Ancient Lavas in SHENANDOAH NATIONAL PARK Near Luray, Virginia

GEOLOGICAL SURVEY BULLETIN 1265

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SHENANDOAH NATIONAL PARK
Near Luray, Virginia

A description of the volcanic rocks of the upper Precambrian(?) Catoctin Formation and a discussion of their environment and mode of eruption

The summit profile of Stony Man (alt. 4,010 ft.) on the crest of the Blue Ridge and the Little Stony Man Cliffs (left) are outcrops of ancient lava flows of the Catoctin Formation described in this report.

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By John C. Reed, Jr.

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SHENANDOAH NATIONAL PARK

Near Luray, Virginia

By John C. Reed, Jr.

Abstract

In the Blue Ridge Province of northern Virginia, Maryland, and southern Pennsylvania, Lower Cambrian beds are underlain by a thick sequence of greenstone and interbedded sedimentary rocks known as the Catoctin Formation. An area near Luray, Va., was studied to determine the thickness of the formation, its relationship to overlying and underlying rocks, and the original nature of the lavas from which the Catoctin greenstone was derived. There the Catoctin Formation lies unconformably on granitic rocks. Its basal sedimentary layer ranges from a few inches to 150 feet in thickness and contains pebbles of underlying basement rocks. The erosion surface beneath the Catoctin is irregular, and in several places, hills as much as 1,000 feet high were buried beneath the Catoctin lavas. No important time break is indicated between the deposition of the Catoctin Formation and the overlying Cambrian sediments.

The original Catoctin lavas were basaltic and were probably normal plateau basalts. Columnar joints, amygdules, sedimentary dikes, flow breccias, low-dipping primary joints, and other primary structures are well preserved.

Introduction

The Blue Ridge is the southeasternmost of the great series of parallel ridges that form the central part of the Appalachian mountain system. All the other ridges of the Appalachians are carved from folded sedimentary rocks of Paleozoic age that were originally deposited in regular horizontal layers on the sea bottom. Near the end of the Paleozoic era these sedimentary layers were warped into a series of enormous elongate folds, some of them several miles across and tens or even hundreds of miles long. Subsequent erosion has sculptured the present topography by wearing away the limestone and softer layers of shale. The intervening harder, more resistant layers of sandstone, conglomerate, and shale were left as the long, parallel, even-topped ridges so characteristic of this part of the Appalachians.

The Blue Ridge, on the other hand, is more varied in both topography and geology. It is not really a single ridge at all, but an irregular chain of hills and ragged peaks, in some places only a few hundred feet high, but locally rising more than 3,000 feet above the floor of the Shenandoah Valley to the northwest (fig. 1) and the Piedmont plateau to the southeast. The Blue Ridge marks the northwest side of an enormous wrinkled upfold in the earth's crust known as the Catoctin Mountain-Blue Ridge anticlinorium. The anticlinorium extends for more than 250 miles from southern Pennsylvania southwest at least as far as Lynchburg, Va. (fig. 2). The southeastern flank of the upfold is marked by Catoctin Mountain in Maryland and by the Bull Run Mountains, Southwest Mountains, and other low ridges in Virginia.

The core of the anticlinorium brings up some of the oldest rocks exposed anywhere in the eastern United States—granite and various granitelike gneisses formed at least 1.1 billion years ago. Because of their great age, their position beneath all the other geologic units, and their enigmatic

Figure 1. View of the Blue Ridge from the west. The flat fertile valley floor (foreground) is underlain by limestone of Paleozoic age capped by terrace gravel. The low wooded foothills (middle distance) are underlain by steeply dipping quartzite and shale of the Chilhowee Group. The main mass of the Blue Ridge is composed of granitic basement rocks, but the highest part of the ridge is capped by greenstone of the Catoctin Formation. National Park Service photograph.

character, these rocks are commonly called basement rocks and are referred to collectively as the basement complex.

Along the southeast side of the anticlinorium the basement complex is overlain by hundreds or thousands of feet of younger rocks that were originally dark shales, sandstones, and conglomerates, which have been metamorphosed to phyllite, gneiss, and mica schist. These sedimentary rocks are called the Lynchburg Formation. In the Blue Ridge, on the northwest side of the anticlinorium, the basement is overlain by the Catoctin Formation, a thick sequence that is composed mainly of greenstone derived from metamorphism of basaltic lavas and that also contains many thin and discontinuous

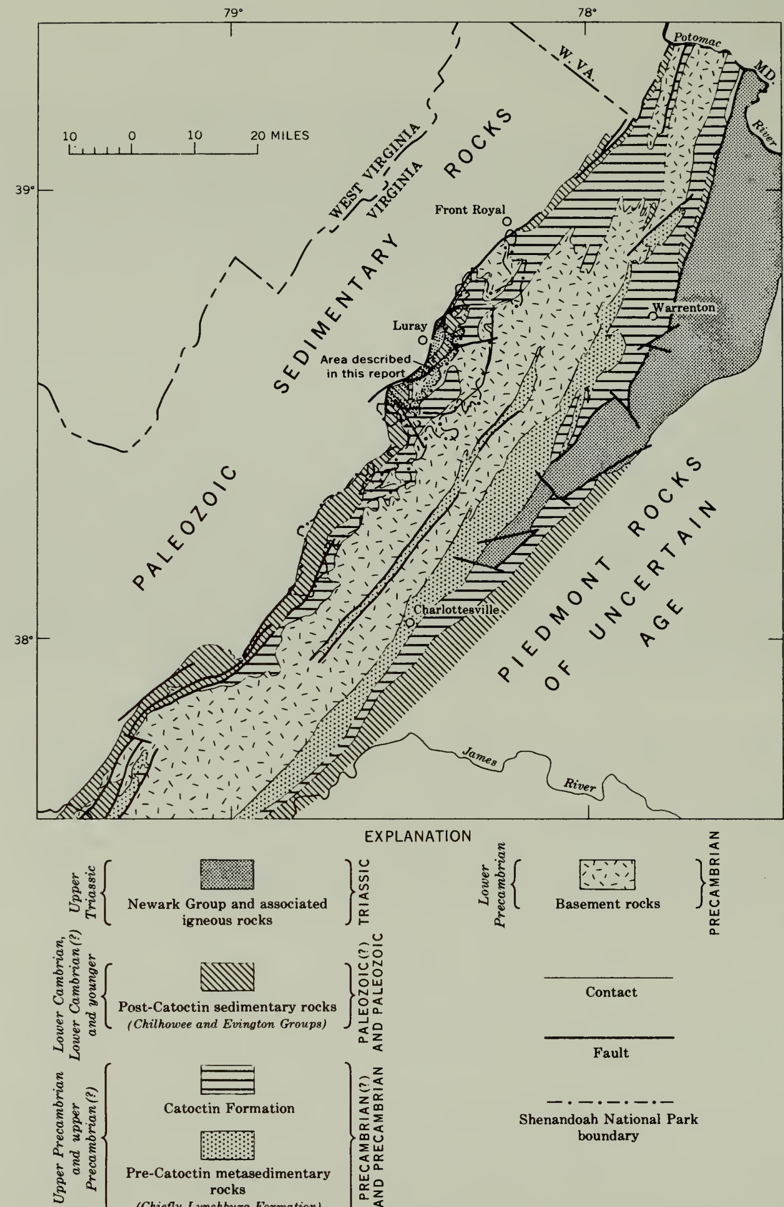

Figure 2. Geologic map of the Catoctin Mountain-Blue Ridge anticlinorium in Virginia. Generalized from the geologic map of Virginia (Virginia Division of Mineral Resources, 1963).

layers of metamorphosed sandstone, shale, and volcanic ash. The Catoctin Formation can also be recognized along the southeast flank of the anticlinorium where it rests on top of the Lynchburg Formation. The Lynchburg Formation, on the other hand, is represented on the northwest flank of the anticlinorium only by a discontinuous layer of sedimentary rock, generally less than 150 feet thick, at the base of the Catoctin.

Along the northwest flank of the anticlinorium, the Catoctin Formation is overlain by slightly metamorphosed sandstone and shale of the Chilhowee Group, the basal deposit of the thick sequence of Paleozoic sedimentary rocks that form the Appalachians northwest of the Blue Ridge. In a few places the uppermost beds of the Chilhowee Group contained fossils that are clearly of Early Cambrian age. The lower part of the Chilhowee Group contains abundant worm borings, but no fossils have yet been found that would definitely establish its age. It is also generally assumed to be of Early Cambrian age (King, 1949).

