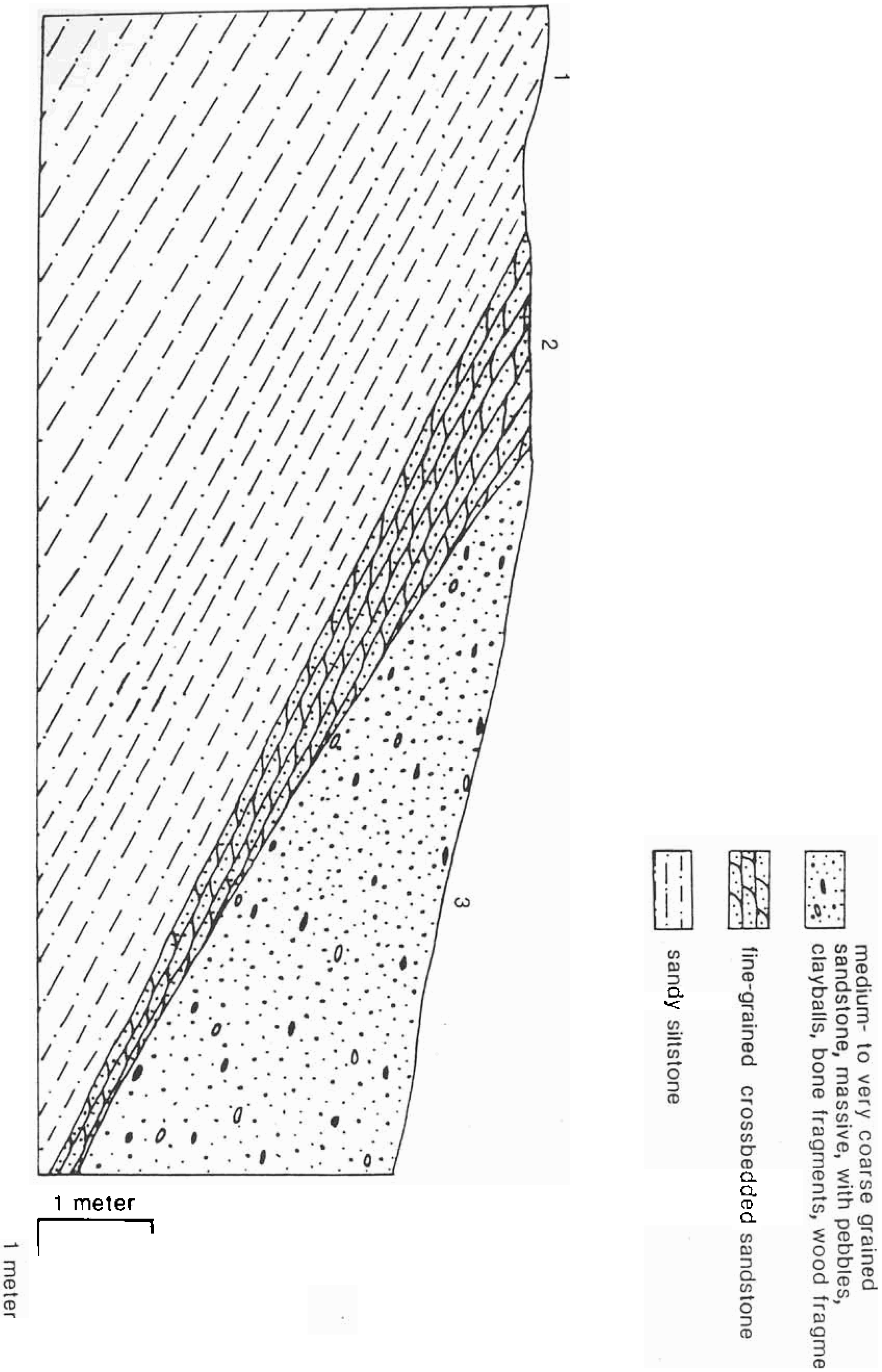

Figure 10. — Diagrammatic portrayal of Outcrop C at Stop 2.

08.6	——	Continue across Horseshoe Bridge over South Anna River.
10.3	1.7	Cross buried Fork Church fault and enter Hylas zone.
11.0	0.7	At stop sign turn right onto Va. Route 795.
11.4	0.4	Bear left on Va. Route 686.
12.1	0.7	Come to large pond on left; turn right onto Va. Route 685.
12.5	0.4	Cross Newfound River; to left are excellent exposures of Hylas zone mylonite gneiss.
13.3	0.8	At stop sign turn right on Va. Route 738. Fork Church is at this intersection.
13.6	0.3	Cross Fork Church fault and re-enter Taylorsville basin.
17.3	3.7	At stop sign cross U.S. Route 1.
18.0	0.7	Cross over Richmond, Fredericksburg, and Potomac Railroad Bridge, pull into gravel access road on right immediately past bridge; descend into railroad cut. WATCH OUT FOR TRAINS, OCCASIONALLY TWO ABREAST MAY COME FROM THE SAME DIRECTION AT THE SAME TIME.

STOP 3: *Doswell Formation, Newfound Member, sandstone/siltstone facies.* This outcrop (located on fig. 11) shows a massive sequence of trough crossbedded sandstones that appear to form fining-upward packages about 3-4 m thick. About 50 years ago, when this cut was made, numerous petrified logs (probably *Araucarioxylon*) were unearthed. Occasional pieces still are found. The textures in this unit are typical of a well-developed fluvial system, being fairly coarse.grained and also rather well sorted. This is considerably different from the poorly sorted, poorly bedded conglomeratic sandstones of the Stagg Creek Member. The paleocurrent direction (northeast) is almost perpendicular to the outcrop trend. Most of the crossbeds are due to dune-scale bedforms, but the large, more tabular sets near the tops of the sequences probably represent transverse bars formed during falling flood stages. This hypothesis is supported by the scatter in the dip orientations of these features.

Two diabase dikes, probably of Early Jurassic age, are present in the cut on the north side of the bridge over the railroad. The larger of these dikes can also be found along the south bank of the Little River to the

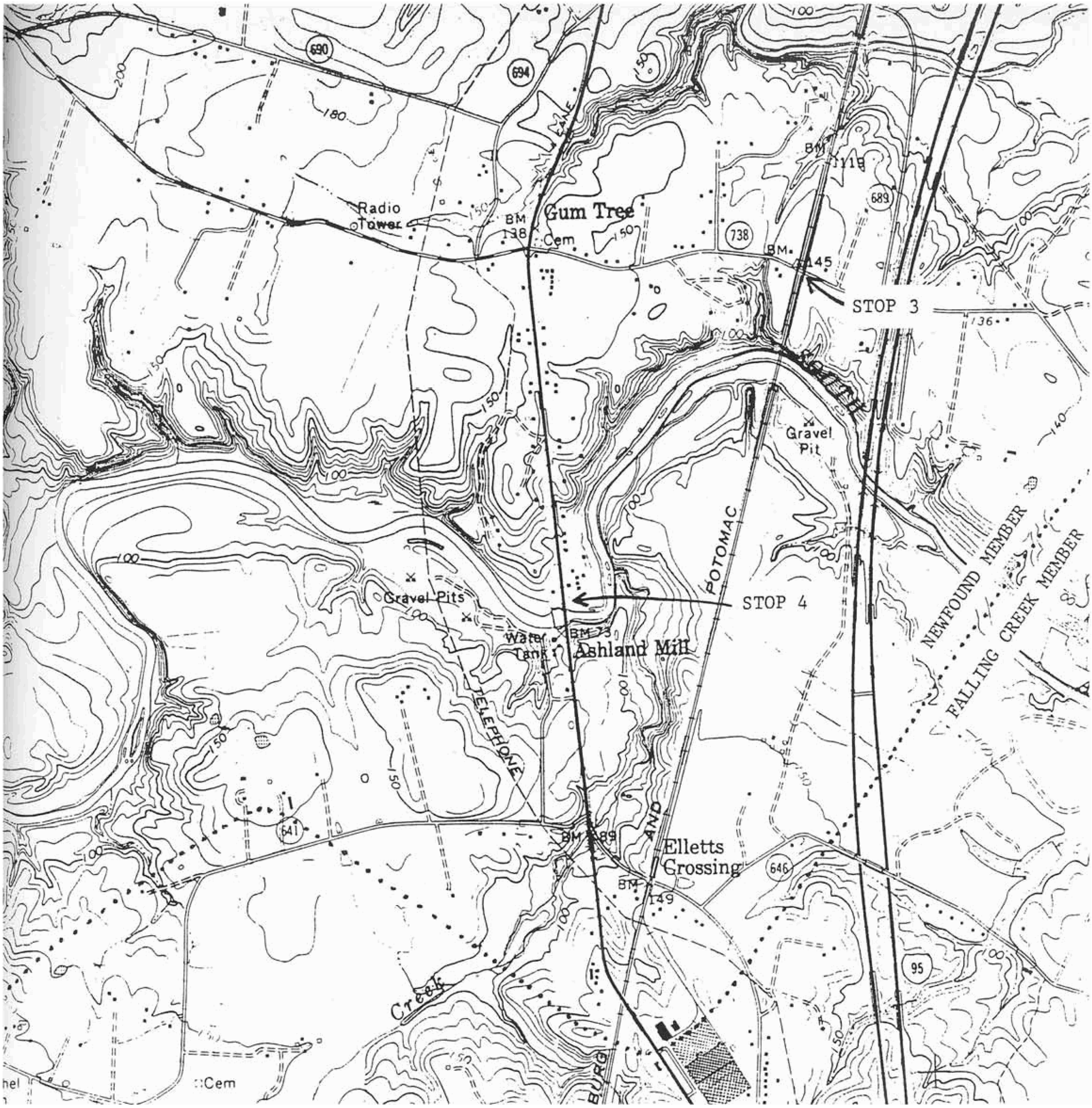

Figure 11. — Map showing detailed location of Stops 3 and 4 in the Ashland 7.5-minute quadrangle.

northwest and along the north bank of the South Anna River to the southeast (Weems, 1985). These dikes are typical of those which have been found in the basin, and all appear to postdate the time of deposition of the exposed strata in the basin.

