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NORTHERN VIRGINIA

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Guidebook 11: Excursions B–4, B–5, B–6

NORTHERN VIRGINIA

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NORTHERN VIRGINIA

INTRODUCTION

By Arthur Bevan

Virginia extends from the Atlantic Ocean westward for 440 miles (708 kilometers) and lies in five geomorphic provinces (5)[1]—namely, the Coastal Plain, Piedmont, Blue Ridge, Appalachian Valley and Ridge, and Appalachian Plateaus. (See fig. 1.) Each of these provinces is characterized by distinctive bedrock formations, structure, mineral resources, and topography.

Coastal Plain.—Exclusive of the Eastern Shore peninsula the Coastal Plain of Virginia is 60 to 80 miles (97 to 129 kilometers) wide and has an area of about 11,000 square miles (28,490 square kilometers). It has a tidal shore line of about 780 miles (1,255 kilometers). The surface is a dissected terraced plain which slopes gently to the sea from altitudes of 300 feet (91 meters) or more along its western margin. The eastern part is dissected into a series of elongate peninsulas by Chesapeake Bay and four rather narrow tributary estuaries. The Coastal Plain extends beneath the Atlantic Ocean, and the submerged part has a width of about 65 to 75 miles (105 to 121 kilometers). Broad estuaries and inlets marking the coast line are the drowned valleys of streams due to subsidence and submergence. The tide flows up these estuaries to the Fall Zone, which lies along the western margin of the Coastal Plain, at the contact of the unconsolidated Coastal Plain deposits with the hard pre-Cambrian crystalline rocks of the Piedmont province. There are falls and rapids where the contact is crossed by the rivers, as Great Falls on the Potomac 14 miles above Washington, falls on the James River at Richmond, and falls on other rivers southwest to Alabama.

The formations of the Coastal Plain are chiefly unconsolidated or loosely consolidated marine and nonmarine gravel, sand, clay, and shell marl of Cretaceous and Tertiary (Eocene and Miocene) age. Greensand, lignitic clay, and diatomite are found in some formations. The Tertiary beds overlap the Cretaceous formations unconformably. The Cretaceous beds dip seaward about 30 to 50 feet or more to the mile (5.7 to 9.5

[1] Numbers in parentheses refer to bibliography, p. 43.

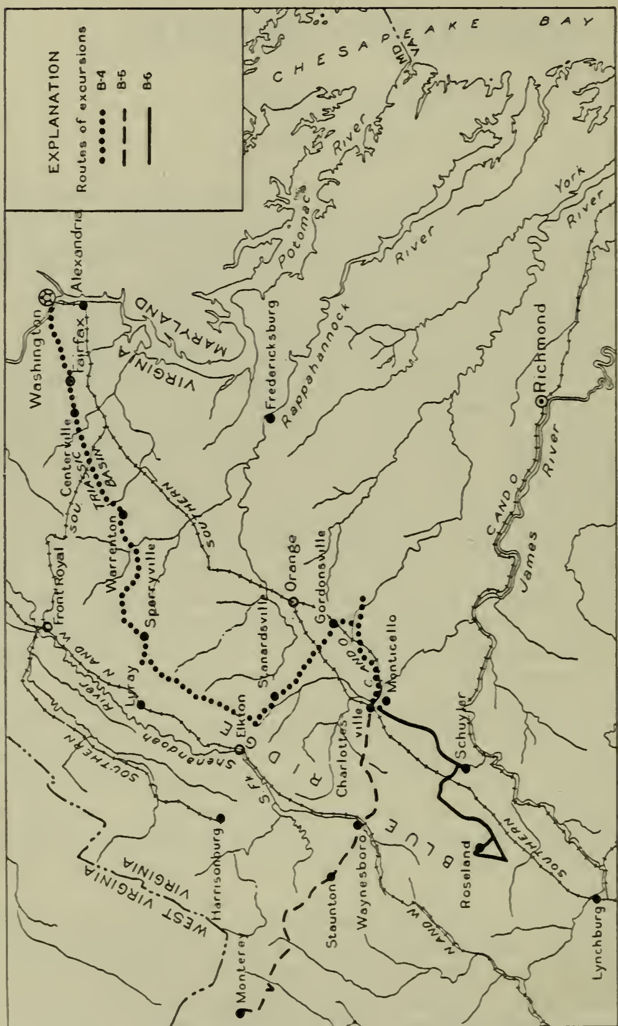


FIGURE 1.—Map of northern Virginia showing routes of excursions B-4, B-5, and B-6

meters to the kilometer) and the Tertiary beds about 5 to 15 feet to the mile (0.95 to 2.85 meters to the kilometer). A dissected mantle of Quaternary marine and fluvial gravel and sand veneers the broad terraces cut into the bedrock formations. A well near Norfolk reached the crystalline floor at a depth of 2,246 feet (685 meters).

The main economic mineral resources of the Coastal Plain are sand, gravel, clay, and shell marl (for cement). Some sandstone (Lower Cretaceous) has been much used for buildings, as in the White House and part of the Capitol in Washington. Diatomite (Miocene) is a potential resource.

Piedmont province.—About one-third of Virginia lies in the Piedmont province, which widens from about 40 miles (64 kilometers) along the Potomac River to about 170 miles (274 kilometers) along the southern border of the State. Its southeastern edge is marked by the Fall Zone, to which the tide flows up the estuaries. Washington, Fredericksburg, Richmond, and Petersburg are located along the Fall Zone.

The surface of the Piedmont Plateau rises gradually westward to the foot of the Blue Ridge, reaching an altitude of about 500 feet (152 meters) at the north and 1,500 feet (457 meters) at the south. It is a vast plain cut across the folded bedrock and since maturely dissected into a rolling topography, having in places a relief of a few hundred feet. Numerous hills and ridges (monadnocks) rise 200 to 1,000 feet (61 to 305 meters) above the plateau surface toward the west and become more abundant near the Blue Ridge.

The formations of the Piedmont province are mostly granites, gneisses, and schists, with some belts of marble and quartzite, of pre-Cambrian age. A belt of basic rocks containing talc and soapstone is found near the western border. Metamorphosed Cambrian sediments occur in a belt extending northeastward through Charlottesville. Belts of fossiliferous Upper Ordovician slates are present in the middle part along the James River and southwest of Mount Vernon. Several elongate basins of Upper Triassic sandstones and shales, cut by diabase dikes and sills, are found in the province. The Richmond Basin contains coal, which was the first mined in North America, about 1750.

The Triassic rocks are gently tilted and cut by numerous normal faults, and all the Piedmont pre-Cambrian and Paleozoic rocks are highly folded and in places cut by great overthrusts and normal faults.

The mineral resources of the province are chiefly soapstone, granite, slate, feldspar, ilmenite, rutile, kyanite, mica, beryl, barite, and gold. One of the largest productive areas of soapstone in the world is in Albemarle County, and the largest known deposits of titanium ores in North America are found in Nelson and Amherst Counties. Iron, manganese, and pyrite were formerly mined.

Blue Ridge province.—The Blue Ridge province includes at the north the Blue Ridge proper, a relatively narrow ridge having somewhat indefinite limits, which extends for 200 miles (322 kilometers) from the Potomac River southwestward to Roanoke. It has an altitude of about 1,000 feet (305 meters) near the Potomac River and reaches more than 4,000 feet (1,219 meters) in the northern half, as in the Knobs and in Stony Man and Hawksbill, southeast of Luray. This part contains the Shenandoah National Park. The new Sky-line Drive runs along the crest from Thornton Gap south to Swift Run Gap.

Southwest of Roanoke the Blue Ridge province is a rolling plateau, about 10 to 65 miles (16 to 105 kilometers) wide and having an average altitude of about 3,000 feet (914 meters). It is bounded on each side by an escarpment 1,000 to 2,000 feet (305 to 610 meters) high. This part of the province includes the highest land east of the Rocky Mountains. Mount Rogers, near the northwestern escarpment 12 miles (19 kilometers) south of Marion, has an altitude of 5,719 feet (1,743 meters) and is the highest point in Virginia. The highest peak in the Blue Ridge province is Mount Mitchell (6,711 feet, or 2,046 meters), north of Asheville, North Carolina.

The northwestern part of the Blue Ridge province consists largely of Lower Cambrian quartzites and slates, which dip gently to steeply away from the Blue Ridge or are locally overturned and dip toward the Blue Ridge. The western front of the Blue Ridge has been in general thrust westward over the Appalachian Valley. The eastern and larger part consists of pre-Cambrian gneisses, schists, granites, and metabasalts. Metarhyolites occur in the southern part (15).

Mineral resources in the Blue Ridge province are few. A large body of pyrrhotite occurs in the southwestern part of the plateau, in Floyd, Carroll, and Grayson Counties. Lower Cambrian sedimentary hematite has been mined extensively northeast of Roanoke, and large reserves still exist. Allanite, cassiterite, barite, kyanite, and other minerals occur in places.

Appalachian Valley and Ridge province.—The Appalachian Valley and Ridge province in Virginia is about 25 to 50 miles (40 to 80 kilometers) wide. The eastern part consists of a series of elongate valleylike lowlands along the northwestern base of the Blue Ridge. Shenandoah Valley, at the north, about 150 miles (241 kilometers) long in Virginia and 10 to 20 miles (16 to 32 kilometers) wide, is an example. These valleys are parts of the Great Valley, which extends from New York into

Alabama. The flattish valley floors bevel highly folded Cambrian (including the Ozarkian of Ulrich) and Ordovician limestones and shales. Numerous large caves and sinks occur in the limestones. The valley floors are from 500 to 2,500 feet (152 to 762 meters) above sea level. The western part of the province is occupied by a group of subparallel elongate, narrow, linear, rather even-crested mountain ridges and somewhat narrow intermontane valleys. Many of the ridge crests form a rather even sky line at an altitude of about 3,000 feet (914 meters). The ridges are formed mainly on folded Lower Silurian sandstone and quartzite, and the valleys chiefly on Ordovician limestones and Devonian shales.

The formations in this province range from Lower Cambrian to lower Carboniferous (Mississippian). Striking features are the thick bodies of Cambrian and Ordovician limestones and dolomites, of Ordovician shales, and of Devonian shales. The total thickness of the Paleozoic formations is estimated to be between 25,000 and 30,000 feet (7.6 to 9.1 kilometers).

The formations are folded into a series of great anticlines and synclines, mostly overturned to the northwest and broken by several great overthrusts, the fault blocks having been thrust to the northwest. Fensters and klippen are found in places, as in Rockingham, Roanoke, Montgomery, and Lee Counties.

The chief mineral resources of the province are limestone, dolomite, cement materials, clay, lead and zinc, manganese, sandstone, and glass sand. Lower Devonian sedimentary hematite occurs in some places in considerable quantity and was once extensively mined in Alleghany and Botetourt Counties. Barite is found in the southwestern part of the province. Hard coal is mined from lower Mississippian beds in Montgomery and Pulaski Counties. Salt brines and gypsum are economically important in Smyth County. Scattered deposits of ocher occur. Natural gas has been discovered in Scott County, 10 miles (16 kilometers) northwest of Bristol. There are numerous thermal springs in the west-central part of the State.

Appalachian Plateaus.—About 1,500 square miles (3,885 square kilometers) of the extreme southwestern part of Virginia lies in the Appalachian Plateaus. This region is a plateau at an altitude of 2,000 feet (610 meters) or more, which has been thoroughly dissected into a maze of sharp hills and ridges and deep ravines.

The surface formations are approximately horizontal sandstones and shales of early Pennsylvanian (Pottsville) age, containing several beds of bituminous coal, some of which is "smokeless," of great commercial value.

GEOMORPHOLOGY OF THE PIEDMONT REGION

[Excursion B-4]

THE COMPOSITE PENEPLAIN OF THE VIRGINIA PIEDMONT

By Marius R. Campbell

The most important events in the development of the science of geomorphology that have taken place in this country in the past century were the publication in 1875 by John Wesley Powell of his concept of the "base-level of erosion," or the limiting level toward which all processes of erosion tend to reduce the surface of the earth, and the elaboration by William Morris Davis in 1889 and later years of this idea so that it could be applied to the erosion of such parts of the earth's crust as are subject not only to periods of vertical movement but also to periods of rest. The greatest contribution made by Davis was his recognition of the orderly succession of events in the reduction of newly elevated portions of the earth's surface, which he designated a cycle. He frankly stated that such a cycle is seldom completed, but when the reduction is carried to the penultimate stage it results in a peneplain ("almost plain"). The basic idea was Powell's, but this of itself would have been almost useless without the brilliant suggestion of Davis that the development of eroding agents and the forms they produce during a cycle may be likened to the development of a human being, through infancy, maturity, and old age.

In the last 40 years the followers of Davis have identified many partial peneplains in the United States and also in foreign countries, and this has thoroughly convinced them that peneplains and partial peneplains have been produced at many times in the world's history and that they are important links in the chain of events which constitute the geologic and geomorphic history of the regions in which they occur.

As some geomorphologists have expressed doubt regarding the interpretation of these forms, the present seems to be an opportune time to call attention to one of the finest examples of a peneplain that can be found in this country. This has been developed in the southern Piedmont region but is particularly striking in Virginia, immediately south of Washington.

In his elaboration of the processes of peneplanation and the attendant conditions that make the formation of such surfaces possible, Davis considered only the formation of a single plain in a single cycle of erosion, but in the southern Piedmont region tilting or warping has probably taken place either continuously or intermittently during the process of peneplanation. The warping appears to have occurred upon a fulcrum or hinge line, which corresponded closely with the present Fall Zone—a zone marking the inner margin of the Atlantic Coastal Plain or the disappearance of the crystalline rocks beneath the Coastal Plain sediments in a seaward direction. As the earth's crust moved on this fulcrum, every rise toward the west, or interior, was accompanied by a depression to the east, and the surface on this fulcrum was practically stationary. Under this condition very complete peneplanation took place along the Fall Zone, and less and less complete reduction in the zones to the west, until in the vicinity of the Blue Ridge the surface was left in a very mountainous condition. The result is a composite peneplain.