The Chilhowee Group also overlies the Catoctin Formation on the east side of the anticlinorium in Maryland and can be traced southward through the Bull Run Mountains as far as Warrenton, Va. South of Warrenton, the Catoctin is overlain by the Evington Group, composed of rocks that somewhat resemble those of the Chilhowee but whose age and correlation are not yet definitely established.

One of the greatest puzzles in the geology of the Appalachians is the question of the age of the vast terrane of schists and gneisses that underlies the Piedmont plateau southeast of the Catoctin Mountain-Blue Ridge anticlinorium. Many of these rocks were deposited as sediments, chiefly shale and sandstone, but most of them have been so deformed and altered by metamorphism that their original sequence is difficult to decipher. The character of the Piedmont rocks before metamorphism was clearly quite different from that of the Paleozoic sedimentary rocks northwest of the anticlinorium, but part or all of them may be also of Paleozoic age. It is also possible that many of the Piedmont rocks are approximately equivalent in age to the Catoctin and Lynchburg Formations and are, therefore, older than any of the rocks of the folded Appalachians. The problem of the age of the Piedmont rocks must be resolved before we can satisfactorily reconstruct the geologic history of this part of the Appalachian mountain system.

The Catoctin Formation is of special interest in this connection because it is one of the few geologic units that can definitely be recognized on both sides of the anticlinorium. Thus it furnishes a tenuous bridge between the folded Paleozoic sedimentary rocks on one side and the Piedmont rocks on the other. It is also of interest because of its position between the Precambrian basement rocks and the oldest fossil-bearing Paleozoic sedimentary rocks and, because it records the only extensive volcanic eruptions in this part of the Appalachians.

This paper describes the Catoctin Formation in a small area in the Shenandoah National Park near Luray, Va., where the formation is particularly well exposed. It is a slightly abridged and modified version of a previous paper by Reed (1955).

The principal objectives of the study were the determination of the original nature of the Catoctin lavas, the manner in which they were erupted, and their relations to the overlying and underlying rocks. The paper is reprinted here in the hope that in spite of its technical nature it will be of interest to many visitors to Shenandoah National Park and that it will serve to increase their appreciation of the landscape and geologic problems of the park.

Many of the geographic features referred to in the text are shown on the index map (fig. 3). These features can also be located on the U.S. Geological Survey topographic maps of the Luray, Thornton Gap, Big Meadows, and Old Rag Mountain 7½-minute quadrangles and on the trail maps of the northern and central sections of Shenandoah National Park published by the Potomac Appalachian Trail Club. Since publication of the original paper, part of the area has been remapped by Allen (1963); some readers may wish to refer to his excellent paper for more detailed descriptions of the rocks overlying and underlying the Catoctin Formation.

Figure 3. Area described in this report.

General geology

STRUCTURAL SETTING

The northwestern flank of the Catoctin Mountain-Blue Ridge anticlinorium in the Luray area is marked by a large asymmetrical northeast-trending anticline. The eastern limb of the fold is gently dipping; the western limb is vertical or overturned (geologic map in pocket). Most of the crest of the Blue Ridge is capped by greenstone of the Catoctin Formation in the upper limb of the anticline, but in the area between Thornton Gap and Stony Man, the Catoctin Formation has been removed by erosion and the underlying granitic gneisses form the crest of the ridge. The steep western limb of the fold is marked by a series of low foothills composed of resistant rocks of the Catoctin Formation and Lower Cambrian quartzites in which bedding is vertical or overturned to the east. In the Shenandoah salient, west of Big Meadows (map in pocket) the gentle upper limb of the anticline has smaller folds superimposed and is complicated by the wedging out of the Catoctin beneath the Cambrian sedimentary rocks. The anticline is cut by several high-angle faults. The Stanley fault, which cuts the fold diagonally, brings the Lower Cambrian sedimentary rocks into contact with the plutonic basement rocks, a relationship that in the past has been explained as the result of a major overthrust along the western foot of the Blue Ridge. Probably no such overthrust exists in the Luray area or in the Elkton area to the south (King, 1950).

Between the Shenandoah salient and U.S. Highway 211, granitic basement is exposed over wide areas on the western slopes of the Blue Ridge in the core of the anticline. On the gentle eastern limb of the fold the Catoctin is cut off by steeply dipping faults which have brought the granitic basement to the surface, where it crops out in the peaks of Oventop, Hazel Mountain, and Old Rag Mountain east of the main Blue Ridge.

The pattern of cleavage and lineation in the Catoctin Formation and Chilhowee rocks conforms to the pattern in the rest of the Catoctin Mountain-Blue Ridge anticlinorium. Cleavage strikes north or northeast and dips southeast; dips of 50° or 60° are common on the eastern limb, whereas dips of 30° or 40° predominate on the overturned western limb of the anticline. Local variations in the dip of the cleavage are related to differences in lithology or to fanning in subsidiary folds. Lineation lies in the cleavage plane and plunges down the dip to the east or southeast, normal to the fold axes. In the sedimentary rocks it is marked by the elongation of phyllite fragments, parallel orientation of minerals, or a faint grooving of the cleavage planes. In the volcanic rocks it is marked by parallel orientation of chlorite blebs.

Slickensiding normal to the fold axes was found on bedding planes and flow surfaces in a few places, which indicates that flexure folding, as well as shear folding, played a part in the deformation of the area.

ROCKS UNDERLYING THE CATOCTIN FORMATION

General character

Two major lithologic types form the basement complex underlying the Catoctin Formation in the Luray area. The first of these is a dark rudely layered granodiorite or quartz monzonite, shown as the Pedlar Formation on the geologic map of Virginia (Virginia Division of Mineral Resources, 1963) and by Allen (1963). It is exposed chiefly along the crest of the Blue Ridge and on the western flank of the mountains. The second, a coarse-grained light-colored granite designated the Old Rag Granite by Furcron (1934) for exposures on Old Rag Mountain, is exposed in the area east of the crest of the Blue Ridge.

The granodiorite is medium to coarse grained, light greenish gray where fresh and weathers to light brownish gray or white. It is composed chiefly of plagioclase, quartz, potassium feldspar, hypersthene, biotite, chlorite, magnetite, and gar-

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net, and it contains minor amounts of epidote and albite. The chlorite forms dark-green clots, probably derived from alteration of ferromagnesian minerals. The plagioclase grains are generally greenish white, although where alteration has been minor they may be clear and show twin striations. In most places, shearing has broken the feldspars and mashed the chlorite blebs.

Most of the granodiorite exposed on the western slopes of the Blue Ridge is only faintly foliated. Along the Skyline Drive between Hughes River Gap and Thornton Gap the granodiorite is well foliated, the foliation being defined by parallel clots and layers of light and dark minerals that are 1 millimeter to 10 centimeters thick. In some outcrops the dark minerals are in parallel spindle-shaped clots which give a spotted appearance to the rock where it is broken across the lineation. A few pegmatitic stringers and pods lie parallel to the foliation. At several places along U.S. Highway 211 east of Thornton Gap, the gneissic granodiorite contains layers composed principally of quartz. Locally, hydrothermal alteration of the granodiorite gneiss has produced a rock called unakite, which is composed of epidote, pink feldspar, and blue quartz. Jonas and Stose (1939) have suggested that the granodiorite is at least in part derived from granitization of a sedimentary series. Radiometric age determinations on zircon from the granodiorite near the south end of the Marys Rock tunnel indicate that the rock was formed about 1,100 million years ago (Davis and others, 1958).

The Old Rag Granite of Furcron (1934) is considerably coarser grained than the granodiorite; individual feldspar crystals are as much as 3 centimeters long. The only abundant minerals are milky-white perthitic microcline and dark-gray or blue smoky quartz. A very small amount of chlorite is present, but no primary ferromagnesian minerals remain. The rock is commonly light gray or white; foliation is defined by parallel stringers or elongate patches of dark quartz. Along faults the Old Rag Granite is commonly intensely sheared and, in places, is finely ground to form white mylonite.

The contact between the granodiorite and the Old Rag Granite is gradational through a zone several miles wide. In the transition zone the granodiorite is more gneissic, finer grained, and much richer in biotite than it is elsewhere. Garnet seems to be confined exclusively to this zone. Dikelets and pods of blue-quartz granite similar to the Old Rag Granite occur in gneissic granodiorite at several places along Skyline Drive, on the flanks of Marys Rock, and along the fire road west of Skyland.

The foliation and layering in the granitic rocks are rudely parallel to the cleavage in the overlying Catoctin Formation over wide areas, but locally there is a distinct divergence between structures in the basement and those in the overlying rocks. A faint fracture cleavage in the basement rocks in many areas is believed to be related to the cleavage in the rocks above.