The Doswell Formation sandstones are capped by a thin sequence of gravel and overlying sand. These are Pliocene-Pleistocene in age and represent a fluvial terrace deposit formed by the ancestral North Anna River. Nearly all of the cobbles in these gravels are composed of quartz. Among these are sparse pieces of chert containing corals which are derived from the Helderberg Group (Lower Devonian) and clasts of quartzite containing tubes of *Skolithos* (*Scolithus*) which are apparently derived from the Erwin Quartzite (Lower Cambrian). Neither of these lithologies crops out within or near the present drainage basins of the North Anna or South Anna rivers, so they were apparently introduced into the basin by Potomac River drainage and redistributed by longshore currents during a high stand of sea level in the Miocene when the eastern Piedmont was at or slightly below sea level. Contrast these lithologies with those which you will see at Stop 8.

18.0	—	Return toward U.S. Route 1.
18.7	0.7	At stop sign turn left onto U.S. Route 1.
19.4	0.7	Go down long hill and turn left into Riverview service station. To right of service station down hill is the bank of the South Anna River (see fig. 11).

STOP 4 (LUNCH STOP): The bluffs across the river are composed of the same Triassic beds as at Stop 3, and large-scale structures are more apparent from this distance. It is suggested that you contemplate their geometry while you eat.

19.4	—	Load up and turn left (south) on U.S. Route 1.
19.5	0.1	Cross South Anna River.
20.0	0.5	Cross Falling Creek

20.4	0.4	Cross bridge over Richmond, Fredericksburg, and Potomac Railroad.
22.8	2.4	Return to stop light and turn left on Va. Route 54. Leave Taylorsville basin.
23.4	0.6	Exit on Interstate 95 south.

End of detailed mileage log. Follow Interstate 95 south to the exit for Interstate 295 west and take that exit toward Interstate 64 west and Charlottsville. Follow Interstate 295 west until it intersects with Interstate 64 and take Interstate 64 east toward Richmond. Get off Interstate 64 at the first exit (Short Pump), and turn right onto U.S. Route 250 heading west toward Short Pump. The detailed road log commences again at this intersection of Interstate 64 and U.S. Route 250.

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mileage		
total	increment	
00.0	0.0	Proceed west on U.S. Route 250 from its intersection with Interstate 64.
00.7	0.7	Pass through the town of Short Pump, well known to fans of Jeff MacNelly's *Shoe*. This area is underlain by the Petersburg Granite.
02.2	1.5	Turn left onto Va. Route 623, Gayton Road.
02.5	0.3	To the right is a good view from the higher land above the Petersburg Granite across the lower terrain of the more easily eroded sedimentary rocks of the Richmond basin.
03.9	1.4	Cross over the contact between the Petersburg Granite to the east and the lower barren beds and productive coal measures of the Richmond basin to the west. Although the contact has not been directly observed in this part of the basin's eastern margin, it appears to be a nonconformity, along which the top of the granite and overlying sedimentary rocks dip westward at angles averaging 20 to 35 degrees. Open pit mines and prospect pits were once common along the exposed coal seams, and waste material from the coal mines is abundant in the soils of this area. Several mines formerly were operated on both sides of

		Gayton Road south of this point and this region was a major coal-mining center of the Richmond basin.
04.1	0.2	Continue straight onto Lauderdale Drive. This road is on the western edge of the area dominated by formerly active coal pits and shafts. However, as mining followed down the dip of the coal beds, much of the developed area here overlies old mine workings. For example, one drill hole penetrated about 90 feet of sandstone and shale before terminating in 15 feet of void. The need for careful site investigation before construction in this area is apparent.
05.7	1.8	Cross creek. Mine waste constitutes the banks and contaminates the soil on the east side of the road. Mines were located on both sides of the road in this vicinity.
05.9	0.2	The eastern margin of the Richmond basin is crossed in this area.
07.3	1.4	Turn right onto Va. Route 6, Patterson Avenue, and proceed west.
07.4	0.1	To the north across the parking lot and on a west-facing slope are large exposures of relatively fresh, spheroidally weathered Petersburg Granite. Such exposures and rounded boulders of granite often occur near the contact with Triassic sedimentary rocks and signal proximity to the contact.
07.5	0.1	When the parking lot to the north was being built, the eastern margin of the Richmond basin was exposed. It appeared to be a nonconformable contact, and the Triassic rocks dipped westward at 30 to 40 degrees. The Richmond basin underlies our traverse from this point westward until beyond Manakin.
08.7	1.2	During widening of Va. Route 6, good exposures of the Vinita Beds temporarily existed in cuts on the south side of the road. On the west slope of the hill, a small exposure of gray siltstone and fine-grained sandstone still remains. Some of these beds yielded fish and plant fossils, and this was one of the palynological localities (VN1) for Bruce Cornet's (1977) studies.
11.9	3.2	Pass through the town of Manakin. This was an old coal mining center on the western margin of the Richmond basin, and mines shafts were situated both north and south of Va. Route 6.

12.5	0.6	Turn left across the center island and onto the road leading into the Boscobel Quarry. As you go down this road there is a good view southward across the valley and floodplain of the James River.
12.9	0.4	Check in at Luck Stone office to obtain permission to enter quarry.
13.2	0.3	After bearing right toward the quarry at the base of the hill, pull off to the right by the high cut banks in sandstone and shale. Beyond these cuts is the deep Boscobel Quarry.

STOP 5: Petersburg Granite and Tuckahoe Group, Lower Barren Beds (Boscobel Quarry). This deep quarry at the edge of the floodplain of the James River (fig. 12) was opened in 1924, and rock has been quarried from this general location for more than 125 years (Gooch, Wood, and Parrott, 1960). This quarry is developed within a small, wedge-shaped horst of granite which is bounded to the east and west by Triassic sedimentary rocks. On the north wall of the quarry, more than 50 ft (15 m) of saprolite showing a spectacular soil profile overlies unweathered granite; this overburden thickens northward under the adjacent uplands. The deep weathering of the eastern Virginia Piedmont and consequent development of thick saprolite, residuum, and soil has greatly reduced the chances of finding fresh bedrock near the surface. As a result, exposures of bedrock are scarce and almost invariably strongly weathered. Most surficial geological studies in this area must be made on saprolite or residuum, and even moderately good exposures of Triassic rocks usually are found only along streams.

A normal fault at the east end of the quarry separates granite from the Triassic sedimentary rocks of the Richmond basin. Quarrying operations have exposed this fault to varying degrees at differing depths and angles over time. Measurements of the fault attitude have varied accordingly, and have ranged from N10^{0}W, 57^{0}NE (Gooch, Wood, and Parrott, 1960) to N-S, 65^{0}E (Goodwin, 1970). A gouge zone as much as 6 in. (15 cm) thick has been observed along this fault. This fault is not the major western border fault of the Richmond basin (Goodwin, 1970; Goodwin and Farrell, 1979) because neither the Hylas zone cataclastics nor a coarse boulder breccia are present. The main border fault occurs to the west (fig.