The beginning of peneplanation in this region is not a matter of record, but it is assumed that the early stages in the production of the present features occurred possibly in the Cretaceous period. This is shown in Figure 2 by the diagram A–B, which represents an east-west section of the Piedmont region at that time. Next came an upwarp in the region west of the Fall Zone and a corresponding downwarp in the region to the east. The surface is supposed then to have been raised from A–B to C–D. In the western part of the area erosion did not remove all of this uplifted mass but merely trenched it, leaving ridges and knobs whose crests coincided approximately with the old surface. Toward the Fall Zone the rocks in a belt 40 miles (64 kilometers) or more in width, being deeply disintegrated by long exposure to the weather, were easily removed, so that in all probability the surface was kept near sea level despite the uplift.

Another upwarp of the same character and of similar amount is represented by section E–F. Again the eastern part was kept near base level by active erosion on a deeply weathered surface, and because of this condition the peneplain persisted in this part of the area. Near the Blue Ridge, however, the valleys were appreciably deepened and the ridges heightened, leaving the region in a slightly more mountainous condition than that shown in section C–D. Another stage of warping, shown in section G–H, produced similar results, except that the difference in appearance between the east and the west was accentuated by the deep and widespread erosion in the 40-mile (64-kilometer) belt near the Fall Zone and by the reduction of the valleys in the more rugged region to the west. This terminated the upwarping west of the Fall Zone and evidently left a broad featureless surface that must have been an almost perfect plain adjoining that zone.

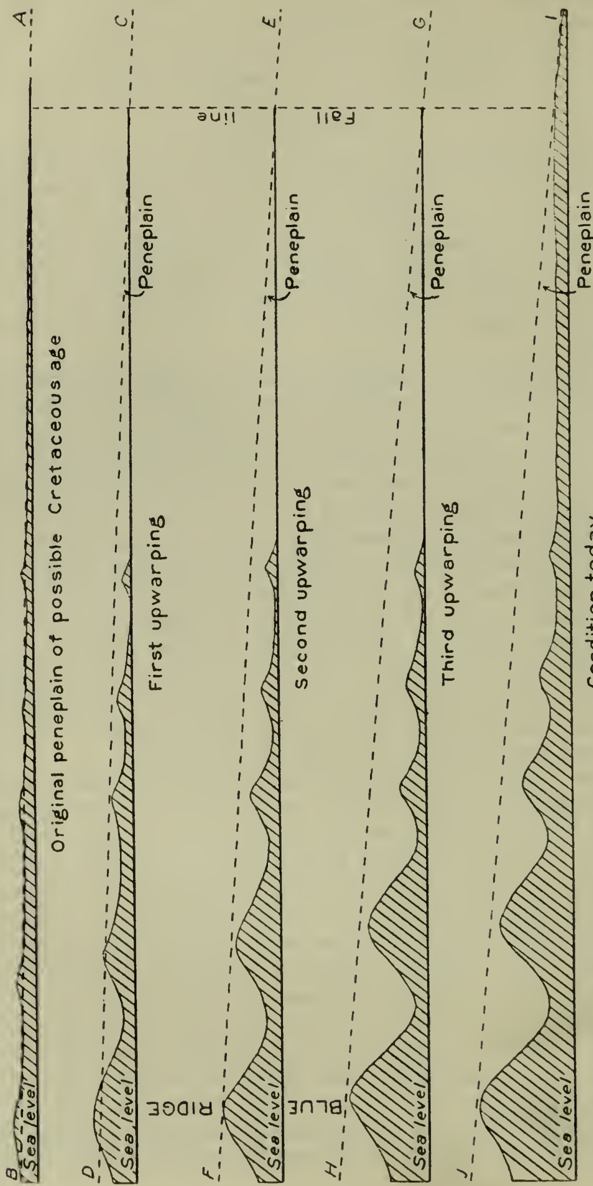


FIGURE 2.—Supposed method of development of the peneplain of the Virginia Piedmont

The date of the completion of this composite peneplain can not be definitely determined, but there is considerable evidence in the deeply weathered quartz gravel which covers large areas near the major streams that the peneplain was completed in Pliocene time and probably near the end of that period.

At a later date the entire area was raised some 200 feet (61 meters) in the Fall Zone and nearly 500 feet (152 meters) at the western edge of the 40-mile (64-kilometer) belt, or at the first monadnocks that are to be seen in crossing this area from east to west. Still farther west the Blue Ridge and its accompanying outliers tower about 2,000 to 3,000 feet (610 to 914 meters) above sea level. On the flat or gently sloping plain the streams found their way to the Fall Zone and intrenched themselves in its deeply weathered surface. They still hold such a position, about 200 feet (61 meters) below the surface of the uplifted peneplain.

The condition of the peneplain as described above can be seen to-day by traveling across it or viewing it from some commanding monadnock. The plain may be crossed by automobile in an east-west direction on several highways, but the region is so densely wooded that on most of the routes it is impossible to see the adjacent country for any great distance. The points from which views of the great plain may be obtained are therefore few, but the panorama outspread at those listed below is well worth seeing by one interested in such geomorphic features.

1. One of the most convenient points from which to see the western part of the peneplain is the summit of the hill upon which Thomas Jefferson long ago built his home, called Monticello, near Charlottesville. From this point, when atmospheric conditions are favorable, a wide view unbroken by any monadnocks may be obtained far to the east and south. The altitude is so great that the surfaces of the peneplain between the streams stand up as low ridges and help the observer to grasp the idea of the great extent of the plain before him.

2. Excellent views to the west and south can be obtained from points on State Highway 39 about 21 and 27 miles (34 and 43 kilometers) east of Charlottesville. These views give a good idea of the southward extent of the plain and of its relation to the outliers of the Blue Ridge in this locality.

3. The best view that the writer has seen is that from the summit of a low ridge 11 miles (17.7 kilometers) south of the James River on State Highway 15. Here there is a widely extended view of almost the whole Blue Ridge front, with the flat peneplain extending up to its foot in an almost unbroken line. At this distance all the outliers merge with the main ridge and give the impression of a pronounced mountain wall with the vast plain at its foot.

ITINERARY

By Arthur Bevan

The excursion to study the geomorphology of northern Virginia will cross the inner margin of the Coastal Plain near Washington, cross the Piedmont province in a southwesterly direction between Washington and Sperryville, ascend the northeastern slope of the Blue Ridge to Thornton Gap, follow the crest of the Blue Ridge southwestward to Swift Run Gap, and then descend the east slope of the Blue Ridge and pass southeastward across the Piedmont region to Charlottesville. (See fig. 1.)

The route of this excursion is covered by United States Geological Survey topographic maps as follows: Washington and Vicinity, Fairfax, Thorofare Gap, Warrenton, Luray, Stony Man, Madison, Elkton, Gordonsville, Palmyra, and University; also by the geologic map of Virginia published in 1928 by the Virginia Geological Survey.

Leave Washington on United States Highway 211. Cross the Potomac River on the Key Bridge, about 13 miles (21 kilometers) below Great Falls, in the Fall Zone. View upstream shows lower part of the narrow Potomac gorge, here about a quarter of a mile (0.4 kilometer) wide and 100 to 150 feet (30 to 46 meters) deep. The walls are of pre-Cambrian crystalline rocks.

The uplands for a few miles contain small gravel-covered remnants of Coastal Plain terraces (Brandywine and Sunderland), of early Quaternary age. These terrace remnants are well shown south of Clarendon and near Baileys Crossroads.

Cross the Piedmont plain on highly folded pre-Cambrian crystalline rocks for about 20 miles (32 kilometers) southwest of the Potomac River. Submature dissection with moderate relief (100 feet, or 30 meters) of widespread erosional plain.

From a point 1 mile (1.6 kilometers) east of Centerville to the vicinity of Warrenton cross a plain that bevels tilted Triassic sandstones and shales (Newark group) containing sheets of diabase. This Triassic basin is about 20 miles (32 kilometers) wide along this route. About 3 miles (4.8 kilometers) west of Centerville there is a quarry in the diabase on the south (left) side of the road.

From New Baltimore, about 5 miles (8 kilometers) northeast of Warrenton, cross dissected Piedmont plain to foot of main Blue Ridge near Sperryville, a distance of about 35 miles (56 kilometers). The underlying rocks are chiefly folded pre-Cambrian greenstone, Lower Cambrian sandstone and schist (Loudoun formation), and granite. The ridge (Bull Run

Mountain) extending north and south through New Baltimore marks the eastern margin of the Blue Ridge-Catoctin Mountain anticlinorium.

View Tree Mountain (1,080+ feet, or 329 meters) and Piney Mountain (901 feet, or 275 meters), west of Warrenton, rise 400 to 600 feet (122 to 183 meters) above the general surface. Cross the Rappahannock River.

As Washington (Virginia) and Sperryville are approached, flattish areas of the Piedmont peneplain and scattered monadnocks are seen to the south and east (left).

The road west from Sperryville ascends a "gulf" or "cove" in the Blue Ridge to Thornton Gap (altitude 2,305 feet, or 703 meters), on the crest.

The route leads southwestward on the Sky-line Drive along the crest of the Blue Ridge for about 30 miles (48 kilometers), through a part of the proposed Shenandoah National Park area.

Fine views of the gently rolling to flattish Piedmont surface are to be had to the east (left) at several points along this route. Spur ridges with intervening deep "coves" are numerous on both slopes of the Blue Ridge.

To the west (right) is the eastern part of the beautiful Shenandoah Valley, which is part of the great Appalachian Valley. Its flattish floor bevels highly folded Cambrian and Ordovician limestones and shales. This is a part of the extensive Tertiary valley-floor peneplain. Its altitude here is about 1,000 feet (305 meters).

Beyond the valley Massanutten Mountain rises to altitudes of 2,500 to 3,000 feet (762 to 914 meters). It is a remnant, about 50 miles (80 kilometers) long, of a huge synclinorium of Ordovician, Silurian, and Devonian shale and sandstone. It has been preserved because highly resistant quartzitic sandstone crops out on its upper slopes. It bisects the northern half of Shenandoah Valley, thus making an almost unique monadnock upon the valley-floor peneplain.

The route passes along Stony Man Mountain (4,011 feet, or 1,223 meters) and Hawks Bill Mountain (4,049 feet, or 1,234 meters), the highest peaks in the northern part of the Blue Ridge in Virginia. They are bold monadnocks that rise several hundred feet above remnants of the summit peneplain (Cretaceous?) along the crest of the Blue Ridge. Several of these remnants are crossed, as south of Thornton Gap and south of Fishers Gap. The altitude of the peneplain surface near Skyland is about 3,500 feet (1,067 meters). This peneplain truncates a large anticline, whose core is exposed in the Blue Ridge.

The front ridges and hills along the western base of the Blue Ridge are composed of resistant Lower Cambrian sandstone and quartzite. They are flanked on the east by a belt of shale and slate, on which coves and linear depressions have developed. Western foothill ridges are absent in places, because the Blue Ridge fault block has been thrust westward over the slightly resistant rocks of the Shenandoah Valley.

Numerous saddles, or wind gaps, in the crest of the Blue Ridge, such as Thornton Gap, Fishers Gap, and Swift Run Gap, are probably the abandoned courses of large streams that flowed across the site of the Blue Ridge before it was uplifted. The headwaters of some of these streams were captured by the Shenandoah River as it developed southward along the western foot of the Blue Ridge.

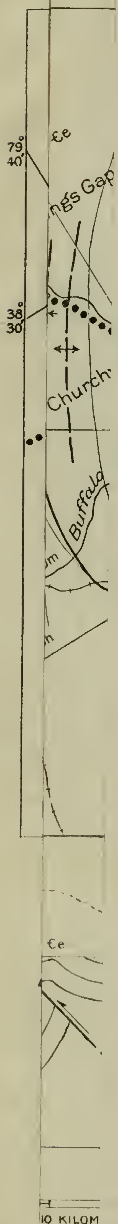
The south end of the northeastward-pitching Massanutten syncline is seen from a point a few miles north of Swift Run Gap. On a clear day the observer can look across Shenandoah Valley, a distance of about 25 miles (40 kilometers), to the elongate mountain ridges that parallel the valley on the west.

The descent from Swift Run Gap southeastward to Stanardsville is made through a typical Blue Ridge cove. To the southeast there are good views of the dissected Piedmont peneplain. Low monadnocks are visible in places.

The Piedmont peneplain for 15 miles (24 kilometers) southeast of Stanardsville is the general surface of an elongate basin between the foot of the Blue Ridge and Southwestern Mountain (to the southeast). This mountain is the easternmost ridge in the Piedmont province in this part of the State. It is on resistant greenstone, whereas the basin to the west is on schistose quartzite, granite, and gneiss.

If time permits, the trip will be continued across Southwestern Mountain, through Gordonsville, then southeast to a point on State Highway 39, about 20 miles (32 kilometers) east of Charlottesville. Here the Piedmont surface is remarkably flat over large areas. It truncates highly folded diverse early Paleozoic and pre-Cambrian rocks.

On approaching Charlottesville there are good views of the Blue Ridge rising abruptly above the Piedmont peneplain surface at its base. Outlying peaks and ridges (monadnocks) are numerous.