Pebbles of foliated granodiorite in the basal sedimentary member of the Catoctin Formation show that the foliation of the basement rocks antedated the deposition of the Catoctin sedimentary rocks. The fracture cleavage in the basement rocks was probably formed at the same time as the cleavage in the Catoctin and overlying rocks. The low-grade metamorphism of the basement rocks probably dates from this period.

Relation to the Catoctin Formation

The flows of the Catoctin Formation rest on an eroded surface of granodiorite and granite that has a relief of as much as 1,000 feet. Valleys in the erosion surface contain a layer of clastic sedimentary rocks as much as 150 feet thick beneath the greenstone. In other places the sedimentary rocks are only a few inches thick. Buried hills of granitic rocks beneath the Catoctin are exposed in cross section in the valleys of Whiteoak Run and Rose River. These exhumed hills superficially resemble intrusive masses of granite, but a widespread basal sedimentary layer surrounding them contains pebbles of gneiss and granite, which shows that the contact is an unconformity, not an intrusive contact.

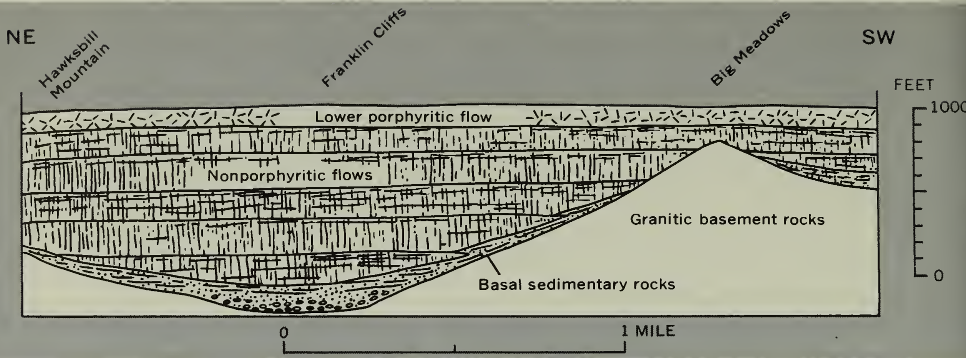

Figure 4. Stratigraphic relations between the Catoctin Formation and the granitic basement rocks along the western edge of the Catoctin outcrop area between Hawksbill Mountain and Big Meadows.

Figure 4 shows the relationship of the basal sedimentary member of the Catoctin Formation to the pre-Catoctin erosion surface as it is exposed on the western slopes of the Blue Ridge between Hawksbill Mountain and Big Meadows. The diagram is based on a series of well-exposed sections from the base of the lowest porphyritic flow in the Catoctin to the base of the formation. The floodlike character of the lavas and the thickening of the basal sedimentary member in the lower areas in the pre-Catoctin surface are well illustrated in this area. These relationships are typical of those observed wherever the bottom contact of the Catoctin Formation was examined.

ROCKS OVERLYING THE CATOCTIN FORMATION

General character

The Chilhowee Group, which overlies the Catoctin Formation, has been well described in other areas in northern Virginia and Maryland (King, 1950; Nickelsen, 1956; Whitaker, 1955; Allen, 1963), and only a general description is necessary here. The Chilhowee Group is subdivided into three formations—the Weverton Formation (at the base), the Harpers Formation, and the Antietam Quartzite (at the top); however, these formations are not distinguished on the geologic map of the Luray area (in pocket). With the exception of the Shenandoah salient and a few small areas around Chapman Mountain on the south and Neighbor Mountain on the north, all the Chilhowee exposures in the area studied are confined to the nose and lower limb of the Blue Ridge anticline where shearing has been intense and outcrops are poor. The lower beds (equivalent to the Weverton Formation) are coarse-grained, thick-bedded, ferruginous quartzites and graywackes, commonly dark gray, brown, purple, or bluish gray with color banding parallel to bedding. Scattered quartz pebbles are common and crossbedding is present in many exposures. Dark slaty interbeds are common. These beds grade upward into a poorly exposed sequence of buff or light-gray sandy phyllite and argillite containing thin beds of quartzite; this sequence represents the Harpers Formation. Bedding in the Harpers Formation is obscured by cleavage except where competent quartzite beds are present. The upper part of the formation is characterized by jetblack, blue, or purple quartzite beds within the phyllite sequence. The combined thickness of the Weverton and Harpers Formations, measured along U.S. Highway 211, is about 2,300 feet; in the Shenandoah salient and in the Elkton area just to the south, King (1950) found the thickness to be 1,900 to 2,500 feet.

The Antietam Quartzite is a white, medium- to fine-grained, sugary to glassy rock that forms prominent cliffs and ledges in areas where it has not been completely shattered during deformation. Where shattering has been intense, outcrops of the Antietam are rare, and the ground is littered with quartzite fragments a few inches in diameter. The upper part of the formation contains abundant worm tubes (*Scolithus*) normal to bedding, but they are absent in the lower part. Megascopic cleavage is poorly developed, and bedding is obscure in many outcrops. According to King (1950), the Antietam is about 800 feet thick in the Elkton area; no reliable estimate was made in the Luray area. The Antietam passes upward through a few feet of shaly beds into the Tomstown Dolomite of well-established Early Cambrian age; the Tomstown marks the bottom of the great Cambrian and Ordovician carbonate sequence of the Appalachian Valley.

Relation to the Catoctin Formation

The contact between the Catoctin Formation and the overlying sedimentary beds is marked by a layer of purple or blue slate as much as 150 feet thick, which was mapped by King (1950) as the Loudoun Formation in the Elkton area. The volcanic nature of this rock is clear; it contains numerous amygdules (filled gas bubbles), and in thin section it shows a relic basaltic fabric. Furcron and Woodward (1936) have described this as an altered rhyolite flow, but the fabric and composition indicate that it is more probably derived from an andesite or basalt. Its petrographic character will be discussed in more detail, but its stratigraphic relations have an important bearing on the relation of the Catoctin Formation to the overlying rocks. In the western part of the Shenandoah salient (map in pocket) the greenstone of the Catoctin is absent, and the purple slate lies directly on granodiorite. Still farther west the slate is absent and the basal beds of the Chilhowee rest directly on faintly foliated coarse-grained granodiorite. The purple slate is thus present in several places where the greenstone is absent. Furcron and Woodward (1936) consider this to be evidence of an angular unconformity beneath the Chilhowee and the purple slate. As no discordance was noted between the Catoctin and Chilhowee, however, it seems more likely that the relationship is a result of overlap of the Catoctin Formation onto a topographic high of basement rocks; the purple slate can then be assigned to the Catoctin Formation, where its volcanic character and similarity to other rocks in the volcanic sequence seem to indicate that it belongs.

Along the Skyline Drive about 4 miles north of Thornton Gap, the slate is absent, and the basal quartzite of the Chilhowee contains rounded cobbles of fine-grained massive Catoctin lava; this indicates that erosion preceded deposition of the Chilhowee sedimentary rocks. Evidence of a major unconformity is lacking, however. Cloos (1951) reports that volcanic rocks are interlayered with the lower beds of the Chilhowee Group in some areas in Maryland, and Bloomer (1950) has pointed out that the similarity of the volcanic rocks of the Catoctin to the volcanic flows in the Chilhowee

Group near Tye River Gap and the James River indicates that there was no major erosion interval between the Catoctin and the Chilhowee.

GENERAL CHARACTER OF THE CATOCTIN FORMATION

In the Luray area, most of the Catoctin Formation consists of lava flows altered to greenstone by low-grade regional metamorphism. Sedimentary members are common but not extensive, and none of these interbeds is more than 40 feet thick, although the basal sedimentary layer locally reaches 150 feet. These sedimentary members mostly are graywacke, arkose, and conglomerate derived from the underlying granitic rocks and micaceous (sericite) phyllite perhaps derived from volcanic ash. The greenstone is green, blue, purple, or gray and generally is so fine grained that only chlorite and epidote can be recognized with the hand lense. Porphyritic varieties containing conspicuous crystals of plagioclase (phenocrysts) as much as 1 cm long are present in several places in the greenstone sequence. In thin section the chief minerals of the greenstone can be identified as albite, chlorite, epidote, actinolite, and sphene, and minor amounts of pyroxene, magnetite, hematite, and ilmenite are also present. Most exposures show a well-developed cleavage, but cleavage is absent in some places. Primary structures such as bands of amygdules, columnar and platy jointing, and sedimentary dikes are preserved where deformation has not been intense. Flow breccias are common. Veinlets of epidote, milky quartz, and anthophyllite cut the greenstone in many places. Complete replacement of greenstone by irregular pods and veinlets of epidote and quartz has formed yellowish-green epidosite which is very common in some areas.