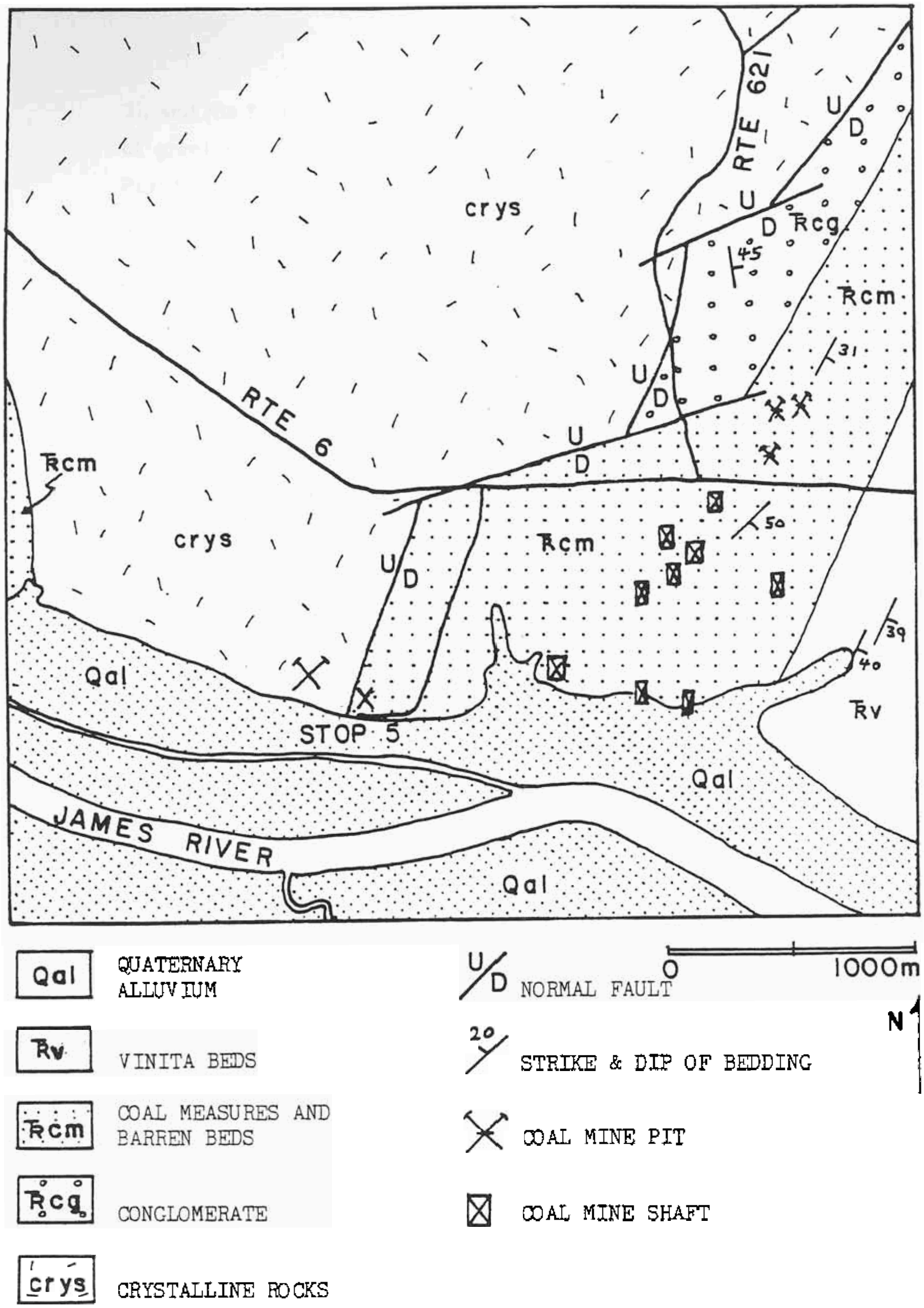
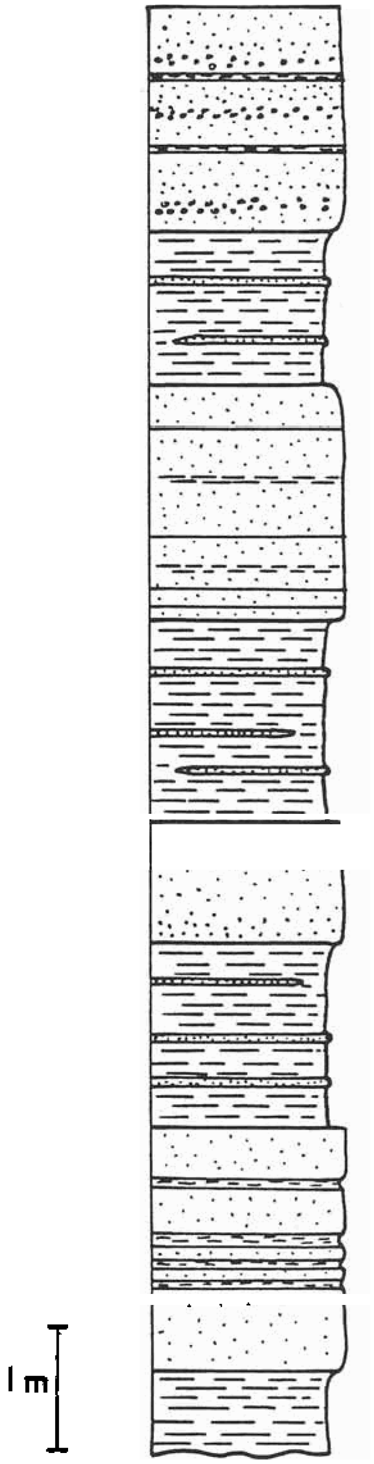


Figure 12. — Geologic map of Stop 5 and vicinity (geology modified from Goodwin, 1970). Coal mines located by G. Wilkes.

3), and the fault seen here bounds the eastern side of a wedge-shaped horst of granite which was uplifted after deposition of the Triassic sediments. Postdepositional uplift and drag on this fault has caused the Triassic rocks to the east of the Boscobel quarry to dip steeply eastward, thereby giving the portion of the Richmond basin along the James River a general synclinal shape between the Boscobel Quarry and the east margin of the basin. Sedimentary rocks elsewhere within the basin, both to the north and south of the James River section, dip regionally westward (Goodwin, 1970; Goodwin and Farrell, 1979). The exact amount of displacement along this fault is unknown, but it is probably less than 500 ft (150 m). Some of the beds next to the fault stand nearly vertical in asymmetric folds. Near the fault, the sedimentary rocks are intensely folded and shales have thickened and thinned dramatically. Much movement has taken place within the shales, which often show smooth, polished shear surfaces and slickensides. Folding diminishes greatly within 50 ft (15 m) of the contact, but farther away numerous subsidiary normal faults with as much as 10 ft (3 m) of displacement cut the sedimentary rocks, forming small fault-bounded blocks. These faults commonly have dips of approximately 60 degrees, and beds show a normal displacement along the faults. Deformation decreases eastward from this quarry until the rocks appear to be relatively undeformed. Possibly more deformation has occurred there than can be recognized from study of the sparse outcrops.

Because of their proximity to granitic rocks, these sedimentary rocks presumably are part of the lower barren beds (Shaler and Woodworth, 1899; Goodwin, 1970), but lithologically they are indistinguishable from the Vinita Beds. Because the thickness of the Triassic section beneath the quarry floor is unknown, a definitive stratigraphic assignment is presently impossible. A detailed stratigraphic section is not given here because this rock is quarried occasionally and the visible section changes as rock is removed, but a generalized stratigraphic column is shown in figure 13.

Dominant lithologies are medium- to dark-gray, fine- to coarse-grained sandstones, and black shales which commonly show no internal structure except for the abundant pinch and swell laminae. The friable sandstone weathers to a medium-brown color; it is immature mineralogically, containing much feldspar and muscovite. Fragments of



SANDSTONE, FINE- TO VERY COARSE-GRAINED, CONGLOMERATIC IN PLACES, MASSIVE WITH SOME GRADED BEDDING, SOME THIN BLACK SHALE INTERBEDS.

SHALE, BLACK, CARBONACEOUS, MICACEOUS, SOME FINE-GRAINED SANDSTONE BEDS UP TO TWO INCHES THICK WITH SHARP CONTACTS.

SANDSTONE, VERY FINE- TO MEDIUM-GRAINED WITH MODERATE SORTING, MICACEOUS, GRAY, SOME GRADED BEDDING IN BEDS UP TO 18 INCHES THICK, SHALE PARTINGS UP TO ½ INCH THICK.

SHALE, BLACK, CARBONACEOUS, MICACEOUS, SOME FINE-GRAINED SANDSTONE BEDS UP TO TWO INCHES THICK WITH SHARP CONTACTS.

SANDSTONE, VERY FINE- TO COARSE-GRAINED, MODERATE SORTING, MICACEOUS, GRAY, WELL JOINTED, SOME GRADED BEDDING.

SHALE, BLACK, CARBONACEOUS, MICACEOUS, SOME FINE-GRAINED SANDSTONE BEDS UP TO TWO INCHES THICK WITH SHARP CONTACTS, HIGHLY DEFORMED, CONTACT WITH UPPER SANDSTONE SHARP.

SANDSTONE, VERY FINE- TO MEDIUM GRAINED, POOR SORTING, MICACEOUS, GRAY, TOP FEW FEET INTERBEDDED WITH BLACK SHALES UP TO FOUR INCHES THICK.

SHALE, BLACK, CARBONACEOUS, MICACEOUS, SOME FINE-GRAINED SANDSTONE BEDS.

COVERED.

Figure 13. — Generalized geologic section of the Triassic rocks exposed in the Boscobel Quarry.

plant fossils and fish scales are locally abundant; Schaeffer and McDonald (1978) and Olsen, McCune, and Thompson (1982) have described fossils of the fishes Dictyopyge macrurus and Cionichythys greeni from this locality.

Exposures away from the faulted contact with the granite show at least two and probably four cyclic alternations of black shale and sandstone which appear to coarsen upward gradually. At the base of each sequence is a 3-5 ft (0.9-1.5 m)-thick black shale which in turn is overlain and cut into by 3-6 ft (0.9-1.8 m)-thick, massive, coarse-grained sandstones. The basal black shales in each sequence are badly sheared and show little or no internal structure. Where they approach the first thin sandstone bed they have pinch-and-swell sand laminae which probably represent poorly developed oscillatory ripples.

The thick sandstone beds in the interbedded sandstone and shale zones have sharp bases with soft sediment load-casts. These sandstones appear to be graded, although the upper contacts have an abrupt transition to the next overlying shale bed. The thinner sandstone beds in the same interbedded zones are internally massive or have flat laminations; the upper parts frequently have a wavy character resembling ripple troughs which, because of the low-angle nature of the internal laminae, may be oscillatory ripples. The planar lamination and ripple troughs are best defined where these thin beds are thickest. These thin beds also may show gently inclined sets of internal laminations which laterally pinch and swell. These roughly resemble hummocky cross-strata, although the internal laminae are less well defined and the characteristic convex-up draping over scours is absent.

The uppermost massive sandstones have scour bases and abundant mud intraclasts. The lower parts have little or no internal structure but the upper parts have flat or hummock-like laminations. Thin shaly interbeds contain abundant flat shale clasts and carbonized wood fragments.