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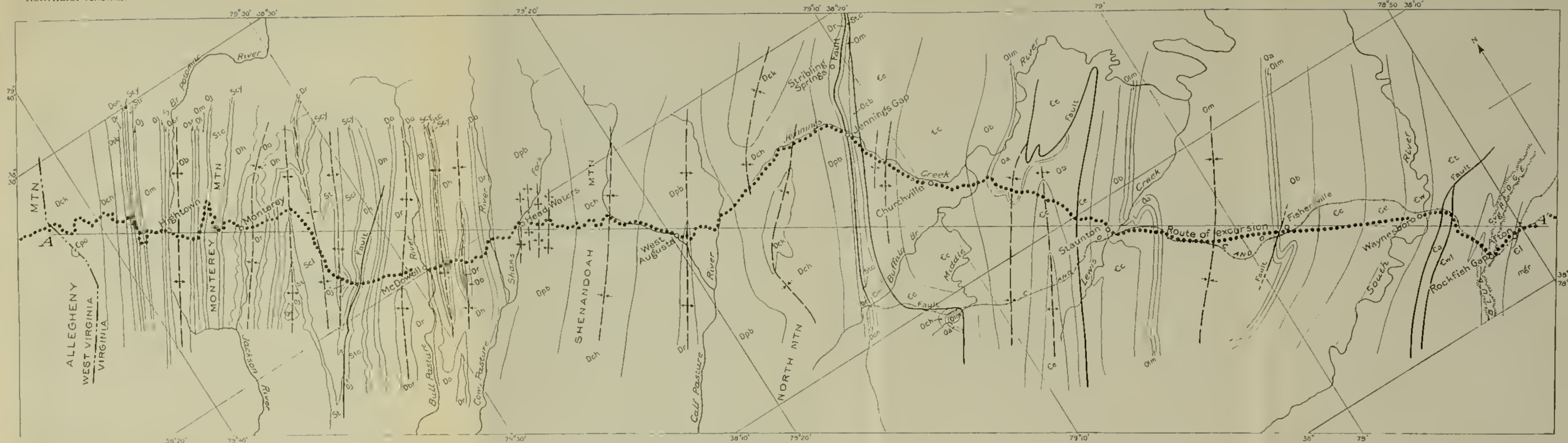

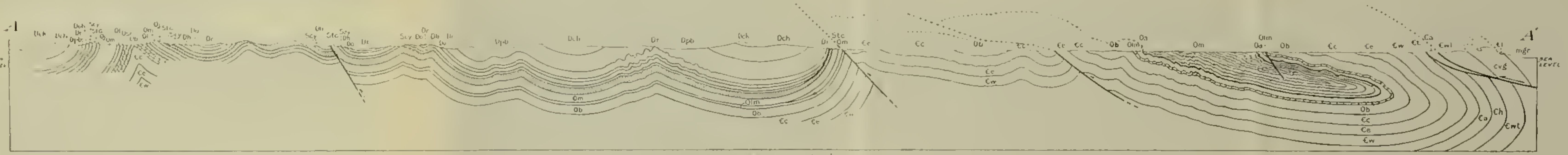

Section along line A-A'

10 MILES

10 KILOMETERS

ROUTE MAP AND SECTION, AFTON TO WEST VIRGINIA LINE

Cpo, Pocono sandstone; Dck, Catskill formation; Dch, Chemung formation; Dpb, Dbr, Portage (Brallier) shale; Dr, Romney shale; Do, Oriskany sandstone; Dh, Helderberg limestone; Doh, Oriskany and Helderberg; Scy, Cayuga group; Scl, Clinton formation; St, Tuscarora sandstone; Stc, Tuscarora and Clinton; Oj, Juniata formation; Om, Martinsburg shale; Och, Chambersburg limestone; Ol, Lowville limestone; Oa, Athens shale; Olm, Lenoir and Mosheim limestones; Osr, Stones River limestone; Ocb, Chambersburg limestone to Beekmantown dolomite; Ob, Beekmantown dolomite; Єc, Conococheague limestone; Єe, Elbrook dolomite; Єw, Waynesboro formation; Єt, Tomstown dolomite; Єa, Antietam sandstone; Єh, Harpers shale; Єwl, Waynesboro and Loudoun formations; Єl, Loudoun formation; cvg, Catoctin greenstone; mgr, Marshall granite.

CHARLOTTESVILLE TO WEST VIRGINIA BY WAY OF WAYNESBORO, STAUNTON, AND MONTEREY

[Excursion B-5]

By Charles Butts and J. K. Roberts

INTRODUCTION

Excursion B-5 covers pre-Cambrian rocks from Charlottesville to the summit of the Blue Ridge and the Paleozoic section from the basal Cambrian quartzite of the western front of the Blue Ridge to the basal Mississippian rocks at the West Virginia State line.

A summary description of the Paleozoic formations crossed by this excursion follows. Most of the route is also covered by the maps of the Staunton and Monterey folios of the Geologic Atlas of the United States. From Waynesboro westward to Little North Mountain, a distance of 22 miles (35 kilometers), the road crosses a nearly level plain (peneplain), which is the final product of erosion during Mesozoic and Tertiary time. (See pl. 1.) This part of the Appalachians is the Valley of Virginia proper. It is underlain by folded lower Paleozoic formations of great thickness. From Little North Mountain west to West Virginia and many miles farther is a rough country of considerable relief, designated the Valley Ridges.

The amount of erosion involved in reducing the region in the Valley of Virginia can be estimated from the structure section in Plate 1. Above the highest formations restored above the surface profile between Staunton and Little North Mountain Devonian rocks at least 10,000 feet (3,048 meters) thick were certainly originally present, and probably the Devonian was overlain by several thousand feet of Mississippian and Pennsylvanian rocks.

PRE-CAMBRIAN

By Anna I. Jonas

The route from Charlottesville 24 miles (39 kilometers) west to Waynesboro (fig. 3) crosses the Catoctin-Blue Ridge anticlinorium, made up of pre-Cambrian schists and igneous rocks with infolds of Lower Cambrian arenaceous rocks. The anticlinorium is bounded on the east by a normal fault that lies east of Southwestern Mountain and 4 miles (6.4 kilometers) east of Charlottesville. On the west side near the western front of the Blue Ridge the anticlinorium is thrust westward over the Paleozoic rocks of the Valley.

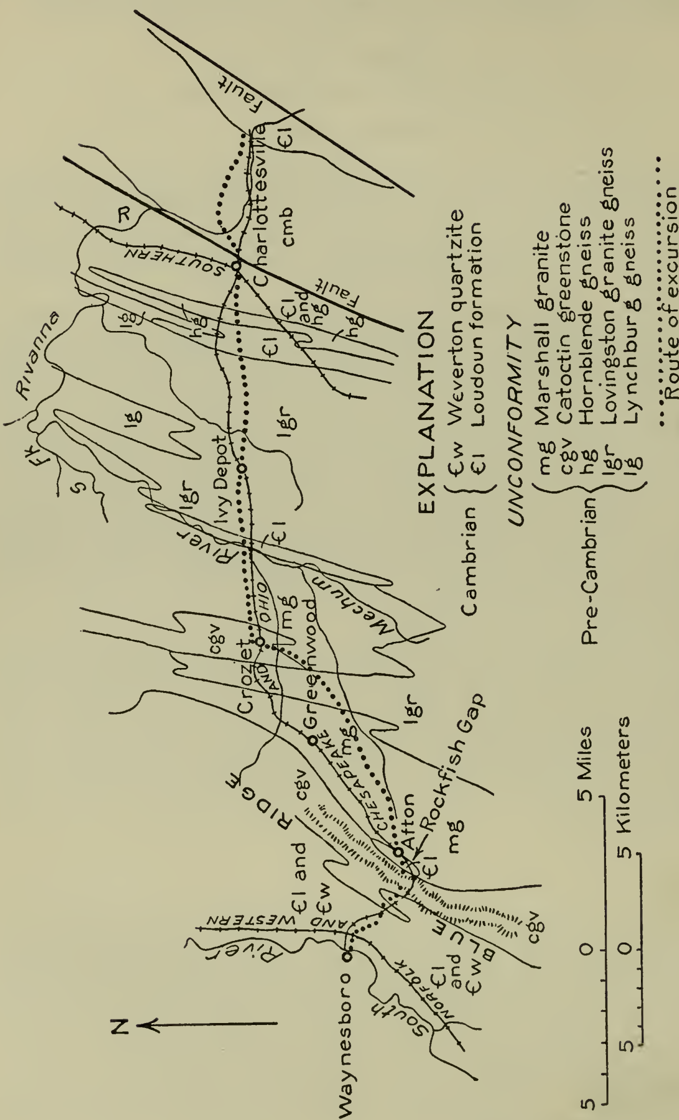

FIGURE 3.—Route map, Charlottesville to Waynesboro

Charlottesville is located on the western edge of pre-Cambrian Catoctin metabasalt, which forms Southwestern Mountain, Carter Mountain, and the hill on which Monticello is built, east of the city.

In the city and near the University of Virginia Lower Cambrian Loudoun slate and quartzite are infolded with pre-Cambrian hornblende gneiss. Two miles (3.2 kilometers) west of Charlottesville the route crosses Lovingston granite gneiss, a biotite augen granite gneiss, the oldest intrusive rock of the anticlinorium. Six miles (9.6 kilometers) farther west is the Mechum River, on the east side of which the Loudoun formation is exposed. For 3 miles (4.8 kilometers) westward to Crozet the road crosses Marshall granite, a gray biotite-muscovite granite with epidote due to alteration. South of Crozet station is Catoctin metabasalt intruded by some Marshall granite. For 5 miles (8 kilometers) westward to Afton the road crosses Marshall granite with good exposures. At Afton, near the station and junction of the State highway to the south, gray slate of the Loudoun formation crops out in the railroad cut. The road westward ascends the Blue Ridge steeply and crosses schistose and epidotic amygdular metabasalt, which forms its crest. West of the summit on the descent basal Cambrian Loudoun formation occurs with a narrow overturned anticline of metabasalt. Loudoun and Weverton quartzite extend down the western slope to a thrust fault east of a foothill of Antietam quartzite near Waynesboro. The Catoctin-Blue Ridge anticlinorium has been thrust westward on this fault over the Paleozic rocks of the Appalachian Valley.

CAMBRIAN

The oldest Cambrian rocks (Lower Cambrian) crop out along the Blue Ridge in northern Virginia and southwestward into Tennessee. Their divisions are named and correlated as follows:

Virginia north of Roanoke	Southern Virginia and Tennessee
Antietam sandstone	Erwin quartzite.
Harpers shale	Hampton shale.
Weverton sandstone Loudoun formation	Unicoi sandstone.

Loudoun formation and Weverton sandstone.—The Loudoun is a heterogeneous formation composed of conglomerate, sandstone, slate, and limestone from a few feet to 800 feet (244 meters) thick. Use of the name is confined to northern Virginia and Maryland. The Weverton is largely a pure sandstone, locally with much feldspar, 200 to 1,000 feet (61 to 305 meters) thick.

Harpers shale.—The Harpers consists essentially of gray siliceous and argillaceous shale and thin-layered sandstone, probably 1,200 to 2,000 feet (366 to 610 meters) thick.

Antietam quartzite.—In northern Virginia the Antietam quartzite is a thick-bedded hard gray to white quartzite 500 to 1,000 feet (152 to 305 meters) thick.

Owing to their hard and resistant character, the clastic formations described above enter largely into the composition of the Blue Ridge and the escarpment bounding the Valley on the southeast, in continuance of the Blue Ridge line southwestward from Roanoke into Tennessee.

Tomstown dolomite (Lower Cambrian).—The Tomstown dolomite abruptly succeeds the Antietam quartzite. It is a coarsely crystalline white to gray dolomite, with more or less blue limestone, the first carbonate deposit of the Appalachian geosyncline. Its total maximum thickness is apparently about 2,000 feet (610 meters). Its equivalent, the Shady dolomite, contains large bodies of zinc ore, mostly sphalerite, at Austinville, in Wythe County. There *Olenellus*, *Dorypyge*, and *Nisusia* occur in limestone of the Shady and prove its equivalence, at least in part, with limestone and shale in the vicinity of York and Lancaster, Pennsylvania, that are correlated with the Tomstown limestone.

Waynesboro formation (Lower and Middle (?) Cambrian).—The Waynesboro formation in Maryland and northern Virginia is a heterogeneous aggregation of red shale, red sandstone, green shale, fine-grained calcareous ferruginous sandstone, thick-bedded coarse bluish dolomite in beds perhaps as much as 100 feet (30 meters) thick, and here and there a bed of pure blue banded limestone as much as 50 feet (15 meters) thick. The formation is called Waynesboro from Pennsylvania to Roanoke, Virginia. South of Roanoke the name Rome is applied to the western belt, and the name Watauga to the eastern belt.

Olenellus sp. and a few ptychoparian trilobites have been found in the Rome in Virginia, and other olenelloids and brachiopods occur elsewhere in the formation. *Olenellus* has in some areas been found near the top of the Rome. According to nearly universal usage the occurrence of *Olenellus* places the beds containing them in the Lower Cambrian. Walcott has reported Middle Cambrian fossils from the Rome in some areas, and Ulrich would assign the whole formation to the Middle Cambrian.

Elbrook dolomite (Middle and Upper Cambrian).—On the southeast side of the valley an aggregation of dolomite, partly shaly, partly thick-bedded, is known as the Elbrook dolomite. This unit is probably the equivalent of the Honaker and the overlying Nolichucky shale of southwestern Virginia and Tennessee.

Conococheague limestone (Upper Cambrian).—The Conococheague limestone occurs along the southeast side of the Appalachian Valley from Pennsylvania to Greenville, in northeastern Tennessee. It is composed mainly of thick-bedded blue limestone ranging from high-calcium to high-magnesium limestone or even dolomite, but fairly pure calcium rock largely predominates. Many of the layers of limestone are banded with argillaceous impurities, and layers of edgewise conglomerate are common. Its most distinctive feature consists of beds of sandstone which are scattered through it from bottom to top. The argillaceous bands forming crinkled laminae in relief on weathered surfaces are also highly characteristic. (See pl. 2, *A*.) In Maryland its most conspicuous fossil is a large *Cryptozoon*, which forms reefs. Trilobites (Saukiinae) from the Conococheague indicate its approximate correspondence with the Potsdam and Hoyt formations of northeastern New York, which Ulrich refers to his Ozarkian system.

ORDOVICIAN

BEEKMANTOWN GROUP

The formations of the Beekmantown group constitute the "Canadian system" of Ulrich.

Stonehenge limestone.—The Stonehenge limestone, thick-bedded and fossiliferous, forms the base of the Beekmantown.

Nittany dolomite.—The Nittany is a thick-bedded gray dolomite yielding on weathering much dense jagged gray chert, possibly 600 to 800 feet (183 to 244 meters) thick on this route. This is one of the most persistent and widely distributed of geologic units, everywhere marked by *Lecanospira*, represented by *L.* (*Ophileta*) *compacta* Salter and many other species. This genus is found from the northwest Highlands of Scotland, where it occurs in the upper part of the Durness limestone, through Newfoundland, Quebec, the Champlain Valley, the Appalachian Valley to Alabama, and west through Texas into Oklahoma, where it occurs in the Arbuckle limestone.