The present study of the Catoctin Formation was concentrated in the southern half of the area shown in the geologic map (in pocket) where excellent exposures of the volcanic sequence occur along the crest of the Blue Ridge between Stony Man and Big Meadows. North of Thornton Gap the Catoctin was not studied in detail.

STRUCTURE

The general attitude of the formation was determined by tracing the basal sedimentary member and two coarsely porphyritic flows of the volcanic sequence. None of the sedimentary interbeds is continuous enough to serve as a marker horizon.

The structure of the formation is simple. North of the Rose River the porphyritic flows and the sedimentary members dip 15° to 20° E. or SE. The western boundary of the formation is the outcrop of the pre-Catoctin erosion surface and is marked by a few inches to 150 feet of sedimentary rocks containing pebbles of the underlying granodiorite. On the east the formation is cut off by a steeply dipping fault, along which the basement rocks are intensely sheared and in places, finely ground to mylonite. There is a reversal of dip of the Catoctin Formation near this fault.

At least two minor faults cut the formation in this area. One extends from Hawksbill Gap down Cedar Run; the other goes through Franklin Cliffs (fig. 5) and down the valley of Rose River.

In the Big Meadows area, south of the Rose River, the Catoctin dips 10° to 15° S. Southwest of Big Meadows the greenstone crops out for several miles down Tanners Ridge. There the formation is exposed in a gentle anticline on the upper limb of the main Blue Ridge fold. Poor exposures and more intense sheering make it impossible to trace the flows in this area, but the anticline is indicated by the lower contact of the formation on the north slope of Tanners Ridge. The top of Chapman Mountain, just south of Tanners Ridge, is capped by several hundred feet of flat-lying lower Chilhowee sedimentary rocks on the crest of the subsidiary fold. These rocks are underlain by 50 to 150 feet of purple, red, or blue volcanic slate. The entire thickness of the greenstone in that area is only about 500 feet, as compared with greenstone at least 1,800 feet thick at Big Meadows, where the top of the formation has been removed.

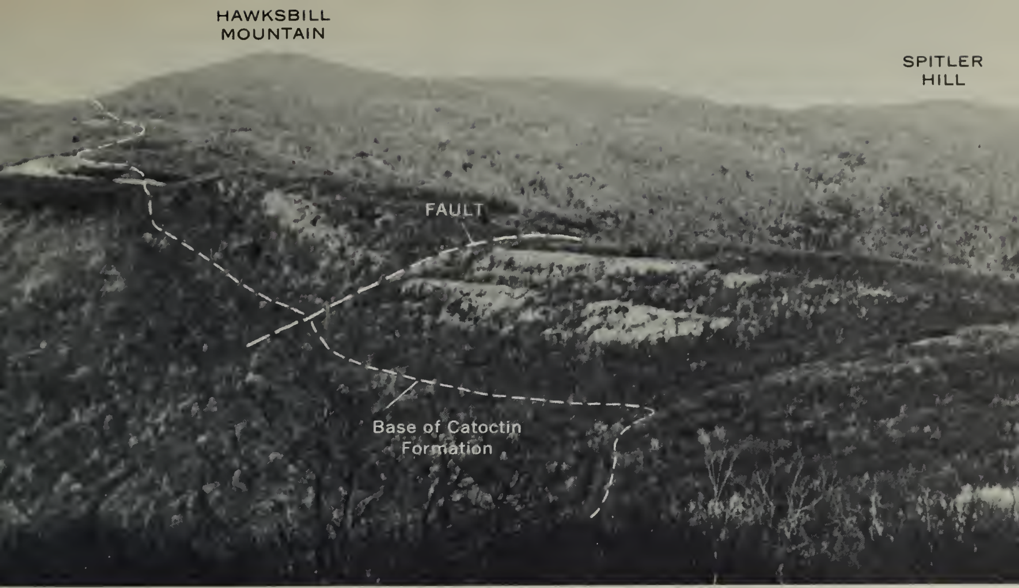

Figure 5. View of Franklin Cliffs from Big Meadows Campground showing the prominent cliffs marking the outcrops of the second and third flows above the base of the Catoctin Formation. Note change in attitude of flows near fault.

Throughout the Big Meadows-Stony Man area cleavage strikes north of northeast and dips 30° to 60° E., except near faults. Lineation plunges east or southeast down the dip of the cleavage planes; it is marked by dark-green elongate chlorite blebs, faint striations on the cleavage, parallel orientation of actinolite needles in greenstone, and by elongated phyllite fragments in the sedimentary rocks.

SEDIMENTARY MEMBERS

The sedimentary rocks associated with the greenstones of the Catoctin Formation occur both at the base of the sequence and in thin interbeds between flows. Jonas and Stose (1939) described a sedimentary layer near the base of the greenstone near Swift Run Gap; they later named this layer the Swift Run Formation (Stose and Jonas, 1944). Bloomer and Bloomer (1947) recognized similar sedimentary rocks near Rockfish Gap and named them the Oronoco Formation. In the Big Meadows-Stony Man area a sedimentary layer occurs beneath the lowest flow, but because it is discontinuous and closely related to the sedimentary rocks interbedded with the overlying greenstones, it is not considered here as a separate formation.

Most of the basal sedimentary rocks of the Catoctin Formation are poorly sorted arkose, conglomerate, and graywacke. The graywacke contains angular to subrounded grains of glassy quartz and feldspar 0.1 to 3 millimeters in diameter in a grayish-green micaceous matrix composed of sericite and chlorite. This matrix material makes up 20 to 50 percent of the rock. Conglomerate composed of pebbles and cobbles of vein quartz and underlying gneisses in a matrix of graywacke is common. Pink, green, and gray phyllite fragments and small greenstone fragments occur locally. Detrital magnetite and hematite are common.

The arkosic sedimentary rocks are composed principally of angular to subrounded grains of clear quartz and white feldspar with a small amount of matrix material, mainly epidote; most arkoses are better sorted than the graywackes and many are crossbedded. Where the basal sedimentary rocks are thick they are generally graywackes or conglomerates; where they are thin they are arkoses or phyllites.

Near the head of Hawksbill Creek west of Big Meadows the basal Catoctin sedimentary rocks are about 100 feet thick and consist of graywacke and purple phyllite interbedded with finely laminated gray argillite. Each lamination in the argillite grades upward from the light-greenish-gray layer of coarse siltstone to a dark-gray argillite layer. The upper contact of the argillite layer is sharp and is overlain by the coarse silt layer of the next couplet of laminations. Thiesmeyer (1939) has described slates with similar laminations from Fauquier County, Va. He assigned them to the Loudoun Formation, apparently on the basis of Keith's geologic map of the Harpers Ferry quadrangle (Keith, 1894). A brief examination of the rocks at his locality, however, indicates that these slates are probably part of the basal Catoctin sedimentary rocks. Thiesmeyer gives an excellent description of the features and concludes that they are fresh-water varves, possibly of glacial origin. Although the general appearance of the laminations near Big Meadows and the gradation from coarse light-colored material at the bottom of each set to fine dark material at the top are very suggestive of glacial varves, no striated pebbles or rafted grains have been found associated with them. A glacial origin is, therefore, unproven.

At many places the lower contact of the basal sedimentary rocks is obscure. Graywackes with angular detrital grains grade downward into slightly sheared and altered gneiss. Some 50 to 100 feet below the sedimentary rocks the gneiss is fresh and contains large feldspar and quartz grains with little sericite. This effect may be due to weathering of the gneiss on the pre-Catoctin erosion surface, and much of the overlying sedimentary rock may be only slightly reworked from this weathered mantle.

The basal sedimentary layer of the formation has well-developed cleavage and lineation, marked by flattened and elongated phyllite fragments and parallel orientation of micaceous minerals. Quartz pebbles in the conglomerates are not visibly deformed, but their surfaces commonly have fine striations caused by flowage of the matrix that are parallel to the lineation of the enclosing rock. Banding in the granodiorite pebbles in the sedimentary rocks is not parallel to the cleavage of the enclosing rock.