It appears that the sands in this sequence were introduced rapidly because they are graded, poorly sorted, texturally immature, and contain load casts. Turbidity currents, flash floods, or storm-wave activity are possible causes of this type of deposition. There is no apparent evidence of subaerial conditions in the form of root casts or mud cracks. If properly identified, the oscillatory ripples indicate some wave action, but the abundance of shale indicates mostly quiet water so this was not a beach environment. There is no direct evidence of fluvial action and no beds of unidirectional flow ripple cross-lamination have been identified as yet, though possibly some of the beds of flat lamination could have been formed by unidirectional current or turbidites. Mudstone intraclasts in the sandstone beds could have been derived from the erosion of dessicated muds, but channelling of wet cohesive material is more likely. The uncommon sediment-filled tubes are probably burrows, and some of the more diffuse bedding could reflect intense bioturbation.

13.9	0.7	Retrace route to the intersection of the road from Boscobel Quarry with Va. Route 6. Turn right (east) onto Va. Route 6.
15.4	1.5	Bear right onto Va. Route 650, River Road.
17.8	2.4	Turn right onto dirt road by sign for Tuckahoe Plantation. At the end of this road on a bluff overlooking the James River valley is Tuckahoe Plantation which was begun in 1715. Thomas Jefferson studied in a little schoolhouse on the plantation grounds before going to the College of William and Mary to complete his higher education.
18.5	0.7	Turn right into the cleared area designated for parking and park there by the trees at the western edge of the area. Walk west through the woods to the intermittent stream bed.

STOP 6A: Chesterfield Group, Vinita Beds (sandstones, siltstones, and shales):

Sandstones, siltstones and shales of the Vinita Beds are present in the bed of the stream and in a small tributary joining the stream from the northeast (fig. 14). Neither the stream nor the tributary are shown on the topographic map, but the small valley which they occupy and a pond into which they empty can be seen. The exposures are small and weathered, but are comparatively good for this area. As is commonly the case, the more resistant sandstones form streambed exposures whereas the softer shales tend to be eroded away and rarely form good exposures. Thus, examination

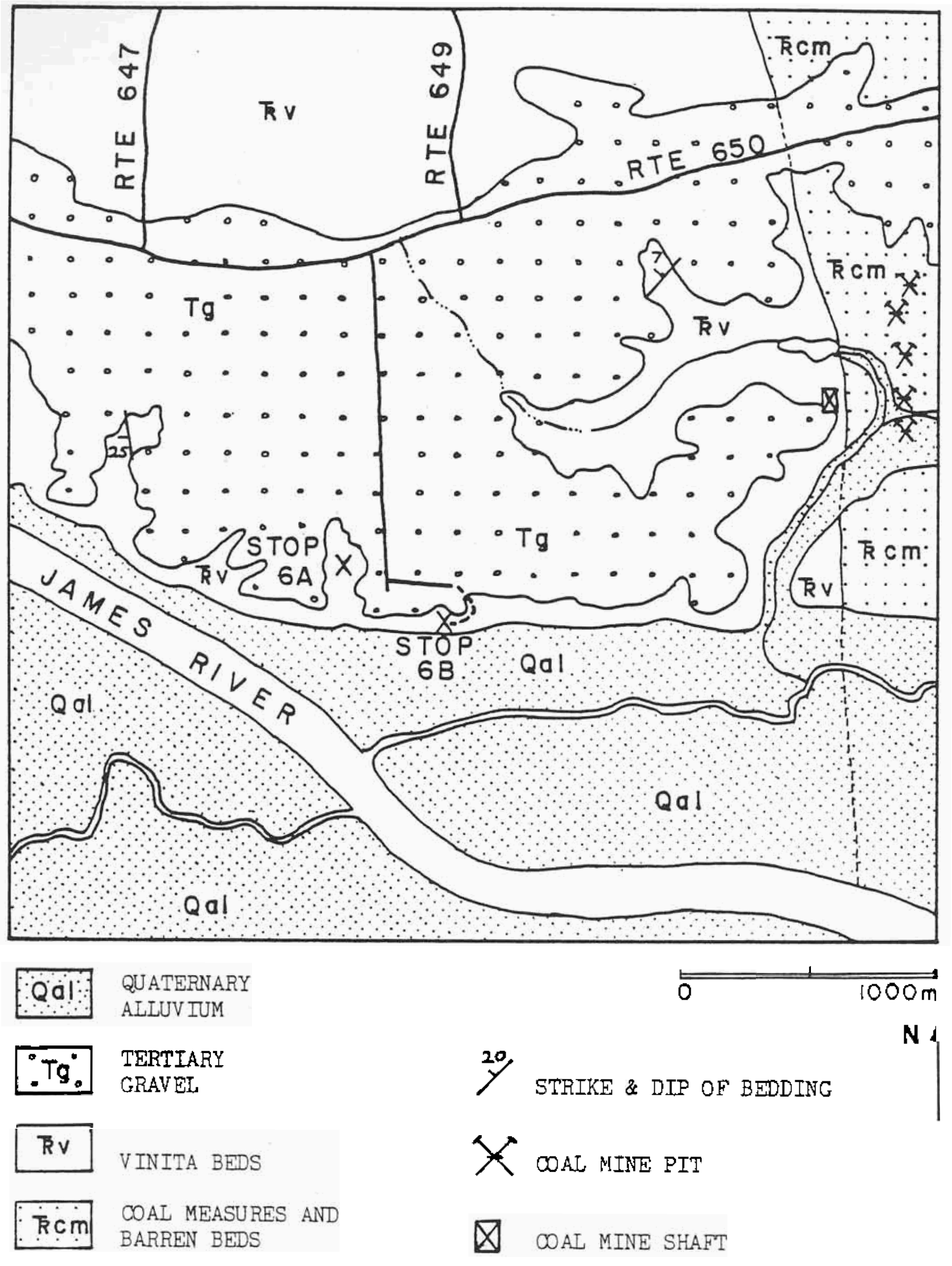


Figure 14. — Geologic map of Stop 6 and vicinity (geology modified from Goodwin, 1970). Coal mines located by G. Wilkes.

of stream exposures usually gives a biased impression of the relative abundance of sandstones versus shales. Heinrich's (1878) section showed 57 percent fine-grained sandstones and 43 percent dark-gray to black, often fossiliferous shales in the central part of the Vinita Beds. At the top of Heinrich's section, gray, fine-grained, arkosic sandstones dominate and make up 80 percent or more of the rocks. In these streams, a sandstone-siltstone-shale sequence can be seen, whereas adjacent to the James River at Stop 6B the exposures are primarily of massive sandstones.

The Vinita Beds here are overlain by nearly horizontal Tertiary gravels at an elevation of about 190 ft (57 m). In both the main stream and the tributary a sharp break in gradient and in depth of the stream bed is found at the Triassic rock-Tertiary gravel contact. Bedding in the Triassic rocks is nearly horizontal, and the sandstones are very well jointed with two prominent joint sets nearly at right angles. This site is another of Cornet's (1977) palynological localities (VBA4) where he obtained his specimens from "...a thin black clayey siltstone within a brown to reddish brown sandstone and conglomeratic sandstone..." He also reported that fossil fishes are found here. A measured section follows. It begins at the first exposure upstream from the pond, follows the stream's bed upstream until the tributary, and then continues up the tributary. The base of the section is nearest the pond.

Feet	Inches	Description
0	3	SANDSTONE, blue-gray, very fine to medium-grained, micaceous with minor pyrite.
0	6	SHALE, blue-gray, silty, minor muscovite.
0	3	SANDSTONE, light-blue-gray, very fine to medium-grained; breaks along muscovite-rich thin zones.
(Tributary)		
1	0	SHALE, blue-gray, silty, minor muscovite, grades up into:
1	6	SANDSTONE, light-gray, medium-grained, minor muscovite
1	0	(Covered)
0	6	SANDSTONE, light-gray, very fine to coarse-grained, poorly sorted; iron occurs as grain coatings, dirty.
4	0	(Covered)

3	10	SANDSTONE, light-gray, very fine to medium-grained, moderately sorted; trace of muscovite.
1	0	(Covered)
0	2	SANDSTONE, light-gray, very fine grained, well sorted, silty.
0	2	SILTSTONE, light-gray.
0	2	(Covered)
2	10	SANDSTONE, light-gray, very fine grained, moderately sorted, beds as much as 6 in. (15 cm) thick; slightly micaceous.
0	5	SANDSTONE, light-gray, very fine to coarse-grained, poorly sorted, silty
0	11	SANDSTONE, light-gray, very fine to coarse-grained, moderate sorting, trace of muscovite.
2	0	(Covered)
2	10	SHALE, blue-gray, silty, minor muscovite.
4	0	(Covered)
		(ANGULAR UNCONFORMITY) Tertiary gravels
27 ft	4 in	Total thickness

		Return to vehicle and exit parking area. Turn right on dirt road at exit of parking area.
18.6	0.1	At "T" in road turn left in front of buildings and follow dirt road east.
18.7	0.1	Pass through gate in fence and then bear to the right and park in this area. Leave vehicle here and walk south and downhill on the middle fork of the dirt road to the left of the corn crib. Follow this road for about 0.2 mile to the railroad tracks.