Beekmantown beds of post-Nittany age.—Overlying the Nittany there is throughout southwestern Virginia a varying thickness of cherty dolomite carrying a fairly abundant gastropod and cephalopod fauna of the age of the Cotter and Powell dolomites of Arkansas and Missouri. *Ceratopea*, *Hormotoma*, *Coelocaulus*, *Oraspira*, and *Tarphyceras* are perhaps the most common fossils. Locally in southwestern Virginia these beds include layers of pure light-gray compact limestone in the upper part. This post-Nittany part of the Beekmantown group, 200 to 800 feet (61 to 244 meters) thick in southwestern Virginia, thickens northward and at Staunton is apparently 1,500 feet (457 meters) thick. This part corresponds to the Bellefonte dolomite of central Pennsylvania, which has a thickness of 1,000 to 2,000 feet (305 to 610 meters) of dolomite and carries a few of the same fossils, including rare specimens of *Ceratopea*.

Ruedemann regards the Deepkill and Schaghticoke beds of eastern New York as of Beekmantown age, and these beds through such fossils as *Dictyonema flabelliforme*, *Didymograptus bifidus*, and *Phyllograptus* are correlated with the upper part of the Tremadoc and the Llanvirnian of Wales and with the Skiddavian of England. Hence the Beekmantown of the Valley of Virginia is correlated with those formations of Great Britain.

STONES RIVER GROUP

In its type region, the Nashville region of middle Tennessee, the Stones River group comprises the following formations, named in ascending order: Murfreesboro limestone, Pierce limestone (thin), Ridley limestone, and Lebanon limestone. In the Appalachian Valley the group is represented by the Murfreesboro limestone at the base, the Mosheim limestone, and the Lenoir limestone (correlated with the Ridley) at the top. The Pierce and Lebanon have not been recognized anywhere in the Valley, and the Murfreesboro does not occur in the part of the Valley traversed by this excursion. The Mosheim is regarded as a distinct formation of eastern origin not represented in middle Tennessee.

Mosheim limestone.—The Mosheim is a thick-bedded compact light-gray fine-grained pure limestone of early Chazy age, much sought for lime burning and cement manufacture. In places it carries many large gastropods. Where present it ranges generally from a few inches to 50 feet (15 meters) in thickness, though in places it reaches 100 feet (30 meters). Commonly, however, it is absent.

Lenoir limestone.—The Lenoir is generally a granular crinoidal dark thick-bedded, more or less cherty fossiliferous limestone. In extensive areas it is in large proportion composed of nodular limestone weathering to loose irregular cobbles. (See pl. 2, *B*.) *Maclurea magna* is common, and through it the Lenoir is correlated with the middle Chazy Crown Point limestone of the Lake Champlain region. It ranges in thickness from 25 to 50 feet (7.6 to 15 meters) on this route but reaches 500 feet (152 meters) or more in the Knoxville region, Tennessee.

BLOUNT GROUP

The Holston marble, Whitesburg limestone, Athens shale, Tellico sandstone, and Ottosee limestone constitute the Blount (pronounced blunt) group of Ulrich, occurring in the middle of the Ordovician system of Virginia as a great intercalated lens 6,000 to 7,000 feet (1,829 to 2,134 meters) thick but entirely absent in Pennsylvania and Alabama. Of these formations only the Athens shale and possibly the Whitesburg limestone locally are present along this route.

Whitesburg limestone.—The Whitesburg limestone is generally a coarse-grained fragmental nodular dark bluish-gray bed 20 to 70 feet (6 to 21 meters) thick in Virginia but reaching perhaps 500 feet (152 meters) near Whitesburg, Tennessee, its type locality. It is highly fossiliferous, about 175 species of fossils having been identified from it, and is one of the few Ordovician formations in the Valley in which *Agnostus* occurs. It persists beneath the Athens shale from northern Virginia to Alabama.

Athens shale, *Athens limestone.*—The Athens consists of black fissile graptolite-bearing shale below and black compact, rather thin-bedded limestone with black shale partings producing a characteristic banded structure in the upper part. In some localities, as in Harrisonburg, nearly the whole thickness is black limestone; in others it is shale and sandstone. The thickness on this route is about 500 feet (152 meters).

The Athens is characterized by the world-wide *Nemagraptus gracilis* graptolite fauna, through which it is correlated with the Normanskill shale of New York, the Glenkiln shale of Scotland, and part of the Llandeilian of England and Wales.

Chambersburg limestone.—The Chambersburg is a moderately thick-bedded dark limestone like that in the upper part of the Athens, which over large areas in northern Virginia it immediately succeeds, owing to the absence of the Tellico, Ottosee, Lowville, and Moccasin. The Chambersburg is also marked by highly nodular layers like those of the Lenoir limestone. The Chambersburg as originally described by Stose and Ulrich in Pennsylvania included the Lowville, but subsequently the name was restricted by Ulrich to the upper or post-Lowville part of the mass, and Lowville limestone was applied to the lower part.

Martinsburg shale.—Gray shale with thin sandstone in the upper part and with thin-layered argillaceous dark limestone in the lower part constitutes the Martinsburg shale, which is 1,500 to 2,000 feet (457 to 610 meters) thick and perhaps more in Massanutten Mountain. The basal 100 feet (30 meters) of the Martinsburg in southwestern Virginia carries one or more thin beds of altered volcanic ash (bentonite). At the top is a persistent and very characteristic thick-bedded calcareous sandy rock full of phosphatic (?) pebbles. It weathers to rotten brown friable sandstone, usually about 50 feet (15 meters) thick. It carries many specimens of *Orthorhyncula linneyi*, *Byssonichia radiata*, and many other pelecypods. This horizon has been recognized from central Pennsylvania southward to the latitude of Morristown, Tennessee, where *Orthorhyncula* occurs near the summit of Clinch Mountain. This genus is one of the best horizon markers of the Appalachian Valley. The Martinsburg crops out in the southeastern belts of the Valley, including the Massanutten Mountain syncline, and continuously through Maryland and Pennsylvania to the Hudson River Valley of New York.

The lower part of the Martinsburg, containing limestone beds, is of Trenton (Middle Ordovician) age; the upper, more purely clastic part is of Upper Ordovician age, corresponding to the Lorraine of New York and to the Eden and Maysville groups of the Cincinnati region. The basal 500 feet (152 meters) or less of the shale which for convenience is mapped as Martinsburg in the Massanutten syncline is of Athens age and older than Martinsburg shale.

A starfish provisionally referred to the genus *Cnemidactis*, recently discovered in the upper part of the Martinsburg, suggests correlation with the Drummock limestone of Scotland.

Juniata formation.[2]—Red mudrock and fine-grained thick-bedded, usually reddish or brown sandstone 100 to 500 feet (30 to 152 meters) thick underlie the Clinch sandstone in Maryland and in most of Virginia except the extreme southwestern counties.

SILURIAN

Clinch sandstone, *Tuscarora quartzite.*—Medium thick-bedded to very massive hard gray sandstone or quartzite, with fine quartz conglomerate common in the base, is called Clinch sandstone in southern Virginia and Tennessee and Tuscarora sandstone in northern Virginia (including the area traversed in this excursion), Maryland, and Pennsylvania and is equivalent to the upper (white) Medina of New York. Its thickness ranges from a few feet to 400 feet (122 meters). These formations are the main ridge makers of the Appalachian Valley and Ridges, and Jack Mountain, between McDowell and Monterey, is a fairly typical example.

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[2] The United States Geological Survey and most other American geologists classify the Juniata as Upper Ordovician, because it is of Richmond age, but the New York State Geological Survey and Ulrich include it as well as the Richmond in the Silurian.

Clinton formation.—In Virginia the Clinton formation has three divisions. The lower one, the Cacapon (ca′pon) sandstone member, is composed of shale and layers of hard, dense dark-red ferruginous vitreous sandstone, which is the distinguishing feature. In southwestern Virginia the lower part of the Clinton, probably corresponding to this member, contains beds of workable fossiliferous hematite. The middle part of the Clinton consists of shale overlain by well-bedded hard gray sandstone which is an expansion of the Keefer sandstone of Pennsylvania and Maryland. In some places most of the middle part is sandstone. The upper part of the Clinton consists of fossiliferous soft shale and thin limestone correlated with the Rochester shale of New York. In the maximum development, say in the region from Clifton Forge to Monterey, the lower division is 300 feet (91 meters) thick, the middle division 200 feet (61 meters), and the upper division 50 feet (15 meters). At the Maryland boundary the entire Clinton is not over 600 feet (183 meters) thick, and in most of Virginia it is much less.

Tonoloway limestone.—In Virginia the four divisions of the Cayuga group have been recognized only locally. In Maryland and farther north they are well developed. They are known (in ascending order) as McKenzie formation, Bloomsburg shale, Wills Creek shale, and Tonoloway limestone. Only the Tonoloway is certainly present in the region traversed, and that is not well exhibited.

The Tonoloway is a thin-bedded to straticulate or even shaly dark limestone with ostracodes and brachiopods, 400 feet (122 meters) thick in Maryland and 200 feet (61 meters) thick in Virginia. It extends southwestward as far as Newcastle and probably occurs throughout the Massanutten Mountain area.

DEVONIAN

Helderberg group.—In Virginia the Helderberg group is represented by dark-gray, somewhat fossiliferous limestone, with sandstone beds in the lower 300 feet (91 meters) in the Covington region of southwestern Virginia, where one of the sandstone beds is 100 feet (30 meters) thick. This lower part represents the Keyser limestone of Maryland and West Virginia and contains some of its characteristic fossils, such as *Chonetes jerseyensis* and *Cladopora rectilineata.* Above is limestone, in part fairly pure and in part argillaceous and cherty, 200 feet (61 meters) thick. This represents the Coeymans, New Scotland, and Becraft limestones in Maryland. The total thickness of the Helderberg in the Covington region of Bath and Alleghany

Counties, Virginia, is about 500 feet (152 meters). Probably it has about the same thickness on this route.

Oriskany group.—In Maryland the Oriskany has two divisions, the Ridgeley sandstone above and the Shriver chert below. The Shriver in Maryland is a dark siliceous shale with chert nodules, 100 feet (30 meters) or so thick. It probably persists into Virginia near the Maryland boundary but has not been recognized as far south as Covington, Alleghany County. The Ridgeley is a thick-bedded calcareous, highly fossiliferous sandstone, weathering to coarse friable sandstone pitted with molds of large fossil shells. It is about 200 feet (61 meters) thick in the Cumberland region, Maryland, and is 100 feet (30 meters) or more thick in the Monterey region of Virginia. *Spirifer arenosus* and *Rensselaeria ovoides* are the common fossils.

Onondaga limestone or shale.—In the extreme southwestern part of Virginia the Onondaga consists mostly of limestone and chert 10 to 100 feet (3 to 30 meters) thick. In that region it carries such characteristic Onondaga fossils as *Amphigenia elongata*, *A. curta*, and *Spirifer duodenaria.* Farther north, in the Valley Ridges division of the Valley and Ridge province and on the route traversed by this excursion, it is prevailingly a yellow or olive-green shale, 60 feet (18 meters) thick, overlying the Oriskany sandstone. This bed also carries a good representation of the Onondaga fauna. In these areas, however, it is included in the Romney shale, as its basal member, as in the type locality of the Romney.

Romney shale.—The name Romney shale was applied to black fissile and olive-green hackly shale in the vicinity of Romney, West Virginia, lying above the Oriskany sandstone and below light-greenish siliceous shale and sandstone of the "Jennings" formation. The constituent units of the general time scale, from below upward, originally included in the Romney, are the Onondaga, Marcellus, Hamilton, Genesee, and lower Portage (Naples), the overlying beds of upper Portage and Chemung age being included in the "Jennings" formation. These black shales are universally present in the valley.

Portage group (*Brallier shale*).—The rocks of the Brallier shale (upper part of Portage group in Virginia) are predominantly siliceous and argillaceous green shale with thin to moderately thick, very evenly surfaced, block-jointed layers of fine-grained greenish sandstone, varying in thickness from a few hundred to 4,000 feet (1,219 meters). They correspond to the middle part of the Portage group of New York (to the Gardeau shale and the Hatch shale and flags, etc., of the section at Portage, New York) and the Brallier shale of central Pennsylvania. They are generally unfossiliferous but here and there yield a few specimens of the Portage fauna such as *Buchiola*, *Paracardium*, and *Probeloceras*. They constitute a part of the Jennings shale of Darton and of the Kimberling shale of Campbell.

Chemung formation.—Lithologically the Brallier passes by imperceptible stages into the overlying Chemung formation, which is composed of greenish or bluish clay shale and mudrock with thick beds of sandstone. In some sections the upper part of the Chemung includes red beds indicating transition to the overlying Catskill. The Chemung and Brallier are fairly distinguishable lithologically at a moderate distance either below or above the boundary, which is fixed at the horizon at which the large fossils of the overlying Chemung appear, such as *Ambocoelia umbonata*, *Spirifer disjunctus*, *Leiorhynchus mesacostale*, and species of *Productella* and *Leptodesma*. These fossils afford a criterion which gives consistent results throughout the Appalachian Valley. The thickness of the Chemung ranges from 2,000 feet (610 meters) down to the vanishing point, for it can not be recognized in southern Virginia.

Catskill formation.—The Catskill is composed of red mudrock and red sandstone as much as 2,000 feet (610 meters) thick in northern Virginia, but it thins out entirely southward and probably does not extend south of latitude 38°. It is nearly unfossiliferous. It occupies the mountain summit between West Augusta and Shenandoah Mountain but does not cross the road traveled, the red beds exposed at the southeast base of Shenandoah Mountain being in the Chemung but well up toward the base of the Catskill.

ITINERARY

From Charlottesville to the crest of the Blue Ridge the rocks are largely pre-Cambrian igneous rocks with infolded basal Cambrian sediments, which will not be examined. The crest of the Blue Ridge is pre-Cambrian Catoctin metabasalt.

On the northwest slope the Catoctin is apparently in faulted contact with thick-bedded, partly coarse-grained sandstone and fine-grained layers that occupy a belt half a mile (0.8 kilometer) or so in width and dip steeply to the southeast toward the older greenstone. Within this formation near the base is a rock of greenstone appearance, perhaps 50 feet (15 meters) thick, with small amygdules scattered through it. This amygdaloid is regarded by some as infolded pre-Cambrian. This sandstone mass is regarded as Loudoun sandstone and is correlated with the Unicoi sandstone of southern Virginia and northern Tennessee, which occupies a similar position in the sequence and also includes an amygdaloidal bed. The Weverton sandstone overlies the Loudoun beds, which normally succeed the Catoctin greenstone.