The pre-Catoctin erosion surface has more than 1,000 feet of relief along the western boundary of the Catoctin outcrop area between Big Meadows and Stony Man. The thickest sections of the basal sedimentary rocks are near the low areas in the erosion surface. This indicates that the relief is not due to later deformation (fig. 4). In two places, streams have cut through Catoctin rocks and exposed hills of granitic rocks in the erosion surface which had been buried by the Catoctin lavas. The hill in Whiteoak Canyon had a relief of 450 feet, whereas the one in Hogcamp Branch was at least 750 feet high.

The sedimentary rocks between the lava flows are similar petrographically to the basal sedimentary rocks but are not extensive and are commonly only a few inches thick. Phyllites in the interbedded sedimentary rocks are common. They are generally gray but may be green, blue, or purple, and they contain few detrital grains. Phyllites of different colors are interbedded within a single outcrop, and they may show complex interfingering relationships. They are composed almost exclusively of sericite and probably were derived from alteration of volcanic ash layers.

Figure 6. The upper falls in Whiteoak Canyon is one of the many waterfalls formed where streams cross the lava flow of the Catoctin Formation. Generally falls occur where streams cross massive greenstone in the middle of a flow; steps between falls occur where streams cross sheared breccia zones between flows.

VOLCANIC FLOWS

In several places it has been possible to recognize and map individual flows within the greenstone sequence. At Franklin Cliffs, at Crescent Rocks, on Stony Man, and in Whiteoak Canyon (fig. 6), massive greenstone layers form series of cliffs 150 feet high separated by talus-covered benches. Near the top of each cliff the greenstone is schistose (fig. 7), but a few feet down it is massive and irregularly jointed. Locally, columnar jointing is well developed. Low-dipping joint sets similar to the flat primary joints in recent lava flows are commonly present, especially just below the schistose upper zone. The rock in the schistose layers is

Figure 7. Schistose greenstone along the Appalachian Trail at the base of Little Stony Man Cliffs. Here, a zone of breccia and schistose greenstone marks the boundary between the second and third flows above the base of the Catoctin Formation. Outcrop is approximately 3 feet high.

commonly a highly sheared breccia with fragments of amygdaloidal greenstone, silvery phyllite, and red argillite. The matrix is either epidote, greenstone, or phyllite. Locally, thin beds of sandstone occur in the sheared zones between the greenstone layers. The character of these breccias may not be apparent except on polished surfaces of hand specimens.

The sheared zones mark boundaries between lava flows and probably represent surface breccias, soil horizons, and thin sedimentary beds developed or deposited at the top of one flow before extrusion of the next flow. Loose blocks of lava and pieces of sedimentary rock torn up and churned into the base of the succeeding flow during its advance also make up part of the breccias. Deformation was concentrated at the flow boundaries, which left the greenstone near the centers intact and permitted preservation of primary features in many places.

In sections at Franklin Cliffs and at Crescent Rocks, both of which expose the lower three flows, all flows but one have a thickness of 150 to 200 feet (fig. 8). The second flow at Franklin Cliffs is about 270 feet thick. Northwest of Big Meadows, seven flows have a total stratigraphic thickness of 1,500 feet and an average thickness of 215 feet each.

It is generally difficult to trace an individual flow in the greenstone sequence because of the lack of continuous exposures, but the two porphyritic flows can be easily recognized and furnish excellent marker beds.

Because the pre-Catoctin erosion surface is irregular, the stratigraphic interval between the lowest of the porphyritic flows and the base of the Catoctin Formation varies. On Hawksbill Mountain the lowest porphyritic flow is the sixth flow above the base of the formation. North of Big Meadows it is the fourth, and west of Big Meadows it is the second or third flow above the base. At the head of the Rose River the lowest porphyritic flow probably abuts against the granodiorite hill exposed in the canyon of Hogcamp Branch.

The flows below the lowermost porphyritic flow are the best exposed in the volcanic sequence. The greenstone of these flows is fine grained and generally nonporphyritic,

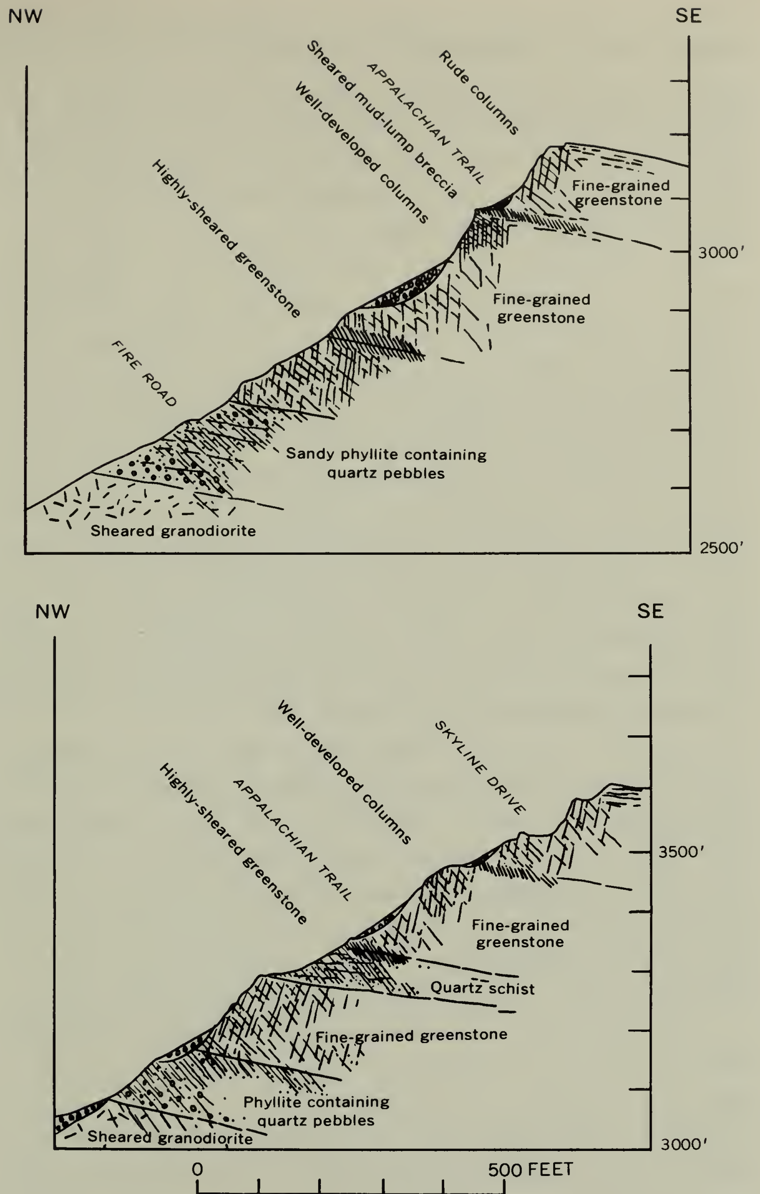

Figure 8. Sections of the lower three flows in the Catoctin Formation at Franklin Cliffs (top) and at Crescent Rocks (bottom).

although sparse small plagioclase phenocrysts are present locally. Interbedded phyllitic sedimentary rocks are common, and columnar jointing is well developed in one flow and distinguishable in several others. Flow boundaries exposed in the cliffs are marked by intensely sheared zones of volcanic breccia. Most of the primary features described below are best observed in this group of flows.

The greenstone of the lower porphyritic flow has a medium- or coarse-grained groundmass with plagioclase crystals about 1 millimeter long. The plagioclase phenocrysts (now albite) are 5 millimeters to 1.5 centimeters long and make up 15 to 30 percent of the rock. The flow has been traced for more than 6 miles, though its position is indefinite in areas where outcrops are poor or where intense shearing has obscured the porphyritic character. The flow commonly forms cliffs, even where exposures of the other flows are poor. On Tanners Ridge southwest of Hawksbill Creek, the flow could not be traced because of poor outcrops and intense shearing. The porphyritic character becomes less distinct to the north near Stony Man. The flow must have covered an area of at least 15 square miles.

The upper porphyritic flow, 400 to 800 feet stratigraphically above the lower porphyritic flow, cannot be traced over as large an area as the lower flow. The upper flow closely resembles the lower flow in most outcrops, but in places it contains large phenocrysts—some are as much as several centimeters long—that make up as much as 50 percent of the rock. Three to five flows may be present between the two porphyritic flows, and sedimentary interbeds are sparse.

The flows above the upper porphyritic flow are poorly exposed, and the maximum number still preserved is undetermined. Much of this sequence consists of fine-grained nonporphyritic greenstone, but coarse-grained types with scattered phenocrysts are common. A few sedimentary interbeds less than a foot thick occur. Approximately 700 feet of greenstone is preserved above the upper porphyritic flow on the slopes south of Spitler Hill. The Catoctin is at least 1,800 feet thick in this area, and the top has been removed by erosion. This may be the maximum thickness preserved in the Big Meadows-Stony Man area.