STOP 6B: Chesterfield Group. Vinita Beds (massive sandstones):

On the north side of the road and up the small valley to the north are exposures of massive sandstone (fig. 14). Similar sandstone forms the bed of the road uphill. The sandstone is gray, coarse- to very coarse grained, and thick bedded with beds as much as 2 feet (0.6 m) thick. It is micaceous and the grains are rounded. Some of the coarse-grained beds are crossbedded and sandstones dominate the exposures. A few hundred feet to the west along the bluffs is a small, long abandoned quarry in which a 15 ft (4.6 m)-high wall is composed almost entirely of similar sandstone. The floor of the quarry is covered with water so it cannot be visited at this time. The quarry provided stone which was used in some of the steps at Tuckahoe Plantation. It is also reputed to have served as a turn-around point for barges on the canal which is at the base of the slope and parallels the James River.

19.6	0.9	Go back to vehicles, board, and retrace route back to Va. Route 650 (River Road). Turn right (east) on Va. Route 650.
21.2	1.6	Cross over the approximate contact between the Richmond basin to the west and the Petersburg Granite to the east.
25.8	4.6	Entrance to the University of Richmond is on the left.
26.5	0.7	Turn hard right onto Va. Route 147 (Huguenot Road). You are now on the floodplain of the James River and, after passing over the canal, you will cross the James River. This bridge is at the western edge of the Fall Zone and rapids and exposures of Petersburg Granite are found in the bed of the river eastward to the point where Interstate 95 crosses the James River.
28.8	2.3	Cross over the contact between the Petersburg Granite and high-level gravels of probable Tertiary age. The base of the gravels is subhorizontal, gently inclined eastward at about 7 feet per mile, and is commonly marked by a sharp break in slope. These gravels underlie the broad, relatively flat, upland surface ahead.
33.5	4.7	Turn right onto Va. Route 677 (Old Buckingham Road). Tertiary gravels have underlain the traverse for the past 4.7 miles.
34.4	0.9	Turn right onto Old Coal Mine Road.
34.8	0.4	Turn right on Deerhurst Drive.
35.2	0.4	Park in cul-de-sac at eastern end of Deerhurst Drive.

STOP 7: Tuckahoe Group productive coal measures:

At this locality (see fig. 15) the productive coal measures are found within a structural trough or sub-basin called the Black Heath basin. Adjoining it to the west is the smaller Cunliffe basin which in turn is adjacent to the main Richmond basin. These two basins are part of the main Richmond basin and are in a downfaulted extension of it. They are on strike with similar basins, the Stonehenge and Union basins, to the south. However, the Stonehenge and Union basins, which also yielded coal, are completely separated from the Richmond basin proper and are enclosed by Petersburg Granite. The relationship between these basins and the flexures or "troubles" found down the dip of coal beds in many mines on the eastern margin of the Richmond basin is shown in the cartoon in figure 16. On that sketch map the main coal exposure is shown and the inferred geometry at depth is shown in cross sections A-A' of the main basin margin, B-B' of the Black Heath area, and C-C' of the Stonehenge and Union basins. This interpretation suggests that the main difference between these areas is in the relative depth of erosion.

Four coal seams were reported in the Midlothian area. At the Black Heath basin, which is just north of Midlothian proper, the lower two coal seams were considered to form a single coal unit 40 ft (12 m) thick which included 15 ft (4.6 m) of parting material. The upper two coal seams are 1 ft (0.3 m) thick and 5 ft (1.5 m) thick. The top seam contains 1.5 ft (0.4 m) of parting material. An analysis of the 40 ft (12 m) thick Black Heath coal by Johnson (1846) showed it to be high volatile A bituminous in rank. Sulfur was less than 2 percent and ash content was greater than 8 percent. Methane was present in the coals of this area, for Wooldridge (1842) wrote that: "Large quantities of inflammable gas are thrown out from the coal in the mines constantly...".

The Black Heath Mine, located near the center of the Black Heath basin, was opened around 1788 by the Heath Mining Company. It began with an 800 ft (240 m) deep shaft mine which was supported by wooden cribbing. Coal, personnel, and equipment were raised and lowered by buckets hung from a wooden head frame, and a mule-driven windlass drove the buckets. The 40 ft (12 m)-thick Black Heath coal was penetrated at the

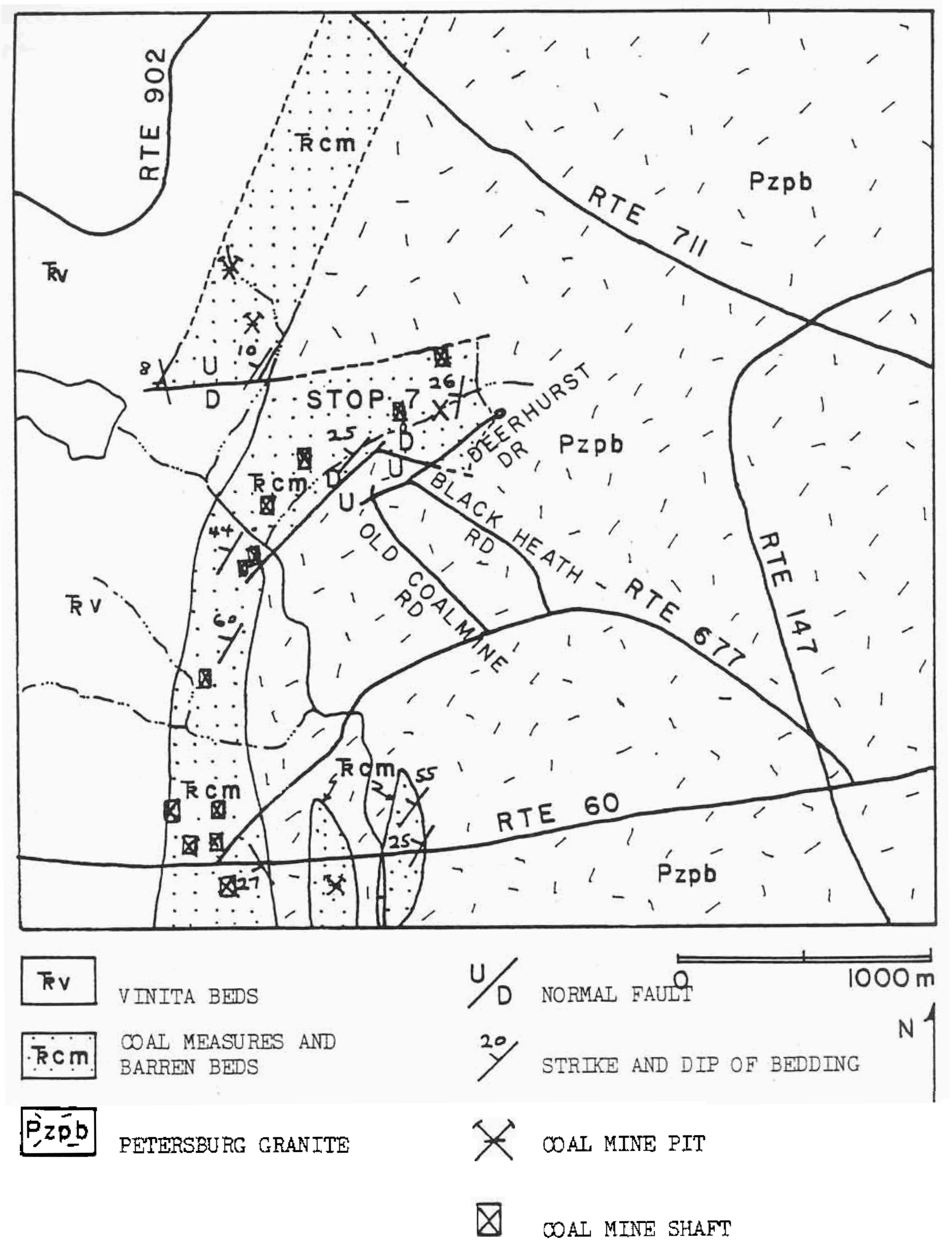


Figure 15. — Geologic map of Stop 7 and vicinity (geology modified from Goodwin, 1970). Coal mines located by G. Wilkes.