For about a mile northwest of the Weverton outcrop the road lies on the Harpers shale, which appears to dip about 30° SE., being overturned. Near the northwest base of the Blue Ridge, about half a mile (0.8 kilometer) east of Waynesboro, the overlying Antietam sandstone, standing about vertical, is well exposed in a large quarry just northeast of the road. The rock is so greatly shattered that it is easily reduced to sizes suitable for railroad ballast.

The Tomstown dolomite, which succeeds the Antietam sandstone, although supposed to be present, is not exposed at the foot of the mountain but is covered by about 100 feet (30 meters) of valley fill along the South River. The Waynesboro formation, marked by red shale, is fairly well exposed in the town of Waynesboro, where at one place a very thin layer of rock is thickly covered with the minute brachiopod *Linnarssonia tennesseensis*. The rocks at this exposure are, as usual for several miles westward, overturned, with a southeast dip of about 30°. West of Waynesboro the Elbrook limestone occupies a belt about 1½ miles (2.4 kilometers) wide. Its scattered exposures in road cuts are mainly a yellowish ocherous rock, which is decalcified argillaceous limestone or dolomite.

Next the Conococheague limestone, thick-bedded laminated limestone and dolomite with a few sandstone beds, covers a width of 1.8 miles (2.9 kilometers). In a small abandoned quarry about 1 mile (1.6 kilometers) on the northeast (right) of the road the peculiar crinkled lamination of the Conococheague is exhibited. (See pl. 2, *A*.)

For a mile or so southeast of Fishersville thick-bedded dolomite of Beekmantown age crops out, its lower (Nittany) part being marked by heavy gray chert. This chert is abundant and conspicuously displayed in an orchard on the slope on the north (right) of the road about 1 mile (1.6 kilometers) southeast of Fishersville. The cherty soil seems to be especially favorable to apple growing. In the northwestern environs of Fishersville there appears to be a small fault, just beyond which the Mosheim and Lenoir limestones and Athens shale crop out but are not well exposed.

For 4½ miles (7.2 kilometers) northwest of Fishersville the route lies on the Martinsburg shale of the great Massanutten syncline. This shale is probably not less than 3,000 feet (914 meters) thick and may be much thicker. Minor folds or plications and slaty cleavage are prevalent. (See pl. 3.) The Martinsburg is composed of argillaceous limestone and shale of

Trenton age, below, and of shale, partly calcareous, and fine-grained sandstone, of Upper Ordovician (Cincinnatian) age, above. The older Athens shale has heretofore been included in the Martinsburg in this syncline.

The Martinsburg is normally overlain in this region by the Massanutten sandstone, possibly representing the combined Clinton and Tuscarora formations, which because of erosion does not descend to the valley level in this latitude, but which is present in the axis of the syncline at the south end of Massanutten Mountain, 23 miles (37 kilometers) northeast of the route. (See guidebook for excursion A–3.)

The prevailing dip along the entire route from the Blue Ridge to Staunton (stan′ton) is southeast, although at a few points the dip is northwest, indicating reversal for short distances. The average southeast dip between Waynesboro and the axis of the Massanutten syncline is estimated at 30°; between the axis and Staunton it is about 60°. These conditions are sufficient evidence of a recumbent anticline, the overturned limb of which lies next southeast of the axis of the Massanutten syncline, which is near the middle of the belt of Martinsburg shale.

In going northwest through Staunton to Little North Mountain at Jennings Gap the same dolomite and limestone formations as those between Waynesboro and Fishersville are crossed in several belts, in which the outcrops are repeated by folds and faults.

In the environs of Staunton, about one-third of a mile (0.5 kilometer) from the Lee Highway (United States Route 11), thick-bedded Conococheague limestone with one or more of its characteristic sandstone beds is exposed dipping 60° SE.

About 1 mile (1.6 kilometers) west of Staunton the concealed outcrop of a great thrust plane is crossed by which the Elbrook dolomite is thrust over the upper, post-Nittany part of the Beekmantown dolomite, the stratigraphic displacement being about 4,000 feet (1,219 meters). As shown by the trace of the fault plane on the map this thrust has a lateral displacement of at least 2 miles (3.2 kilometers). About 1 mile (1.6 kilometers) northeast of Galena the Elbrook dolomite of the overthrust mass can be seen immediately overlying the limestone of the Athens. For about a mile northwest of Galena the road lies on Athens shale in the southwest end of a broad, shallow northeastward-pitching syncline.

At the crest of the low ridge northwest of Galena the road crosses the Mosheim and Lenoir limestones. A few hundred feet to the west down the slope on the left is a good exposure of thick-bedded upper Beekmantown dolomite (of Bellefonte age). Lower Beekmantown (Nittany) dolomite shows just beyond the bridge over the Middle River. In a road cut on the south (left) side of the road three-quarters of a mile (1.2 kilometers) southeast of Churchville is a good exposure of Conococheague limestone with sandstone layers. The Conococheague with sandstone is also well exposed a quarter of a mile (0.4 kilometer) northwest of Churchville, on the bluff on the left and opposite the bridge on the right.

In the low bluff of Jennings Creek on the northeast (right) of the road beginning about 2½ miles (4 kilometers) southeast of Jennings Gap the Elbrook limestone is extensively exposed in open folds with dip varying from 10° to 50°. Just west (left) of the road 1 mile (1.6 kilometers) southeast of Jennings Gap is a good exhibit of *Cryptozoon undulatum* in this limestone.

About three-quarters of a mile (1.2 kilometers) southeast of Jennings Gap the route crosses the outcrop of another great thrust plane, which for 250 miles (402 kilometers) along the strike of Little North Mountain brings the Cambrian (Elbrook) into contact with younger formations ranging from Beekmantown to Upper Devonian (Brallier shale). At the latitude of Buffalo Gap the trace of the fault cuts across the general strike of the region on level ground and approaches the southeast base of Little North Mountain.

Along Little North Mountain the formations that crop out vary greatly within short distances, but the details can not be given here. As an example, below the fault in the Jennings Gap section, the sequence in ascending order comprises the Beekmantown, Mosheim, Lenoir, Athens, Chambersburg, Martinsburg, Tuscarora, and Romney. Apparently only a small part of the Martinsburg is present, for there is only a narrow space between the Chambersburg and the Tuscarora, which are ordinarily separated by 1,500 to 3,000 feet (457 to 914 meters) of Martinsburg. Furthermore, there is no Juniata or Oswego sandstone in this section, whereas at Brocks Gap, 32 miles (51 kilometers) northeast of Jennings Gap, as well as southwest and northeast of Brocks Gap, those two formations are present and several hundred feet thick. Still more, the Clinton, Cayuga, Helderberg, and Oriskany formations are absent in Jennings Gap, but at Buffalo Gap, 6 miles (9.6 kilometers) southwest, and at Stribling Springs, 2½ miles (4 kilometers) northeast of Jennings Gap, there is a full sequence of the named formations between the Tuscarora and Romney, which are in contact at Jennings Gap. Whether all these variations in sequence of outcrops are due to faulting or to accidents of deposition and erosion has not been ascertained.

At Jennings Gap there is a narrow exposure of the black fissile Romney shale apparently directly succeeding the Clinch sandstone. The Romney also comes up on the anticline just east of West Augusta.

For 14 miles (23 kilometers) northwest of Jennings Gap the route is upon thick Upper Devonian formations repeated by folds.

At the gap the road passes into a wide belt of Portage (Brallier) shale. This is composed of siliceous shale and even-bedded, fine-grained green sandstone in thick or thin flags.

The Chemung formation is similar lithologically to the Brallier, but it includes more sandstone, and the shale is rather more of a mudrock and on the whole less fissile or less thinly laminated than the shale of the Brallier. The Chemung also includes thick red beds in the upper part, where it approaches the overlying Catskill formation.

The lithologic boundary between the Chemung and Brallier is difficult to place. The boundary is rather a paleontologic one. The Brallier is very sparsely fossiliferous, and its fossils are invariably small forms—pelecypods such as *Buchiola*, *Paracardium*, and *Pterochaenia*. It contains the Portage, particularly the Naples fauna of New York. The fossils of the Chemung, on the contrary, are much larger forms, such as *Spirifer mesacostalis*, *S. disjunctus*, *Leiorhynchus mesacostale*, *Productella*, and *Ambocoelia*, which come in at about the same stratigraphic level from Pennsylvania southward through Virginia and afford a boundary between the Brallier and Chemung that can be consistently drawn throughout.

A good exhibit of the Chemung including some red beds is to be seen on the road ascending the southeast slope of Shenandoah Mountain on the northwest limb of the syncline at the head of Ramsey Draft. The best exhibit of the Brallier is just beyond the crest, along the winding road descending the northwest slope of Shenandoah Mountain to Headwaters. Several reversals of dip occur here and account for the great width of the outcrop in this belt.

On the southeast slope of Bull Pasture Mountain, ascending from the Cow Pasture River, there is an excellent display of the Romney black shale, and halfway up the slope the road follows the strike of the mountain for some distance about on the contact of the Romney and the immediately underlying Oriskany sandstone, affording a good view of the Oriskany. At the angle where the road turns northwest toward the crest of the ridge the Oriskany is passed, and the road then cuts across Helderberg limestone, which is well exposed on the right in the road cuts recently made. The Helderberg cherty limestone just below the Oriskany is highly fossiliferous, *Spirifer macropleura* being plentiful.

Descending toward McDowell the route crosses first a syncline carrying Romney beds and next an anticline exposing the Clinton, with the red (Cacapon) sandstone characteristic of its lower part, the axis of the anticline being about three-quarters of a mile (1.2 kilometers) southeast of McDowell.

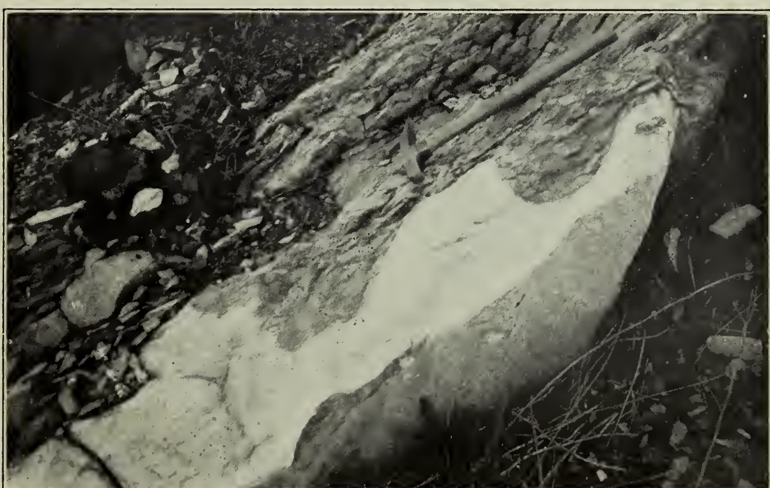
West of McDowell the road crosses a synclinal belt of Romney shale 2 miles (3.2 kilometers) wide. On the west side of this belt is a good exposure of the Oriskany sandstone on the right (north) side of the road. Next in order come the Helderberg, Cayuga (not exposed), Clinton, Tuscarora (a massively bedded gray quartzite), and Juniata (red shale and sandstone). Next a fault is crossed by which the Juniata is brought up alongside the upper cherty limestone of the Helderberg with *Spirifer macropleura*, etc. Then the same sequence is again passed in reverse order down to the Juniata, which is well exposed in a triangular area in the offset axis of the Jack Mountain anticline. On both sides of the Juniata here the Tuscarora is exposed in vertical or steeply inclined ledges.

From Jack Mountain to Monterey the outcrops of the Silurian and Devonian formations as given above are again crossed up to the Romney shale, on which Monterey is located. Just south of Monterey is a conspicuous conical hill which marks the site of a much weathered volcanic plug about on the contact of the Romney shale and Oriskany sandstone. Basaltic débris is scattered over this hill. There are several such small areas of volcanic or dike rocks in the vicinity of Monterey.

Northwest of Monterey to the West Virginia line the formations already seen crop out on both sides of the anticline in the Hightown belt, which is on the northwesternmost line of outcrop of the Beekmantown, the lowest formation exposed in this part of the Appalachian Valley province. The Ordovician rocks here differ from those just southeast of Little North Mountain. There is no Athens or Chambersburg. The Lowville limestone, the horizon of which lies between the Athens and Chambersburg but which is absent along the line of Little North Mountain, is present here. Below it are the usual Lenoir limestone, probably the Mosheim limestone, and limestone of Stones River age below the Mosheim, all of which may aggregate a thickness of 500 feet (152 meters) and which taken together constitute the Stones River group, the main (lower) part of which in this locality is believed to connect southward with the Murfreesboro limestone of the Nashville Basin, Tennessee. This belt is in a different geologic province from that southeast of Little North Mountain and belongs rather with the interior (Nashville) basin.

A. CONOCOCHEAGUE LIMESTONE WITH CRINKLED LAMINATIONS

Old quarry by roadside, route 39, about 1¼ miles (2 kilometers) southeast of Fisherville, Virginia. Photograph by J. K. Roberts.

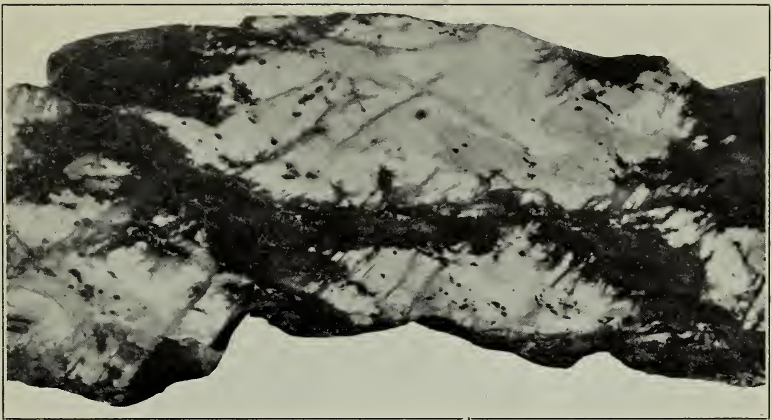


B. IRREGULAR CONTACT OF LENOIR LIMESTONE ON MOSHEIM LIMESTONE

Also shows the dark color and nodular character of the Lenoir and the light color and compact character of the Mosheim. The character of each is persistent from Maryland to Alabama. The peculiar channeling of the Mosheim at the contact has been observed at several places as far southwest as Mosheim, Tennessee, the type locality of the formation. Old quarry 1 mile (1.6 kilometers) east of Staunton, Virginia. Photograph by Charles Butts.