PRIMARY FEATURES

The preservation in the greenstone of some of the typical primary structures of more recent basalt flows is of interest because these structures afford important clues to the origin of the greenstone and because their preservation indicates the small amount of deformation that some of the rocks have undergone.

Columnar jointing

A flow with unusually well-developed columnar jointing can be traced discontinuously near the bottom of the greenstone sequence from Big Meadows to Stony Man. The columns are approximately a foot in diameter and as much as 20 feet long (fig. 9, left photo). The faces of the columns are commonly marked by faint grooves normal to the axes. Most of the columns are broken along cleavage planes (fig. 9, right photo). In most exposures of this flow the axes of the individual columns are parallel, but in a few places, for example at Crescent Rocks, the axes are curved and randomly oriented.

Many flows show rude columnar jointing; generally the columns are 2 or 3 feet in diameter and considerably shorter than those in the flow just described. Some flows have large columns near the base and smaller ones near the top.

The columns have been deformed so that their axes are no longer perpendicular to the surfaces of the flows, but plunge to the south or southeast at angles of as much as 50° with the normals to the flow surface.

Low-dipping primary joints

Many greenstone exposures have a prominent low-dipping joint set, which gives the outcrops a steplike appearance. The joints are related to flow surfaces, and they may be used in the field to determine the approximate attitude of the flows. The joints are probably analogous to the original joints parallel to flow surfaces, which are common in recent basalt flows. The joints are spaced a few inches to several feet apart and are more pronounced near the top of a flow. Farther down in a flow they are generally absent.

Figure 9 (above and right). Columnar jointing in greenstone. Left photograph: Small wavy columns at top of cliff above the Appalachian Trail about 0.15 mile north of Hawksbill Gap. Right photograph: Large column along the Appalachian Trail about 200 feet south of Little Stony Man parking area. The column is cut by cleavage which dips east, away from the observer. Note that the segment of the column above each cleavage plane is offset westward from the segment beneath as a result of movement during formation of the cleavage. Column is approximately 2 feet in diameter.

Amygdules

Amygdules, or filled gas bubbles, occur in almost every greenstone outcrop and are especially abundant in zones near flow tops. The characteristic minerals in the amygdule fillings are milky quartz, epidote, albite, calcite, and chlorite (fig. 10). An amygdule may be filled with a single mineral or with several minerals in concentric layers or irregular intergrowth. Epidote, quartz, and albite are commonly associated, in the amydule fillings. Chlorite and albite are common associates, albite forming the rim and chlorite forming the core of the amygdule. Chlorite occurs alone in some amygdules.

In thin section (fig. 10, photomicrograph), the chlorite filling commonly shows an outer layer composed of a fibrous aggregate of chlorite in which the long axes of the fibers are perpendicular to the walls of the amygdule. The core is composed of an aggregate of chlorite of the same color.

Amygdules in the greenstone are generally almond shaped where scattered, but in the highly amygdaloidal zones they are irregular in outline. Some of the larger amygdules have rounded upper surfaces and flat bottoms parallel to the flat primary jointing. In some places the amygdules are arranged in layers which are probably related to flow planes in the lava.


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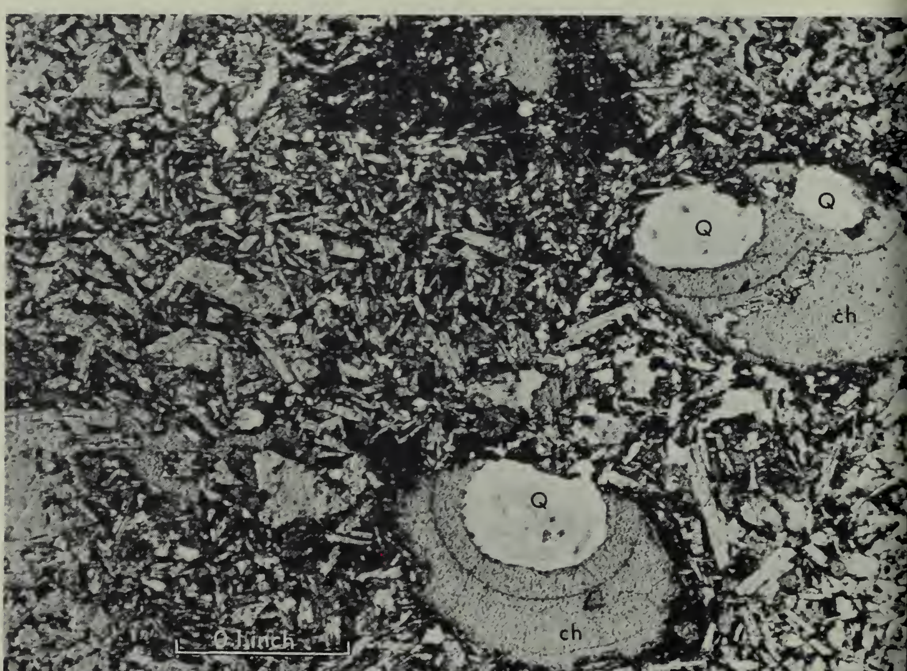
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Sedimentary dikes

Interbedded sedimentary members of the Catoctin Formation commonly show complex and confusing relations to the greenstone. Near the top of a flow, sedimentary rocks from an overlying lens may extend downward along cracks 5 or 10 feet into the greenstone. These sedimentary dikes are as much as 3 inches wide and contain sediments similar to those immediately overlying the flow. They probably represent sand and mud that sifted down into cracks soon after the molten rock solidified.

Sedimentary dikes of a different type occur near the bases of some of the flows (fig. 11), where sedimentary rocks project upward into the greenstone in a network of branching veins. These veins extend 10 or 15 feet above the bases of the flows, beyond which they gradually die out in solid greenstone. These dikes were probably formed as a result of the advance of a lava flow over wet sediments. Steam pressure and the weight of the overlying lava forced the soft unconsolidated sediments up into cracks in the abruptly chilled lava at the base of the flow, and formed a network of sedimentary dikes. On polished surfaces the greenstone is dark green and very fine grained for a few millimeters away from the contact with the sedimentary rocks, whereas farther away it is greenish gray and coarser grained. The

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Figure 10. Amydules in Greenstone.

Upper photograph: Amygdules in outcrop on the north side of Skyline Drive at mile 40.9 about 0.3 mile west of Thorofare Mountain Overlook. The fillings consist of an outer rim of white albite (ab) and a core of gray quartz (Q) and yellow-green epidote (E). Elongation of the amygdules is probably due to deformation of the original gas bubbles during flowage of the still viscous lava.

Lower: Photomicrograph of thin section of chlorite-filled amygdules in the lower porphyritic flow north of Big Meadows. The amygdules are filled with quartz (Q) and chlorite (ch). As the lava cooled, the original gas bubbles were partly filled with material that was later altered to chlorite. The remaining bubble at the top of each of the original cavities was later filled with quartz. The section shows the microscopic texture of the greenstone (crossed nicols). The randomly oriented rudely rectangular laths are plagioclase; now they are albite, but originally they were probably labradorite. The material between them is now chiefly chlorite and epidote, probably derived from original pyroxene or volcanic glass. This texture is typical of unmetamorphosed basalts, although none of the original minerals remain.

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Figure 11. Sandstone dikes in greenstone. Outcrop is on the north side of Skyline Drive at mile 47.3 on the south side of Hawksbill Mountain. Sandstone (light gray in photograph) displays faint subhorizontal bedding. Greenstone (darker gray) displays a dark chloritic border at edge of dike. Arrows show direction in which dike was emplaced. Knife is about 3 inches long.

dark fine-grained border probably represents a thin selvage of glass that formed when the lava came in contact with the wet sediments, but the glass has been altered to a dense, fine-grained aggregate consisting mostly of chlorite.

Flow breccias

Flow boundaries are generally marked by zones of breccia as much as 20 feet thick containing fragments of amygdaloidal greenstone, purple phyllite, and red or pink sandy argillite. Angular fragments of specular hematite are common in some of the breccias. The most common types of breccia are epidote-amygdaloid breccia and mud-lump breccia. The epidote-amygdaloid breccia (fig. 12) is composed of angular or irregular rounded fragments of purple, red, or blue-gray amygdaloidal greenstone set in a matrix of fine-grained greenstone, quartz, and epidote. The amygdules are filled with milky quartz and epidote. Fragments range from 2 inches to several feet across. This breccia probably represents a frothy crust that formed on the lava flow and was broken up by further movement of the still-liquid lava beneath. Because of easy access along these zones, hydrothermal solutions, have almost completely replaced the breccias with epidote and quartz.