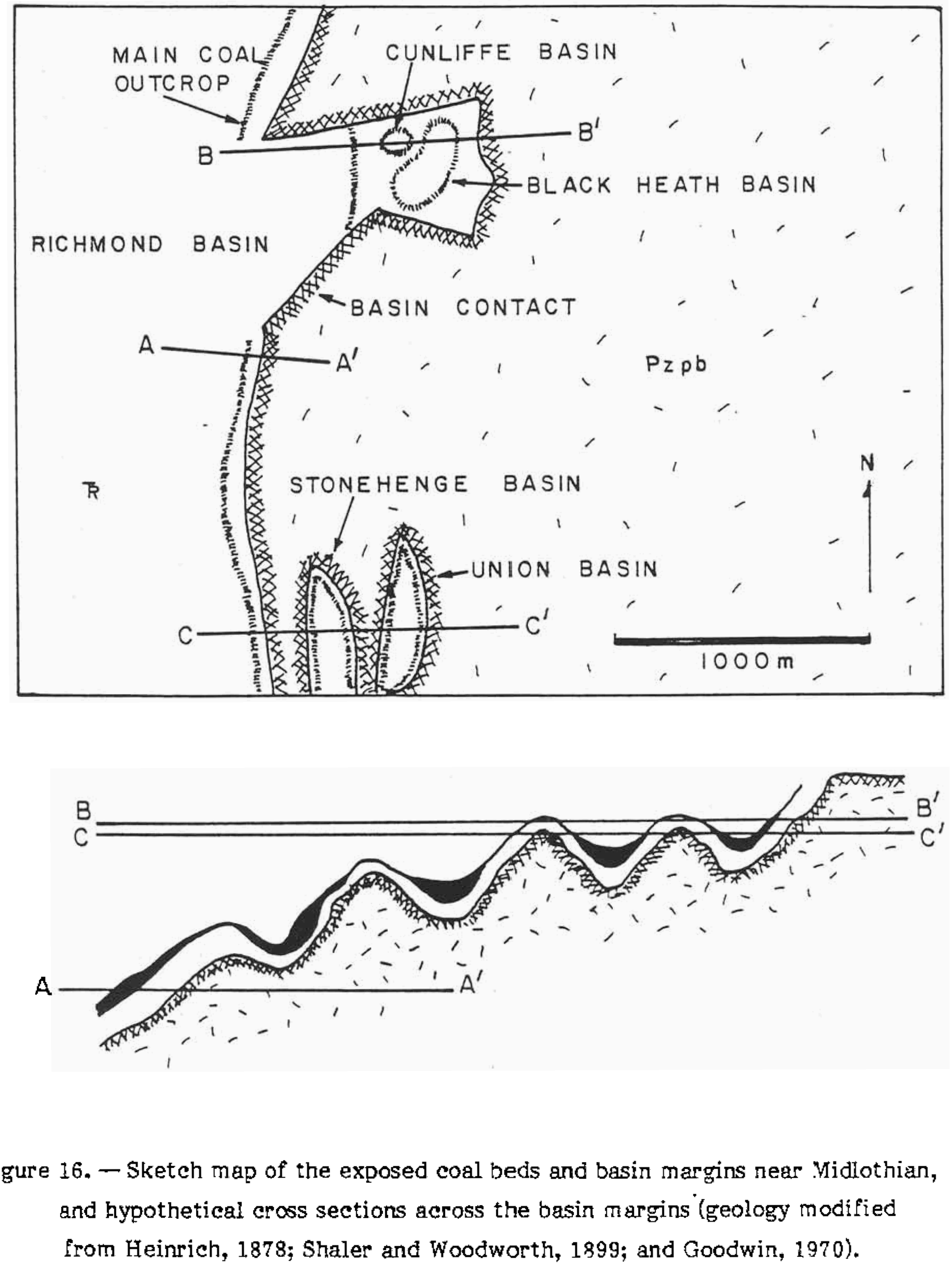


Figure 16. — Sketch map of the exposed coal beds and basin margins near Midlothian, and hypothetical cross sections across the basin margins (geology modified from Heinrich, 1878; Shaler and Woodworth, 1899; and Goodwin, 1970).

bottom of the shaft, and the main gangway developed in a westerly direction for 1,350 ft (412 m) and dipped from 8 to 42 degrees. Galleries or rooms were driven off the main gangway in a haphazard manner, depending on coal thickness and structure. The coal was first undercut by pick and then several 1 in. (2.5 cm) holes were drilled into the coal face. The holes were then loaded with black powder which was set off with a fuse. The fallen coal then was loaded into carts and pulled by mules to the base of the shaft. Roof support was added as needed by wood timbers and cribbing, which was in ample supply from the adjacent forests.

By 1836, part of the workings were on fire but had been sealed off from active sections. A unique ventilation system was developed by using this abandoned burning section. A mandoor, located in the stopping separating the active and abandoned workings, was occasionally opened to suck fresh air into the mine at the portal by the natural tendency of air to be drawn into a damped fire. Care had to be exercised because flammable concentrations of methane also could be drawn into the fire. In 1839 this did happen, and a violent gas explosion occurred which threw three men in a basket, which was descending the shaft at the time, over a hundred feet into the air. Fifty-three men in the mine were killed, and the underground workings could be outlined on the surface due to the collapse of sections by the explosion.

Sir Charles Lyell descended the Black Heath Shaft in 1844 and published his view on the coal and surrounding stata (Lyell, 1847). He visited the workings just in time, because later that year a gas explosion killed eleven men. The mine was still active in the 1850's, but all minable coal in the Black Heath and Cunliffe basins was mined out by the early 1860's. All that remained of the Black Heath Mine by 1887 was a pond. This pond was filled in 1985 (too late to stop E. I. Robbins from falling into it) with tree trunks and brush from local urban development as a prelude to the obliteration of the remaining traces of mining activity in this area.

When Lyell entered the Black Heath Mine, he noted "...a chamber more than 40 feet high, caused by the removal of coal." As the workings progressed, the dip of the coal bed sometimes increased to as much as 84 degrees. In these steeply dipping sections, the coal bed gained more parting material. Coal thickness diminishes away from the center of the basin and the marginal coals are heavily slickensided. At upward flexures, the coals are thin and of poor quality.

The stratigraphy and characteristics of these coals suggest deposition and lithification in a tectonically unstable area. As the middle Carnian land surface subsided, sediments poured in and filled the lowlands. Favorable climate, surficial geography, and flora contributed to formation of peat swamps (Robbins and others, in press), while occasional lowering of the land surface or runoff from storms introduced silt or sand to the swamp. Eventually, the swamps were covered by sands, silts, and clays and lithification of peat to coal began. Probably this area was still tectonically active, thus affecting the lithification process and distorting the less competent beds such as the coals. The coals found in the trough of a flexure (or of a basin such as the Black Heath basin) are blocky, bright, and attain their maximum thickness, whereas near or at the top of flexures they become part of the distorted structural framework.

From the parking place at the cul-de-sac on Deerhurst Drive, walk north through the woods, over the tracks of the Southern Railroad, and down the embankment to Black Heath Creek. The large boulders in and near the creek are of a highly porphyritic phase of the Petersburg Granite. Between the granite and the first exposure of Triassic sedimentary rocks, you will walk over the nonconformity between the two units. Unfortunately, it is entirely concealed in this area. Continue walking downstream, taking note of the sedimentary rock debris of sandstone, shale, and coal in the creek. Begin the following measured section in the creek at the first exposure you find. The section follows along Black Heath Creek going downstream. During high water stages this section will be almost totally covered and not available for study.

Strike and dip	Thickness (in feet)	Lithology	Description
N10°E, 25°W	1.0	COAL	Well developed medium cleat, face cleat: N17°W, 67°SW; butt cleat: N70°E, 77°SE.
	1.5	MUDSTONE	Light-gray, plastic, plant fragments

	2.7	SHALE	Micaceous, medium-gray, one 3-in. thick CARBONACEOUS SHALE bed.
	9.0	SILTSTONE	Medium-gray, micaceous
	5.0	SANDSTONE	Medium-gray, very fine to coarse-grained, rounded, poorly sorted, with minor CLAYSTONE interbeds.
	1.0	SANDSTONE	Dark-gray, poorly sorted, abundant clay, micaceous, undulating contact with overlying sandstone.
	0.2	COAL	Poorly developed cleat, dirty.
	0.1	MUDSTONE	Medium-gray, coal laminations, plant fragments.
	0.5	COAL	Moderately developed medium cleat, includes 0.1 ft interbedded parting material, two sets of face cleats: N80^{0}W,85^{0}NE and N60^{0}W, 87^{0}NE.
	0.2	MUDSTONE	Light-gray, plastic, micaceous.
N47^{0}E, 20^{0}NW	0.5	COAL	Moderately developed fine cleat, top of coal is covered.
	5.0	(COVERED)	
	20.0	SANDSTONE	Medium-gray, very fine to medium-grained, poorly sorted, dirty, with interbeds of SILTSTONE and MUDSTONE, grades into overlying mudstone.
	2.0	MUDSTONE	Medium-gray, silty, micaceous.
	0.2	COAL	Incomplete section
	15.0	(COVERED)	BLACK HEATH POND
N29^{0}E, 22^{0}NW	3.0	SILTSTONE	Brown/gray, dirty, incomplete section.
	4.0	(COVERED)	
	5.0	SILTSTONE	Brown/gray, bedding 1.5 ft thick.
	0.1	MUDSTONE	Light-gray, plastic.
N35^{0}E, 35^{0}NW	20.0	SANDSTONE	Gray, grades from poorly sorted, very fine to coarse-grained with MUDSTONE interbeds at top to CONGLOMERATIC SANDSTONE with 0.25 in clasts at the

			base, joint sets: N5^{0}E, 81^{0}W and N40^{0}W, 84^{0}NE.
	26.0	SILTSTONE AND MUDSTONE, INTERBEDDED	Partially covered, medium-gray, micaceous includes minor interbeds of poorly sorted SANDSTONE and one 0.5 ft thick COAL.
N50^{0}E, 26^{0}NW	4.5	SANDSTONE	Dirty brown, very fine to medium-grained, trace of conglomerate, moderate sorting, indurated; joint sets: N70^{0}W,65^{0}SW and N27^{0}E, 45^{0}SE.
N40^{0}E, 28^{0}NW	8.0	SILTSTONE AND MUDSTONE INTERBEDDED	With minor SANDSTONE stringers and a 0.3 ft foot thick CARBONACEOUS SHALE/COAL interval.
	5.0	(COVERED)	
	3.0	SANDSTONE	Gray, very fine to medium-grained, moderate sorting, micaceous.
	20.0	(COVERED)	
	11.0	SANDSTONE	Gray, very fine to medium-grained, moderate sorting, micaceous, indurated, with minor CLAYSTONE interbeds; joints: N5^{0}W, 50^{0}NE.
	0.8	UNDERCLAY	Light-gray, plastic, rooted.
N35^{0}E,32^{0}NW	0.6	COAL	Well-developed medium cleat, moderate thin lamination, face cleat: N89^{0}W, 73^{0}S; butt cleat: N17^{0}E, 65^{0}NW.
	3.0	MUDSTONE	Gray, plant fragments, minor SILTSTONE lenses.
	10.0	SANDSTONE	Gray, coarse- to very coarse grained, well sorted, micaceous, indurated.
	10.5	SANDSTONE	Gray, fine- to very coarse grained, moderate sorting, micaceous, with MUDSTONE interbeds up to 1.5 ft thick.