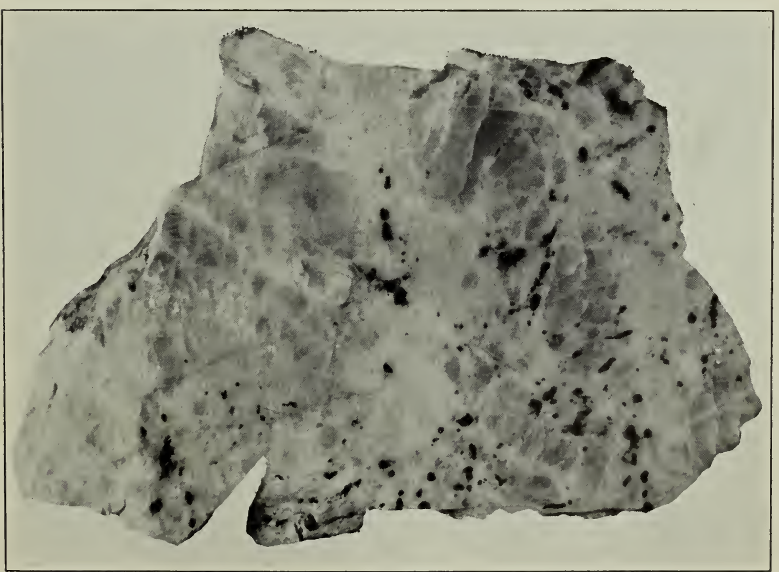
LOW ARCH IN MARTINSBURG SHALE

Perhaps overturned and faulted on the northwest (left). Layers of argillaceous limestone cut by slaty cleavage parallel to the general dip, as shown 50 to 100 feet (15 to 30 meters) both to the left and to the right of the view. Route 39 about 3 miles (4.8 kilometers) southeast of Staunton, Virginia, looking northeast. Photograph by Charles Butts.



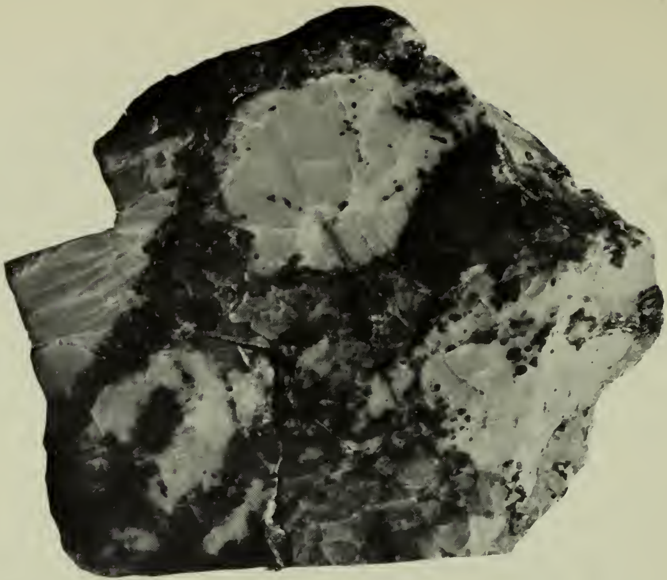
A. POLISHED SPECIMEN OF PEGMATITE SHOWING REPLACEMENT BY FERROMAGNESIAN MINERALS ALONG SHEAR ZONES

The broad black veins are dominantly fibrous amphibole, secondary to pyroxenes and containing disseminated grains of ilmenite. The narrower gray veins cutting white feldspar are phlogopite. Along the borders of the veins the feldspar has been extensively replaced by sericite and clinozoisite. Natural size. From mine of American Rutile Co., Roseland, Virginia.



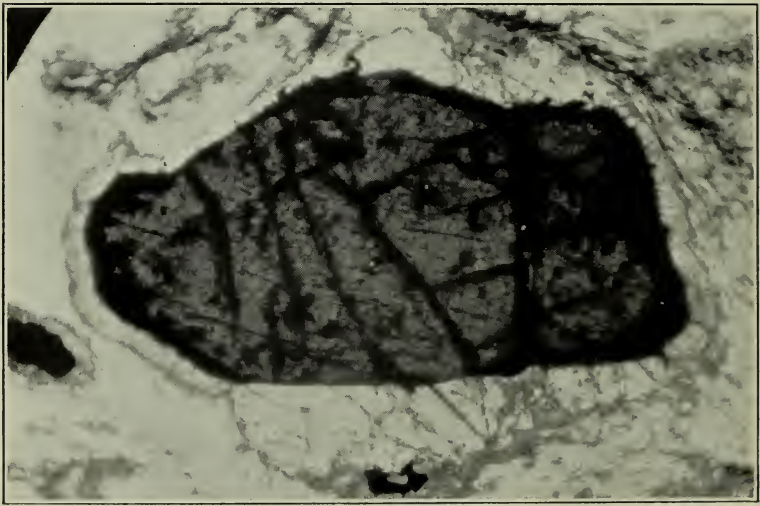
B. ANTIPERTHITIC PLAGIOCLASE (GRAY) REPLACED BY ALBITE (WHITE)

The black areas are rutile that is confined to areas of secondary albite. One-half natural size. From mine of American Rutile Co., Roseland, Virginia.



A. PEGMATITE THAT HAS BEEN EXTENSIVELY REPLACED BY RUTILE

Note the small amount of rutile in feldspar and its occurrence only in veinlets of secondary albite cutting primary antiperthitic plagioclase. Natural size. From mine of American Rutile Co., Roseland, Virginia.



B. PHOTOMICROGRAPH OF RUTILE (DARK GRAY) SHOWING PARTIAL REPLACEMENT BY ILMENITE (BLACK)

The reaction rims around the grains are leucoxene, and on the left side is an area of titanite. Enlarged 40 diameters. From mine of American Rutile Co., Roseland, Virginia.

TITANIUM AND SOAPSTONE DEPOSITS

[Excursion B-6]

TITANIUM DEPOSITS OF ROSELAND DISTRICT

By Clarence S. Ross

Deposits of titanium minerals are found in several localities in Virginia, but the most valuable and most interesting one is in Amherst and Nelson Counties, about halfway between Charlottesville and Lynchburg. This locality lies in the Piedmont region but is broken by the foothills of the Blue Ridge. The intrusive igneous rock with which the titanium minerals are associated and which incloses most of the titanium-bearing nelsonite ore bodies is an elliptical mass having a length of about 13 miles (21 kilometers) and a maximum width of 2½ miles (4 kilometers).

The titanium deposits of Virginia have been described by Watson and Taber (20) in a very careful and detailed paper, which has been the basis for this outline of the geology of the Amherst-Nelson County titanium deposits, though recent studies have somewhat modified our ideas of their paragenesis.

Being a part of the southern Piedmont region, the titanium-bearing area is a moderately dissected peneplain and is very deeply weathered. Over much of the area a kaolinitic soil mantles the intrusive rock, and outcrops are to be seen only along the streams, and even here the rocks are not entirely fresh. Thus many of the geologic relations are obscure, and only at the open-cut mine of the American Rutile Co. are good rock exposures accessible.

The Roseland locality is the world's principal source of rutile. The production in 1927 (the last year for which statistics are available) was 524 tons. The American Rutile Co. has long been the only commercial producer of the district and operates an open-cut mine in the pegmatitic rock, which carries several per cent of rutile. Ilmenite and rutile are recovered in nearly equal proportions, but the production of ilmenite is incidental to the recovery of rutile. Recently the Southern Mineral Products Corporation, a subsidiary of the Vanadium Corporation of America, has built a plant for the production of titanium pigment. The titanium ore used is recovered from the weathered portion of a large ilmenite-nelsonite dike, and the apatite is used for the production of calcium monophosphate.

The country rock of the region is the Lovingston granite gneiss, a biotite-quartz monzonite with gneissic habit. This has been intruded by a rock that consists essentially of sodic plagioclase, with minor amounts of potash feldspar, a characteristic blue quartz, and locally rutile and ilmenite. Nelsonite, a rock composed of apatite, ilmenite, or rutile and various accessory minerals, forms dikelike or irregular masses, which are localized along the southeast border of the pegmatitic mass.

PEGMATITE

The elliptical intrusive mass of feldspathic rock has been called a pegmatite by Merrill (10) and a syenite by Watson and Taber (20, p. 68), although the later authors observe that it might more properly be called an andesine-anorthosite.

The following description of the pegmatitic rock (syenite) is abstracted from the paper by Watson and Taber (20, pp. 70–76 passim).

Two facies of the rock mass are recognized—(*a*) feldspathic, which includes the central and vastly the largest part of the rock mass, and (*b*) hornblendic, which is developed chiefly as a border zone. The two facies are not separated by a line of sharp demarcation but apparently grade into each other. Except in a few places, rutile and in smaller quantity ilmenite are more abundant toward the border portion of the rock mass, especially along the southeast side. In general the central portion of the rock mass consists almost exclusively of feldspar, with only scattered grains of quartz and scarcely any rutile or other visible accessory minerals. The feldspar is usually white, rarely grayish or pinkish. Deep-blue quartz ranks second in abundance as an essential constituent; it is present everywhere, though in places sparingly, and in some localities of small area it may become the dominant mineral. It ranges in size from grains of almost microscopic dimensions to masses several feet across. Quartz masses several tons in weight were at one time encountered in the American Rutile Co.'s mine. Hornblende, derived from pyroxene, is a prominent constituent near the border portions of the rock mass. Rutile, the fourth mineral in relative abundance, associated with some ilmenite and in places with apatite, ranges in amount from practically nothing up to about 10 per cent in small areas. Ilmenite, in black grains of varying size, is in general less abundant than rutile in the feldspathic rock but is more noticeable in the hornblendic facies. Graphite is a prominent constituent at several places in the vicinity of the mass formerly worked by the General Electric Co. The sulphides, pyrite and pyrrhotite, have been noted at several points. Microscopic studies show that the feldspars are plagioclase, ranging in composition from andesine to albite, with antiperthitic microcline in spindle-shaped intergrowths. Minor accessories are apatite, zircon (?), biotite, graphite, secondary muscovite, epidote, zoisite, kaolin, calcite, leucoxene, garnet, and chlorite.

A chemical analysis of a typical specimen of the feldspathic rock from the American Rutile Co.'s mines is as follows:

SiO_2	60.03	H_2O+	0.66
Al_2O_3	21.38	MnO	.01
Fe_2O_3	.50	TiO_2	3.66
FeO	.25	P_2O_5	.39
MgO	.19	CO_2	Trace.
CaO	4.59	S	Trace.
Na_2O	5.80		
K_2O	2.81		100.43
H_2O-	.16		

NELSONITE

Nelsonite is the name given to a group of high titanium and phosphorus bearing rocks, occurring in dikelike bodies of varying size and irregular shape in Amherst and Nelson Counties, Virginia (17, p. 300; 19, p. 206).

The varietal forms included under nelsonite are dark-colored rocks of holocrystalline and even-granular texture, composed essentially of the ore minerals apatite with ilmenite or rutile, or both, and, in some occurrences, of magnetite. Here and there porphyritic texture is developed in the rock by phenocrysts of apatite. The ratio of the minerals is subject to rather wide variation, but usually ilmenite or rutile and rarely magnetite is in excess of apatite. Subordinate silicate minerals (chiefly hornblende and biotite) may or may not occur; in a few occurrences either hornblende or biotite is present in sufficient amount to be designated a principal constituent, and pyrite is an almost constant minor mineral. The granularity of nelsonite is remarkably uniform, the essential minerals being developed in grains and crystals of approximately equal size and of nearly equal dimensions in all directions. The individual minerals usually range from 1 to 3 millimeters in diameter and are rarely less than 1 millimeter.

Nelsonite, including the several varietal forms based on differences in mineral composition, is the most abundant dike rock occurring in the district. The size of the dikes varies greatly. Several of the more persistent ones may be traced along their strike for considerable distances. In length the dikes attain 2,000 feet (610 meters), as exposed on the surface, but lengths of several hundred feet are more common. They range in width from a few inches to 65 feet (20 meters) or more, and some of them have been prospected for 100 feet (30 meters) or more below the surface and undoubtedly extend much farther.

Though dikelike in character, the nelsonite bodies are subject to considerable irregularity in outline. Several of them are lenticular in shape, and where the more continuous bodies have been exposed for some distance they are found to pinch and swell both in dip and along the strike. Some of the dikes before pinching out split into several parallel stringers. They trend in almost every conceivable direction, but the dominant direction of strike is northeast. Usually the boundaries between the dikelike bodies of nelsonite and the inclosing rock are sharply marked, but in places there is a gradation between the two, which is especially true of the rutile nelsonites.

A microscopic study of nelsonite shows the presence of leucoxene, pyrite, and pyrrhotite. The silicate-bearing types of nelsonite contain pyroxenes, hornblende, biotite, plagioclase, apatite, ilmenite, magnetite, and occasionally rutile and quartz. The ratio of titanium minerals to apatite varies, the rocks ranging from one composed largely of the dark minerals with but little apatite to one composed practically of all apatite. The apatite in the several varietal forms of nelsonite recognized is a fluorapatite. Biotite, partly altered to chlorite, is an abundant constituent in some of the nelsonites.

A second facies of the nelsonite shows a predominance of the dark ferromagnesian minerals, more especially hypersthene and secondary hornblende, over the ore minerals. This facies of the rock also contains essential feldspar, chiefly plagioclase with a little microcline, and sparse quartz. It is composed chiefly of pyroxene (hypersthene), feldspar (plagioclase principally), apatite, and ilmenite or magnetite.