The mud-lump breccias consist of angular or subangular fragments of pink or reddish-brown sandy argillite or sandstone in a matrix of fine-grained schistose greenstone or silvery phyllite, and they contain only minor amounts of epidote (fig. 13). On slightly weathered surfaces the mud lumps stand out in relief. Most are dense very fine grained pink or red rocks whose sedimentary character is not apparent except where thin sandy stringers are present or where

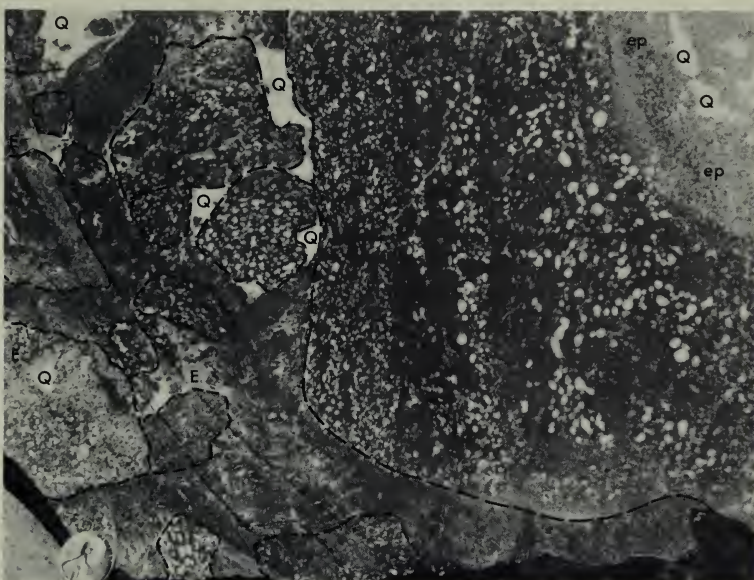

Figure 12. Sawed slab of amygdaloid breccia.

Slab is from outcrop on south side of road about 500 feet southeast of Big Meadows Lodge. The angular blocks (some of which are outlined with dashed lines in the photograph) are probably pieces of frothy lava crust that formed at the top of the flow. The crust was broken by continued movement of the still-molten lava beneath, and jumbled pieces were rafted along and were eventually frozen in place when the flow came to rest and solidified. During later metamorphism the amygdules and some of the interstices between the blocks were filled with white quartz (Q) and yellow-green epidote (E). Locally, part of the rock has been altered to epidosite (ep), a fine-grained light-green aggregate of epidote and quartz. The arcuate lines in the lower left part of the photograph are marks left by the saw when the specimen was cut. Specimen collected by Professor Ernst Cloos, The Johns Hopkins University. Photograph by J. P. Owens, U.S. Geological Survey.

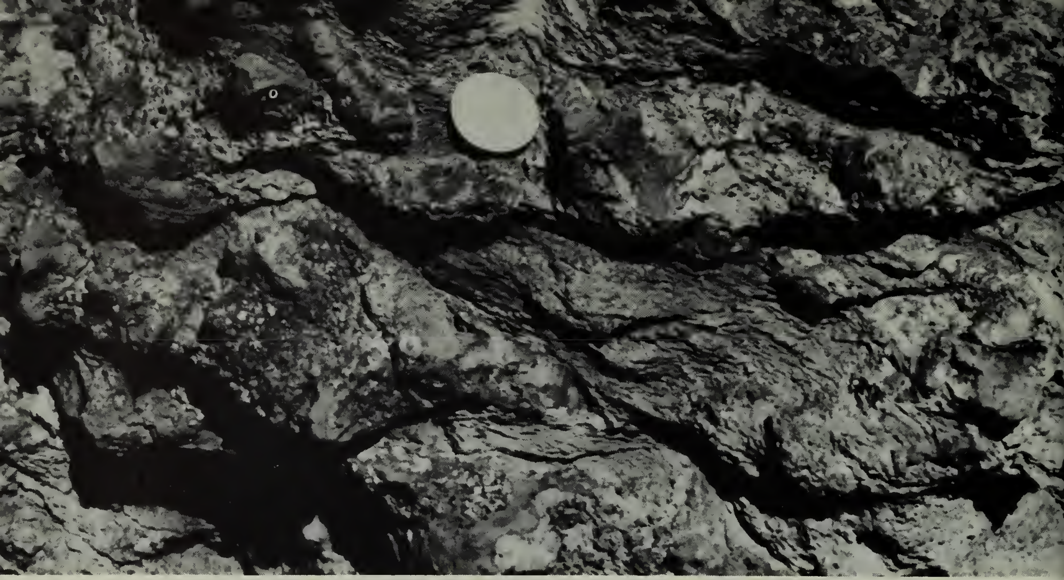

Figure 13. Mud-lump breccia in outcrop along Appalachian Trail at north end of the base of Little Stony Man Cliffs. Lumps of hard red argillite stand out as knots on the weathered surface. Light-gray streaks are irregular wisps of silvery phyllite. Matrix is fine-grained schistose greenstone.

there is a gradation from sandstone into red argillite containing scattered sand grains. The mud lumps may be pieces of a thin soil mantle or sedimentary layer formed on top of one flow and later churned into the base of the next flow. The red mud which formed the bulk of the sedimentary material probably was derived from weathering of underlying lava; the sand grains, mostly quartz, must have come from an outside source, probably some nearby granitic hill still unburied by lava. The silvery phyllite may represent tuffaceous material. In a few places thin layers of material similar to the mud lumps are found undisturbed between flows, possibly indicating old soil horizons.

PETROGRAPHY AND MINERALOGY OF THE FLOWS

Feldspar laths, chlorite, and epidote are seen with a hand lens in coarse greenstone, but in the fine-grained greenstone none of the rock minerals can be identified without a microscope. Native copper occurs in minute flakes at a few localities.

Some flows contain scattered phenocrysts of plagioclase, but phenocrysts are rare at most localities. The two porphyritic flows contain plagioclase phenocrysts as much as 1 centimeter long (fig. 14); the phenocrysts make up as much as 30 percent of the rock. On freshly broken surfaces the phenocrysts may be obscure, but they weather bone white and are conspicuous on slightly weathered surfaces. The unusual porphyritic texture of these flows has made it possible to distinguish them from the other flows in the lava sequence and to trace them for considerable distances.

The greenstone is commonly cut by veinlets of quartz and epidote which are also the typical minerals in the amygdule fillings. In many places the greenstone has been completely replaced by epidote and quartz and forms a hard yellowish-green rock. The epidote-quartz rock is characteristically cut by narrow, nearly horizontal gash fractures containing quartz and fibrous anthophyllite. The veins are generally only a few millimeters thick, but are as much as several centimeters thick at a few localities.

The epidote-quartz rock occurs in large pods and irregular masses associated with epidote-quartz veinlets. The contact of these masses with the normal greenstone may be sharp, in which case it is usually a joint plane, or is gradational for several inches. Where this type of alteration has occurred, amygdules and plagioclase phenocrysts have been replaced by quartz.

Minor amounts of native copper are found in the greenstones of the Catoctin Formation, and unsuccessful attempts at copper mining were made at several localities. Two prospects within the area were worked in 1854–56 and are described briefly by Weed and Watson (1906). One of these, just north of the summit of Stony Man, was opened by a shaft of unknown depth which has now been filled. The other prospect is on the ridge north of the confluence of the Rose River and Hogcamp Branch in the zone of northwest-trending cleavage which is believed to mark the Rose River cross fault. Its workings comprise a few shallow prospect trenches and a shaft that is flooded to the surface. Judging from the size of the dump, the prospect is only a few feet deep.

Figure 14. Sawed slab of porphyritic greenstone.

Slab is from outcrop on south side of Skyline Drive at mile 80.9, about 100 yards east of Big Run Overlook in the southern section of the park (south of area described in this report). Angular to slightly rounded phenocrysts of plagioclase (now albite) occur in matrix of finer grained albite, chlorite, and epidote displaying relict basaltic fabric. The phenocrysts in this specimen are somewhat larger than those in the porphyritic flows in the Big Meadows-Stony Man Area, but the texture is typical. Specimen collected by Professor Ernst Cloos, The Johns Hopkins University. Photograph by J. P. Owens, U.S. Geological Survey.