	1.5	UNDERCLAY	Sandy, medium-gray, rooted.
N20°E, 27°NW	0.7	COAL	Well-developed medium cleat, bright, lowest 0.1 ft slickensided, face cleat: N39°W, 76°NE; butt cleat: N19°E, 73°SW.
	1.5	MUDSTONE	Gray
	1.0	SILTSTONE	Sandy, gray, incomplete.

GAS PIPELINE — END OF SECTION

203.1 ft	Total thickness

35.2	0.0	Turn around and retrace route west on Deerhurst Drive.
35.4	0.2	Turn left onto Black Heath Road.
35.8	0.4	Turn left onto Va. Route 677 (Old Buckingham Road).
36.6	0.8	Turn right onto Va. Route 147 (Huguenot Road).
36.7	0.1	Turn right at traffic light onto U.S. Route 60 (Midlothian Turnpike). The high level Tertiary gravels are well exposed in some of the construction areas on the right side of the road.
37.3	0.6	Cross the contact between overlying Tertiary gravels and the Petersburg Granite. This contact was once well exposed at the western end of the former gravel pit to the right.
37.6	0.3	In the small roadcut on the right side of the road is the contact between the Petersburg Granite and Triassic sandstone, shale, and coal. The Triassic rocks here occur within the Union basin (fig. 16), a small outlying basin to the east of the main Richmond basin. Immediately north of the road are waste piles from the old coal mines and remnants of the former mining operation. Granite lies between the Union basin and the Richmond basin.
37.9	0.3	Cross over the approximate contact between Petersburg Granite and the Richmond basin.
38.0	0.1	Cross over the contact between Triassic sedimentary rocks of the Richmond basin and overlying, nearly horizontal Tertiary gravels. These gravels underlie a flat upland surface along

		U.S. Route 60 for the next 4 miles to the west.
38.5	0.5	Pass through the center of the town of Midlothian. This was an active coal mining center in former years, and mines were situated both north and south of U.S. Route 60. A few of the old shafts can still be seen, although they are rapidly being destroyed and covered by urbanization.
40.1	1.6	Turn left onto Va. Route 667 (Otterdale Road) and proceed south.
40.3	0.2	Cross the tracks of the Norfolk-Southern Railway. Good exposures of Tertiary gravels occur in cuts along the railroad tracks to the west of this intersection.
41.2	0.9	Cross over the approximate contact between Tertiary gravels and Triassic sedimentary rocks.
42.7	1.5	Cross Va. Route 652 at stop sign. Continue south on Otterdale Road.
44.3	1.6	Cross Swift Creek with its broad floodplain. The larger streams have commonly developed broad floodplains over the easily eroded sedimentary rocks of the Richmond basin.
44.6	0.3	Weathered exposures of the Vinita Beds occur on the left side of the road in a high roadcut.
44.9	0.3	Cross Va. Route 604 (Genito Road). Continue south on Otterdale Road.
45.6	0.7	Cross Otterdale Branch where conglomerate is exposed in the bed of the creek on the right side of the road.
46.5	0.9	Three wells were drilled around 1983 by Merrill Natural Resources between this road and the floodplain of Deep Creek to the east.
47.6	1.1	At "T" junction, turn left and continue to the southeast on Va. Route 667 (Otterdale Road).
49.4	1.8	Turn right on U.S. Route 360 (Hull Street Road) and proceed west.
50.6	1.2	Turn left onto Va. Route 730 (Baldwin Creek Road).
51.9	1.3	Park near intersection of Baldwin Creek Road and Va. Route 655 (Beach Road).

STOP 8: Chesterfield Group, Otterdale Sandstone: A series of 8-foot high exposures in the roadcut on the west side of Va. Route 730 (fig. 17) are developed within residuum of the Otterdale Sandstone. Although these exposures would be considered to be small in many areas, for the Richmond basin they are superb. Quartz grains remain, but feldspars mostly have been converted to clay. This has caused many of the former rocks to thoroughly decompose. Although quartz clasts remains hard and relatively fresh, schist, phyllite, granite, and sedimentary rock have been thoroughly altered to sandy clay and usually are recognizable only as relicts of former clasts..

One problem of geologic mapping in this area is in distinguishing residuum of conglomeratic parts of the Otterdale Sandstone from residuum of upland gravels of Miocene(?) to Pleistocene age which occur as nearly horizontal sheets on many upland surfaces. The Tertiary upland gravels have also been deeply weathered and have pebbles and cobbles similar in size to those of the Otterdale Sandstone. However, the basal contact of the Tertiary upland gravels occurs at quite predictable elevations (except at the base of channels cut deeply into the underlying rocks) on a surface that is inclined gently eastward along a gradient averaging 7 ft/mi (1.3 m/km). It reaches a minimum elevation of about 250 ft (75 m) at a scarp which commonly marks the eastern limit of this gravel unit south of Richmond. In the vicinity of this locality, the basal contact of the Tertiary gravels should be at an elevation of about 330-350 ft (100-106 m), if they once were present. The exposures here are at 270 ft (81m), a much lower elevation. Also, a short distance north in the upland east if State Road 730 is an old coal mine (fig. 17) which exploited a 5 ft (1.5m) seam of coal at an unknown, but presumably shallow, depth. No detailed comparison of clast composition has been made between the Triassic conglomerates and the Tertiary gravels, but it appears that the Triassic rocks have many more clasts derived from igneous, metamorphic, and cataclastic rocks than the Tertiary gravels, which appear to be much richer in quartz, sandstone, and quartzite clasts. Some quartzite clasts in the Tertiary gravels bear tubes of the fossil Skolithos (Scolithus). These have never been found

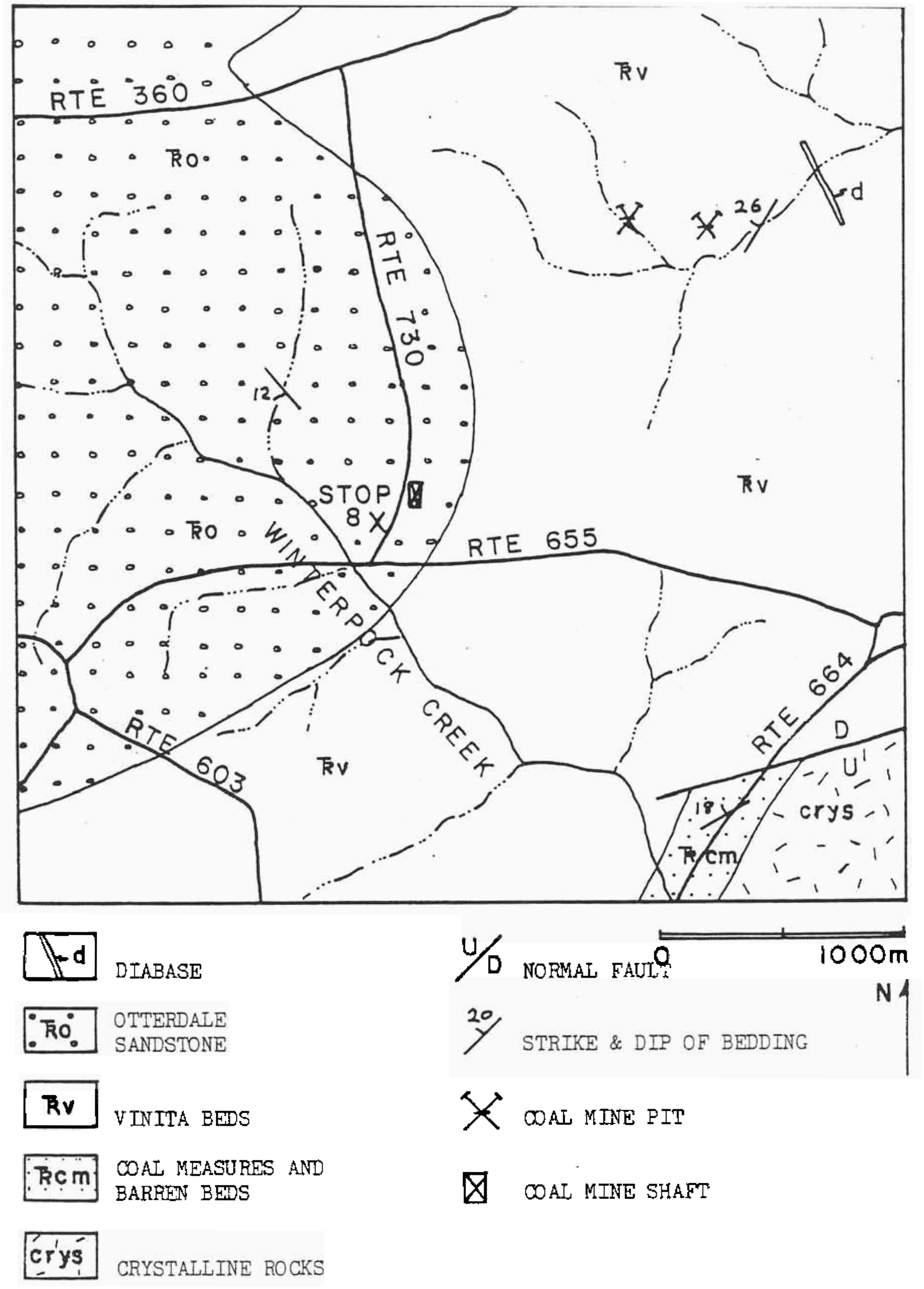


Figure 17. — Geologic map of Stop 8 and vicinity (geology modified from Goodwin and Farrell, 1979). Coal mines located by G. Wilkes.

in the conglomerates of the Richmond or Taylorsville basins or in Coastal Plain sediments older than Miocene. This suggests that the pebbles and cobbles in the Triassic conglomerates were derived mainly by erosion of nearby Piedmont areas adjacent to the Richmond basin, whereas many of the similar-sized clasts in the Tertiary gravels were transported much farther, some from beyond the crest of the Blue Ridge. The clasts in the conglomerate and conglomeratic sandstone at this locality reflect the mineralogically more heterogeneous compositions characteristic of Triassic rather than Tertiary sediments. Thin conglomerates also are found within the Vinita Beds, and fanglomerates are found locally along both the eastern and western margins of the Richmond basin.