The variation or range in mineral composition of nelsonite gives rise to several varietal forms of the rock—ilmenite nelsonite, rutile nelsonite, magnetite nelsonite, biotite nelsonite, hornblende nelsonite, and gabbro-nelsonite.

PEGMATITE REPLACEMENT

Field and laboratory studies by the author show that the pegmatitic rock was originally composed almost exclusively of oligoclase ranging from Ab_{75} to Ab_{79}, with antiperthitic inclusions of microcline. The rock was coarse grained, and the oligoclase crystals averaged 10 to 15 centimeters or more in diameter. The original rock has been highly modified by replacement and recrystallization; and the primary oligoclase now makes up a variable but commonly minor portion of the rock. The rock is similar to many pegmatites in having been composed almost exclusively of feldspar, in the large size of the crystals, in the almost complete absence of original ferromagnesian minerals, and in the extensive replacement and recrystallization that has occurred subsequent to the original crystallization. The size of the whole rock mass is unusually large, but this does not serve to differentiate it from pegmatite. Microcline is a minor constituent, but in this it does not differ from many pegmatites, especially the pegmatites associated with the serpentines of Maryland and Pennsylvania. For these reasons it is best described as a pegmatite, as the genetic affiliations are those of pegmatites in general.

The best examples of the primary feldspar and the mineral as profoundly modified by secondary replacement will be observed in the open-cut mine of the American Rutile Co. at Roseland. Here the primary feldspar can be recognized by the large, partly replaced crystals of a light bluish-gray color. The least modified of these crystals are cut by numerous veinlets of nearly white secondary plagioclase, as shown in Plate 4, *B*. The composition ranges from albite (Ab_{95}) to oligoclase (Ab_{72}).

The secondary plagioclase nearest the veins of dark minerals has nearly the composition of the original plagioclase prior to recrystallization, and some of that in closest proximity to clinozoisite and pyroxene veins may have become more calcic on recrystallization. On the other hand, most of the secondary plagioclase at some distance from the veins that furnished the replacing solution is albite of about the composition Ab_{95}. Some specimens show almost complete replacement by albite (Ab_{95}) with at most only a few small residual grains of the original bluish oligoclase. More extreme replacement has left only fine-grained plagioclase, and a large proportion of secondary ferromagnesian silicates have developed near the fractures by which the replacing solutions were introduced.

In numerous exposures throughout the area the same relations of antiperthitic oligoclase replaced by plagioclase and other secondary minerals are shown. In some of these, especially in the vicinity of ferromagnesian facies, titanium minerals are present, but in many others titanium minerals are very sparse. The widely distributed blue quartz universally carries minute needles of rutile. Much of it forms veins that cut pegmatite, and this type of quartz is clearly secondary, having been introduced after the replacing solutions began to carry titanium.

The pegmatitic rock at the American Rutile Co.'s mine contains hornblendic facies and is cut by dark-colored rocks that have been called "gabbro" (20, p. 165). A polished specimen of this hornblendic facies is illustrated in Plate 4, *A*. This shows that large veins of ferromagnesian minerals have formed by the replacement of feldspar along shear zones in the original pegmatitic rock, and smaller veinlets of dark minerals extend far out into the feldspar. The larger replacement veins are composed dominantly of fibrous hornblende, which is in part at least an alteration product of pyroxenes. The smaller veinlets and the borders of the larger ones are marked by solid masses of disseminated grains of phlogopite. Farther from the borders of the dark veins colorless sericite and other secondary minerals are abundant in the feldspar, and even the freshest-appearing feldspar has been profoundly replaced. Minute grains of clinozoisite are very abundant, being disseminated in secondary albite. Veins of coarser-grained clinozoisite reach a centimeter or more in width. Some specimens show abundant actinolite as minute disseminated grains in feldspar. The dark veins contain abundant ilmenite and apatite and smaller quantities of rutile. There is a very definite association of ilmenite with the portion of the pegmatite containing dark minerals, but rutile is much more abundant in the white secondary feldspar, as shown in Plate 5, *A*. It seems evident that the solutions that caused albitization of the antiperthitic oligoclase and the replacement of feldspar by ferromagnesian minerals were the carriers of the titanium.

Ilmenite was deposited within and in close proximity to the veins of dark minerals, but where the solutions penetrated far into feldspathic rock rutile was formed in greater proportion than ilmenite. This seems to imply greater solubility of rutile than of ilmenite in the solutions that replaced pegmatite by ferromagnesian minerals. Nearest the feeding fracture planes the pyroxenes, the amphiboles, phlogopite, and ilmenite rich in iron were deposited. Where these solutions penetrated far into the pegmatite the feldspar was albitized, and sericite, tremolite, clinozoisite, and rutile—minerals almost free from iron—were deposited; that is, calcium, magnesium, sodium, and titanium were able to travel farthest from the source of the solutions, while iron was precipitated nearer the source. The wide distribution of albite shows that sodium traveled much farther than calcium.

Microscopic studies demonstrate that in many specimens rutile has been replaced by ilmenite. This is shown by the formation of ilmenite veinlets in rutile (pl. 5, *B*) and by the widening of these veinlets until only isolated remnants of the original rutile remain. Here there is evidence that rutile marked the advance wave of titanium introduction and that ilmenite followed. The rutile is most abundant in the albitized portions of the pegmatite at the American Rutile Co.'s mine at Roseland (pl. 5, *A*) and is so sparse in the bluish-gray primary antiperthitic oligoclase that rock of this type is culled out and rejected during mining operations. Titanium minerals almost nowhere penetrate far into unaltered primary plagioclase, and it is evident that the primary magma was titanium-free, this element all being introduced by later replacing solutions.

Thus the pegmatitic rock of the Roseland district of Virginia is an excellent example of the later hydrothermal replacement processes which have been recognized in pegmatites by a number of geologists in recent years. Schaller [3] has reported the albitization of the gem-bearing pegmatites of San Diego County, Calif., accompanied by the introduction of lithium minerals, and other geologists have confirmed this genetic relationship in many localities.

Ferromagnesian phases of the pegmatite from a number of localities in the district have been described as "gabbros." The "gabbro" at the mine of the American Rutile Co. has the same origin as the ferromagnesian phases of the pegmatite, and this is evidently true for other occurrences. Some of the "gabbro," however, probably represents true intrusive rock, but it will be considered in connection with the nelsonite.

ORIGIN OF NELSONITE

The most unusual rock of the region is nelsonite (20, pp. 100–106; 17, p. 300), a rock composed of apatite and rutile or ilmenite with various minor accessories. The mode of origin of the nelsonite is far less clear than that of the rutile-bearing pegmatite and of the gabbroic rock formed by replacement of pegmatite, because deep weathering and the difficulty of obtaining adequate specimens constitute handicaps to its study. A magmatic origin seems to be most generally accepted, and Watson and Taber (20, p. 152) concluded that the nelsonite was the result of magmatic segregation from the magma that formed the syenite (pegmatite).

The typical ilmenite nelsonite, composed dominantly of apatite and ilmenite, commonly gives little direct evidence of its mode of origin, but the varieties of more complex mineralogy, such as the phlogopite, amphibole, and "gabbro" nelsonites, show much more clearly their mineral relations and genetic history.

In the "gabbro" nelsonites the pyroxene has been very largely altered to hornblende, and the biotite to chlorite. Olivine seems to have been present in some specimens but has been completely altered to a serpentinelike material. The biotite has replaced feldspar, forms reaction rims around other minerals, and fills fracture planes in ilmenite and apatite. In many specimens the ilmenite occurs in irregular veinlike stringers that

[3] Schaller, W. T., The genesis of lithium pegmatites: Am. Jour. Sci., 5th ser., vol. 10, pp. 269–279, 1925; Mineral replacements in pegmatites: Am. Mineralogist, vol. 12, No. 3, pp. 59–63, 1926.

cut older minerals. Apatite is very generally rounded in a manner that suggests partial resorption by ilmenite. The ilmenite has been partly replaced by rutile, and veinlets of titanite cut older minerals. Quartz and antiperthitic plagioclase similar to that in the pegmatitic rock have been very largely replaced by secondary minerals and give evidence of being residual areas of almost completely replaced pegmatite. It seems probable that part of this "gabbro," and especially that which seems to have contained olivine, was originally an igneous intrusive, but this can not be true for all of it. All the rocks examined give evidence of very profound modification by postmagmatic processes, and part of the "gabbro" nelsonite is obviously the result of almost complete replacement of pegmatite as in the ferromagnesian phases in the mine of the American Rutile Co. It seems probable that gabbroic or pyroxenitic intrusive bodies and probably also fracture planes served as feeders for solutions that profoundly altered the original rock and more or less completely replaced adjacent pegmatitic rocks. Titanium minerals may have crystallized from some of these primary intrusives, but much of the rutile and ilmenite was introduced during the replacement. There is abundant evidence that olivine (?), pyroxene, and apatite were early minerals and that amphiboles, phlogopite and its alteration product chlorite, rutile, and at least part of the ilmenite were late.

This evidence of hydrothermal processes in the "gabbro" and "gabbro" nelsonite raises a question as to the origin of the purer apatite-ilmenite types of nelsonite by magmatic segregation. The rounded and embayed character of much of the apatite, the presence of phlogopite in fractures in ilmenite, and the evidence that Watson and Taber (20, p. 152) present for rutile preceding ilmenite all show that even this type of nelsonite is not the result of a single genetic episode.

Whether there was an original pyrogenic intrusive nelsonite and what part was played by secondary mineral replacement in the development of the rock as now seen can be determined only by more thorough study, based on an adequate suite of specimens obtained below the zone of weathering.

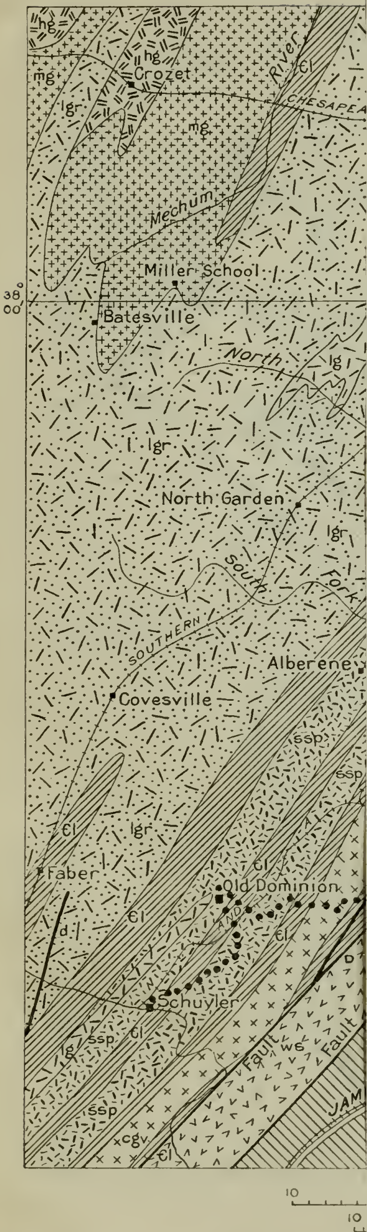
TALC AND SOAPSTONE DEPOSITS OF VIRGINIA

By J. D. Burfoot, Jr.

INTRODUCTION

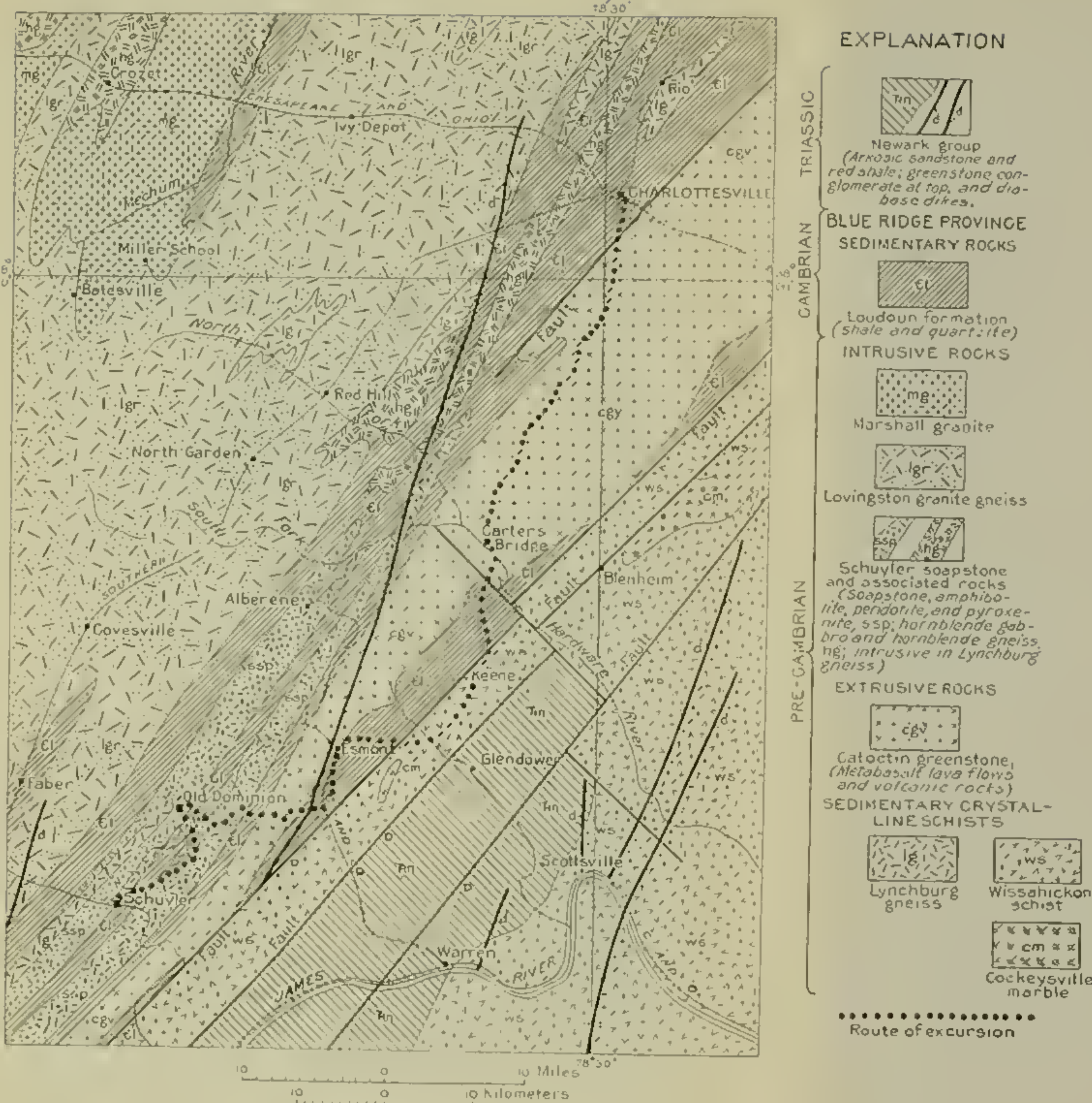
The talc, steatite, and soapstone of Virginia occur in the crystalline rocks of the Blue Ridge and Piedmont provinces. (See fig. 4.) The classification of these rocks according to Miss Jonas

NORTHERN VIRGINIA



GEOLOGIC MAP OF THE SO
NELSON

After Jonas, A. I., Geologic ma



GEOLOGIC MAP OF THE SOAPSTONE DISTRICT IN ALBEMARLE AND NELSON COUNTIES, VIRGINIA

After Jonas, A. I., Geologic map of Virginia, Virginia Geological Survey, 1928.

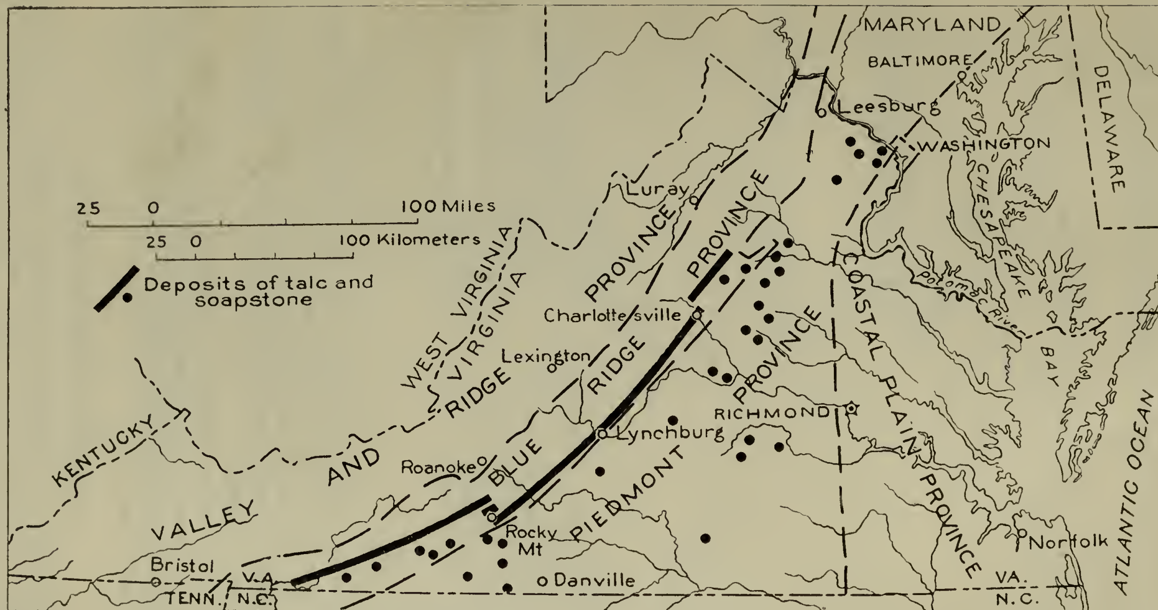


FIGURE 4.—Map of Virginia showing distribution of talc and soapstone. The highly productive Albemarle-Nelson County belt is shown by the heavy lines. The boundary between the Blue Ridge and Piedmont provinces is adapted from Jonas (7). After Burfoot (1, p. 806)

(15) [4] is shown in the following table. The talc and soapstone are associated with the metagabbro-metaperidotite group of basic intrusives.

Classification of rocks of the Piedmont and Blue Ridge provinces, Virginia

Blue Ridge-Catoctin Mountain anticlinorium.	Eastern belt.
TRIASSIC	
(Sedimentary and intrusive rocks)	
LATE PALEOZOIC	
	Petersburg granite (includes "Red Oak granite," "Leatherwood granite").
ORDOVICIAN	
	Arvonia slate. Quantico slate (sedimentary, including some rhyolite).
CAMBRIAN	
Weverton quartzite. Loudoun formation.	
PRE-CAMBRIAN	
Igneous: Felsite (dikes). Blue quartz pegmatite (albitite). Marshall granite. Catoctin greenstone (extrusive). Aporhyolite (extrusive). Hypersthene granodiorite. Metagabbro-metaperidotite group. Lovingston granite gneiss. Sedimentary: Lynchburg gneiss. White marble.	Igneous: Pegmatite. Columbia granite (including Shelton granite gneiss facies). Greenstone, Aporhyolite (Virgilina volcanic group). Metagabbro-metaperidotite group. Sedimentary: Wissahickon formation. Cockeysville marble.

The Albemarle-Nelson County belt (fig. 4) is said to produce more soapstone than any other locality in the world. This belt is made up of a series of metamorphosed, ultrabasic igneous rocks, in which lenses and irregular bodies of soapstone are unevenly distributed.

The varieties of talc found in Virginia are (1) foliated talc, which occurs in veins, (2) steatite, and (3) soapstone, which is the most widely distributed variety in the State and commercially the most important.

SOAPSTONE AND ASSOCIATED ROCKS

General features.—The rocks of this belt consist of metagabbro, metapyroxenite, metaperidotite, serpentine, soapstone, and

[4] Also Jonas, A. I., personal communication, June, 1931.

steatite. Gradations exist between the first three of these rocks, and they are differentiation products of the same magma. The last three types are special developments of the first three.

The rocks of the first group are rather widely distributed in the Blue Ridge and Piedmont provinces as squeezed dikes, stocks, and plugs, having generally a northeasterly strike. They intrude the pre-Cambrian metasediments and extrusives of the region, but are thought (15) to be older than the other intrusives, some of which intrude them. They are thought to be middle or early upper Algonkian.

Metagabbro-metapyroxenite group.—The metagabbro is a green to gray, coarse to fine grained, locally porphyritic, holocrystalline, massive or somewhat schistose rock of mottled or speckled appearance. The prominent light-colored constituents are quartz and saussuritized feldspar; the dark one is amphibole. The metapyroxenite is a feldspar-poor facies of the metagabbro.

These rocks in thin section are seen to contain the following minerals, named in the order of paragenesis: Amphibole; albite-oligoclase, epidote, and clinozoisite; ilmenite; titanite; chlorite; talc and magnetite; quartz.

It seems probable that the original rocks of this group ranged from gabbros to pyroxenites, carrying, along with other minerals, plagioclase and pyroxene. These rocks are thought to have been acted upon by magmatic solutions, which started at conditions of approximate contact-metamorphic intensity and, gradually cooling, developed the above-mentioned minerals at successively lower temperatures. These solutions were probably rejuvenated after the chlorite stage and before the deposition of talc.

There were peridotites and probably dunites in this series, but these olivine-bearing rocks had, so far as observed, a somewhat different history.

Serpentine, soapstone, and steatite.—The soapstone and steatite occur as lenses or irregular bodies in or along the edges of the metagabbros and metapyroxenites and grade into these rocks. A few separate bodies also occur. The soapstone in places and the steatite everywhere grade into serpentine, which in turn grades into the basic meta-igneous rocks. In some localities the soapstone grades directly into metapyroxenite. The lenses lie parallel to the igneous bodies, which in turn are parallel in dip and strike to the other rocks of the region.

The serpentine is a massive, dense greenish-gray to greenish-black rock with flecks of talc and crystals of carbonates scattered through it. The purest steatite is a fine-grained massive, compact light-gray rock with a greenish or bluish cast. The soapstone is a medium to fine grained bluish-gray, greenish-gray, or grayish-green rock showing varying degrees of schistosity and facility for sawing. The following table shows the mineral composition, in percentages, of several grades of commercial soapstone as determined from thin sections.

Mineral composition of commercial grades of soapstone in Virginia

	1	2	3
Talc	40–85	30	0–5
Chlorite	5–45	20	40–50
Serpentine	0–few.	25	0
Amphibole	0–few.	15	40–49
Carbonate	5–25	5	0–7
Magnetite	1–5	4	0–2
Pyrite	0–2	1	0–1

1. Soft stone (determined from several specimens).
2. Tough stone (one specimen).
3. Hard stone (several specimens).

All these rocks commonly show signs of having been crushed. They contain veinlets of talc, chlorite, chrysotile, carbonates, magnetite, and sulphides, either separate or mixed.

In thin section the serpentine-soapstone-steatite rocks are seen to contain these minerals, named in the order of paragenesis: Amphibole; biotite; chlorite; serpentine and magnetite; tremolite; talc, magnetite, carbonate, chrysotile, and pyrite; tremolite; specularite.

It is probable that the original rocks of this group were pyroxenites, peridotites, and dunites, representing separate bodies or segregations in larger bodies. These rocks, like those of the metagabbro-metapyroxenite group, are thought to have been acted upon by magmatic solutions, which started at conditions of approximate contact-metamorphic intensity and, during gradual cooling, developed the paragenesis mentioned above. The intensity of the solutions was probably rejuvenated immediately before the first tremolite stage. In one place there is a secondary growth of tremolite with slightly later specularite. It is thought that here the solutions died out or were choked off, and then the source was rejuvenated or some barrier in the path of the solutions was removed and they again had free access to the rock.

The stages that have brought these rocks to their present state seem to be correlative with the stages of the metagabbro-metapyroxenite development, as in both groups there were either two invasions of solutions or one invasion which showed a decided rejuvenation. The first invasion was widespread and affected both groups of rocks; the second was more local and affected chiefly the rocks that now contain talc.

Detailed study suggests these points relative to the conditions of formation of talc:

1. The condition of differential stress is not necessary. None of the talc studied shows more than 35 per cent of the mineral having parallel arrangement, and the great majority of the thin sections show a random arrangement of nearly all the talc flakes.

2. The mineral association and paragenesis seem to indicate that talc is formed under conditions of deep or intermediate vein zones.

ITINERARY

The geologic map (pl. 6) shows the route of this trip. The first stop is at the Old Dominion quarries of the Virginia Alberene Corporation. (See pl. 6 and fig. 5.) Immediately west of the quarries is to be seen metapyroxenite, which passes into soapstone to the east. Rather soft stone is being obtained from these quarries, which are operated by modern machinery and modern quarrying methods.

At the northeast end of the old quarries is found rather schistose, soft soapstone spotted with carbonates ("nail neads") and cut by veins of chlorite, talc, carbonate, and sulphides. In the walls of the quarries are peculiar bodies, carrying amphibole, biotite, chlorite, and carbonate, which were probably formed by solutions when the main body of rock was altered. At the extreme northeastern edge of the quarries a fault makes the soapstone body narrower. East of this fault the rocks pass from fine-grained to rather coarse-grained amphibolite, which is also cut by veins. This amphibolite is gneissic near the fault.

At the southwest end of the same body, about 1,200 feet (366 meters) southwest, rather soft stone, which in places contains considerable serpentine, is being quarried. The serpentine is generally more plentiful on the east side of the quarries. It is thought to be a serpentinized metapyroxenite, which has been replaced by talc and other minerals. Several hundred yards southwest along the strike occurs the serpentinized igneous rock with little or no talc.

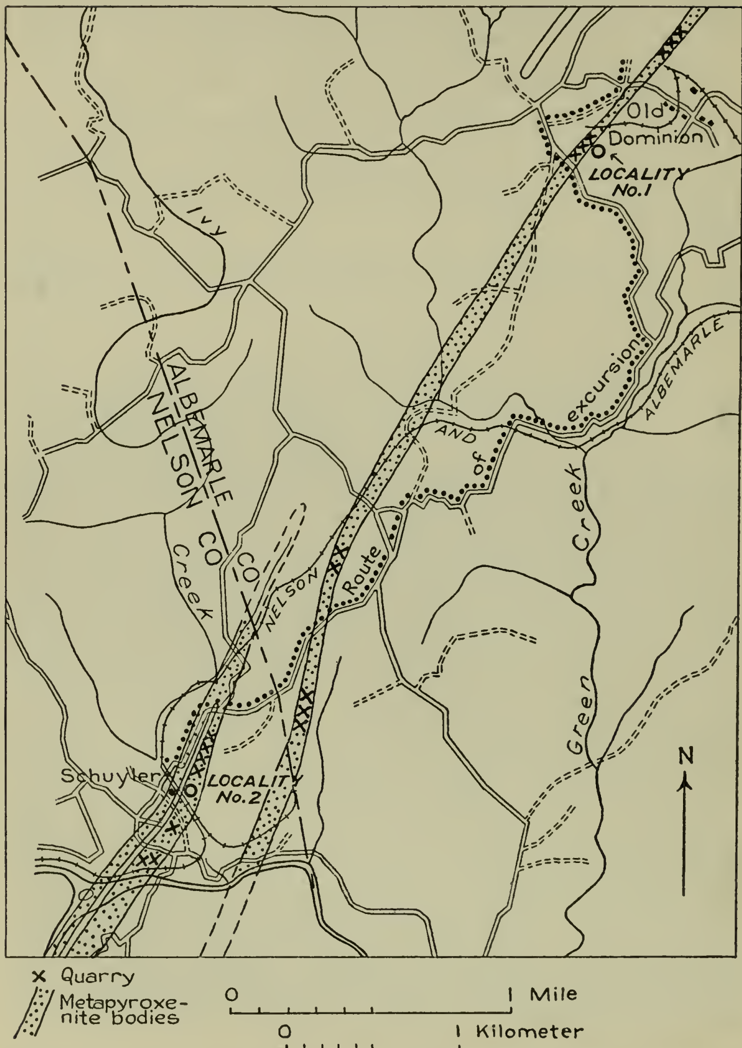


FIGURE 5.—Sketch map showing distribution of metapyroxenite bodies of the Schuyler area

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