As no diagnostic fossils have been found as yet within the Otterdale Sandstone, except for common petrified logs and tree branches, these rocks have always been assumed to be Triassic in age. However, this age was based more on the stratigraphic position of the Otterdale than on hard evidence. If, as suggested by some drill hole correlations, the Otterdale Sandstone and the Vinita Beds interfinger, then the Otterdale must necessarily be Carnian in age. However, if the Vinita Beds and the Otterdale Sandstone are separated by an unconformity as Cornet (1985) has suggested, then the Otterdale might be younger than Carnian in age. The petrified logs of Araucarioxylon, one of which can be seen at this locality, are found in rocks of Triassic and Jurassic age but have not been reported from rocks of Cretaceous age. A more exact paleontological age assignment for the Otterdale must await further study. However, the fact that diabase dikes of presumed Early Jurassic age cut across the Otterdale Sandstone, and no basaltic flows have been reported within it, tends to suggest that the Otterdale is older than Jurassic in age.

These exposures are developed in what was once medium- to coarse-grained, arkosic sandstone, pebbly sandstone, and conglomerate. The residuum is dominantly yellowish-brown to reddish-brown or orangish-brown with some light-gray sand. Channels cut into the formerly arkosic sandstone were filled by gravel, pebbly sands, and coarse-grained sands with pebbles and cobbles most abundant at the base of the channel fill. These larger clasts are rounded and are of variable compositions including granite, gneiss, quartz, quartzite, and cataclastic rocks. Some probable phyllite or schist has been completely altered to clay and cannot be identified exactly. Most of the minerals in the granite and gneiss clasts are thoroughly decomposed, but the original texture and composition of the rocks can still be discerned. Near the base of the channel fill, many of the larger clasts are elliptical and their long dimensions are parallel or subparallel to the base of the trough. The basal contact is rather sharp with only minor mixing, but this contact is somewhat irregular as some of the cobbles have become partially depressed into the underlying coarse-grained sandstone. At this locality, the pebbles and cobbles are most abundant at the lowest point of the channel troughs and grade laterally into coarse-grained sandstones up the dip of the prominent trough cross-beds. The channel fill has been truncated on top, which has produced a sharp contact marked by nearly horizontal beds of coarse-grained arkosic sandstone.

Walk 110 ft (33 m) north (uphill) along Va. Route 730 until the bank on the west side diminishes in height. Then turn left, climb bank, and walk west for about 140 ft (42 m) through the cleared out woods. After descending the slope to a cleared gravelly area, turn right and go north a short distance. To the right (north) are 15-20 ft (4.5-6 m) high vertical faces of a small borrow pit in the Otterdale Sandstone. During this traverse your path has been littered with abundant quartz cobbles, characteristic of cleared areas overlying conglomerate phases of the Otterdale Sandstone. This borrow pit has been worked primarily for fill, but due to the high clay content of the residuum, it was not very satisfactory for that purpose.

These large exposures once were dominated by coarse conglomerates, now reverting to gravels, and by dune scale trough cross-beds which are best shown on the north and east walls of the pit. At the northeast corner of the pit is a 6 in. (15 cm) wide, vertical clay seam cutting across the strata. This is the weathered remnant of the gouge zone of a fault. Formerly this fault could be traced across the east side of the pit and roughly paralleled it. Displacement could not be determined, as only monotonously thick gravels are present on both sides of the fault. These cuts were once much better exposed, but their bases are mantled now by alluvium and sediment deposited by slope wash.

The lowest units in this exposure, totaling more than 10 ft (3 m) in thickness, are cobble-rich and appear to be basal portions of troughs because the cobbles are dispersed in a coarse, sandy matrix and they grade into beds less rich in cobbles laterally. There are cobbles at the base of most of the obvious crossbeds as well. In general, the thick conglomerate appears to be coarser near the base of the exposure and becomes slightly finer upward. A few boulders more than 1 ft (30 cm) across have been found near the base of the exposures, but these are now usually covered by alluvium. These boulders are more angular than the average pebbles or cobbles and invariably are decomposed completely to clay. Most appear to have been originally igneous or metamorphic rocks, but a few are reddish in color and resemble deeply weathered Triassic siltstone or shale. A few deeply weathered pebbles and cobbles are also suggestive of Triassic lithologies. The more angular boulders are set in a matrix of granules, pebbles, and cobbles of heterogeneous composition, and coarse- to very coarse grained, formerly arkosic sands. Most are decomposed, but many quartz clasts remain firm and largely unweathered. Many of the pebbles and cobbles are flattened and the flat surfaces are roughly parallel to bedding. In general, the composition and weathering of the larger clasts is similar to that described at the road cuts earlier at this stop.

Above the thick conglomerate sequence is a 2.5 ft (75 cm)-thick, crossbedded, coarse-grained sandstone dipping gently westward. It is overlain at a sharp contact by more conglomerate. This unit also has a sharp basal contact with the thick underlying conglomerates which is marked by a 2 in. (5 cm)-thick layer of gray clay.

Walk about 140 ft (42 m) toward the northwest corner of the large cleared area facing this borrow pit and turn northward onto the narrow path which cuts through the woods. Follow this path for about 180 ft (54 m) to a large cleared area, now growing up in scrub, which is bounded to the east or northeast by large vertical cuts about 30 ft (9 m) high. These exposures are continuous for about 300 ft (90 m) to the north and mark the edge of another very large borrow pit in the Otterdale Sandstone.

Dune-scale, trough crossbedding dominates these exposures and is well displayed at the southern end of the cut in coarse-grained, arkosic sandstones. The general lithologies, colors, and degree of weathering are similar to those shown at the other two places described at this stop; however, these exposures show a much broader view of the crossbedding, conglomerates, and sandstones. About 200 ft (60 m) along the wall from the south end of the cut is a wide hole cut into the face about halfway up the wall. At the very back of the hole is a poorly exposed cross section of a silicified conifer log, probably *Araucarioxylon*. The log is about 1 ft (30 cm) in diameter, and chips of the silicified wood usually litter the base of the hole. This log formerly was exposed at the surface of the pit face, but rock and fossil collectors have gradually removed pieces of silicified wood over a long period of time, so now it is recessed into the wall. When this pit was being worked for fill, several such logs were exhumed and some of them were more than 20 ft (6 m) long. This log is found within a thick, coarse, conglomerate sequence of channel deposits, and two partial-fining upward sequences may be present. The absence of fine sediment and smaller scale bedforms as well as the dominance of gravels and large scale crossbedding suggest a braided-stream type of deposit for the Otterdale Sandstone at this locality.

51.9	0.0	Turn right onto Va. Route 655 (Beach Road) and proceed west on Beach Road.
52.7	0.8	Turn left onto Va. Route 603 (Beaver Bridge Road), and continue to the southeast on Beaver Bridge Road.
55.1	2.4	The center of the town of Winterpock is at the intersection of Beaver Bridge Road with Va. Route 664 (Coalboro Road). Winterpock was a coal mining center, and coal mines were active at this intersection and both north and south of it. Waste material from the mining can be seen in the soils and in heaps in this area. Turn left onto Coalboro Road.
55.7	0.6	The left bank of the road is composed of waste debris from the old Cox-Clover Hill Mine. The shafts of this mine can be seen a short distance in the woods to the west of the road. CARE MUST BE TAKEN IN VISITING THE SITE BECAUSE NO FENCES OR SIGNS OCCUR AROUND THE SHAFTS.
59.6	1.2	Bear right at the fork in the road.
57.2	0.3	Turn right onto Va. Route 655 (Beach Road).

58.5	1.3	Turn left at stop sign onto Va. Route 621 (Winterpock Road).
61.5	3.0	Turn right onto U.S. Route 360 (Hull Street Road). Coarse, boulder conglomerate was formerly exposed in low road cuts on the east side of Va. Route 621 south of this intersection. The contact between the Richmond basin and gneiss is near this intersection.
63.1	1.6	Cross over Swift Creek. Igneous and metamorphic rocks are exposed in the bed of the creek at this point. Note the deep creek valley and the absence of a floodplain. This contrasts with the valley of Swift Creek where it was on Triassic sedimentary rocks earlier on this trip.

End of detailed log. Continue east on U.S. Route 360 until its intersection with Va. Route 150 (Chippenham Parkway); go north on Chippenham Parkway until its intersection with the Powhite Parkway. From there, follow the signs to Interstate Route 195 (The Downtown Expressway), to Interstate 95 north, to Interstate 64 east to Williamsburg. Follow Interstate 64 back to Williamsburg.

END OF TRIP