In thin section, the chief minerals of the normal greenstone are seen to be chlorite, actinolite, epidote, albite, magnetite, specular hematite, sphene, and pyroxene. Small amounts of quartz and calcite are also common. Only the pyroxene and part of the magnetite are believed to be primary minerals of the original lava.

Where the greenstones are not sheared the texture is that of the original lava (fig. 10, photomicrograph). The rock consists of interlocking plagioclase laths (now albite) in an interstitial mat of chlorite, actinolite, epidote, sphene, leucoxene, and magnetite. Original pyroxene grains are common between the laths in some specimens, but in most of the finer grained rocks the pyroxene is almost completely altered. This texture suggests the typical basaltic textures in which the spaces between the plagioclase are filled with either granular crystals of pyroxene or basalt glass. Large irregular patches of chlorite are fairly common in the greenstone.

In the sheared or more schistose greenstone the original texture has been destroyed, and the rock consists of actinolite needles and equidimensional grains of epidote, sphene, and opaque minerals set in a chloritic matrix. Small irregular grains of plagioclase are generally present.

Where the greenstone is completely replaced by epidote and quartz, these secondary minerals form equal-sized grains. Under the microscope, the basaltic fabric may still be seen and is almost perfectly preserved. Feldspar laths are entirely replaced by fine-grained aggregates of quartz, and the interstitial minerals are replaced by epidote and quartz. Outlines of amygdules are preserved, but their fillings have been replaced by mosaics of fine-grained quartz.

DIKES OF GREENSTONE

The granitic rocks underlying the Catoctin Formation are cut by dikes of greenstone ranging from a foot to 50 feet or more in thickness. Most of the dike rocks are fine grained and resemble the greenstones in the flows. Many dikes have columnar joints normal to the walls; some have a faint cleavage parallel to that in the rocks overlying the granitic basement. Most dikes have a thin fine-grained margin, prob-

Figure 15 (above and right). Greenstone dikes in basement rocks. Left photograph: Dike on Ridge Trail, Old Rag Mountain, about 0.4 mile northeast of the summit. Wallrock is Old Rag Granite of Furcron (1934). Right photograph: Dike at west side of north portal of Marys Rock Tunnel, mile 32.1, Skyline Drive. Wallrock is granodiorite.

ably caused by chilling against the walls. Several dikes on Old Rag Mountain contain crystals of plagioclase as much as 1 centimeter across.

Good examples of these dikes are found along the Skyline Drive in the roadcut north of Shavers Hollow parking area where at least six crop out within a distance of 1,500 feet.

Several large dikes, one of them 50 feet thick, and many smaller ones cut through the granite near the summit of Old Rag Mountain; they are less resistant to erosion than the granite and form deep notches in the summit ridge (fig. 15, left photo). A dike 15 feet thick with columnar jointing is exposed at the north end of the tunnel on Skyline Drive about three quarters of a mile south of Thornton Gap (fig. 15, right photo). The attitude of the dikes is generally difficult to determine precisely, but most strike north and dip between 65° E. and 65° W.

The greenstone in the dikes is composed of pyroxene and plagioclase in a mat of secondary chlorite and minor amounts of calcite, quartz, and epidote. Chlorite replaces plagioclase in many places and isolated rounded grains of pyroxene are left in a chloritic mat.

PURPLE VOLCANIC SLATE

In most places the Catoctin Formation and the overlying Chilhowee sedimentary rocks are separated by a thin layer of purple, reddish- or chocolate-brown volcanic slate which is spotted with tiny white circles or ovals and which has been described by Furcron and Woodward (1936) as a basal Cambrian lava flow. King (1950) mapped the slate in the Elkton area as the Loudoun Formation and considered it to be composed of detrital materials that were explosively ejected from a volcanic vent. This rock underlies the Chilhowee sedimentary rocks that cap Chapman Mountain; it crops out in a narrow belt west of Lucas Gap on Tanners Ridge and crops out discontinuously along the upper contact of the Catoctin at least as far north as Knob Mountain, north of Jeremys Run. The slate averages 50 to 100 feet in thickness but locally reaches 200 feet. North of Beahms Gap it is absent in several places, and the lower beds of the Chilhowee Group rest directly on greenstone of the Catoctin Formation. Furcron and Woodward (1936) state that the slate "has been found * * * above granodiorite in the absence of any greenstone—a fact that strongly suggests that the extrusive [slate] is later or younger than either the greenstone or granodiorite."

Under the microscope the rock commonly shows rectangular laths, probably representing original plagioclase that is now completely replaced by sericite, in a matrix of sericite and dark opaque material. Scattered throughout the rock are green chlorite clots, and small wedge-shaped crystals of sphene are common. A few unaltered remnants of pigeonite occur. The spots, which range from 1 to 2 millimeters in diameter and appear white in the hand specimen, are dark and nearly opaque in thin section. They are oval in general plan, but in detail their boundaries are highly irregular and spongelike. They include sericitized plagioclase laths, some of which extend across the boundaries of the spots. Where shearing has destroyed or modified the fabric of the rock as a whole, the replaced plagioclase laths within the spots preserve a basaltic texture.

Field relationships and petrography suggest that the slate is a metamorphosed saprolite (weathered residual rock) developed at the top of the Catoctin Formation before deposition of the overlying sediments. Where the weathered material was reworked during deposition of the basal bed of the Chilhowee, the volcanic texture was lost, but where the saprolite was not disturbed the texture is locally preserved.

Thin layers of similar slate and purple argillite lie between flows in the greenstone of the Catoctin, and veinlets of jasper with detrital sand grains penetrate the greenstone near the tops of some flows. Weathering of basalts commonly leads to the formation of similar jasper veinlets. King (1950) reports jasper masses in the slate in the Elkton area.

That the slate immediately overlies the granitic rocks in a few places may merely indicate that a thin Catoctin flow was completely weathered in place before deposition of the Chilhowee beds.

ORIGINAL NATURE OF THE CATOCTIN LAVAS

The volcanic nature of the greenstones of the Catoctin Formation has long been recognized, but little has been published concerning the original composition of the Catoctin lavas and their mode of eruption. Most authors agree that the bulk of the lavas were basalts, although Bloomer and Bloomer (1947) concluded that the lavas were andesites on the basis of the composition of the plagioclase, which they reported as being andesine. Determinations by the writer, however, indicate that the plagioclase is albite. Conclusions about the original character of the Catoctin lavas, however, cannot reasonably be based on the present composition of the plagioclase. Relic textures strongly indicate that the lavas were basalts, and this conclusion is supported by the mineralogy of the rocks and by the available chemical analyses (Reed, 1964).

The Catoctin lavas probably were plateau basalts erupted from fissures in the basement rocks. The thickness and extent of the flows, absence of known central volcanoes, and flood-like character agree with the characteristics of plateau basalt accumulations.

The association of the greenstone of the Catoctin with the sedimentary rocks of the Appalachian geosyncline brings up the question of its relationship to albite-bearing (spilitic) lavas so characteristic of the early stages of many geosynclines. Although the origin of the albite in basalt has been much debated, many recent authors agree that it is secondary because partially replaced labradorite cores are common in some of the albite crystals and because albite and pyroxene would probably not crystallize simultaneously from a magma (Gilluly, 1935).

The greenstone of the Catoctin is similar to some spilites in certain respects, but it differs from them in other important features. First, the Catoctin flows were clearly erupted on land as is shown by the presence of columnar jointing, absence of pillow structure, areal extent of individual flows, and relatively thin breccia zones between flows, while spilites are typically erupted under water and show well-developed pillow structure. Second, spilities are characteristically associated with great thicknesses of graywackes and bedded cherts containing occasional limestone lenses, whereas the sedimentary members of the Catoctin Formation are insignificant and are arkoses derived from local sources in the nearby granitic rocks. Third, there is no evidence that the albite and other secondary minerals were formed during or immediately following consolidation of the flows. Alteration did not occur until after soil zones had formed and the overlying sedimentary rocks were deposited. For these reasons the mineralogy of the Catoctin greenstone can best be explained as the result of low-grade regional metamorphism of an accumulation of plateau basalts without important change in the bulk composition (Reed, 1964).

Conclusions

The Catoctin Formation unconformably overlies the granitic basement rocks in the Luray area and is not intruded by them as was suggested by some earlier workers. The basaltic Catoctin lavas poured out on land over an erosion surface of considerable relief. The lava drowned the valleys and, at least in the earlier stages of the volcanic activity, flowed around and isolated hills of granitic rocks. Several thousand feet of lava flows, volcanic ash, and sedimentary material accumulated before volcanic activity ceased and the entire area was submerged beneath the sea in which the sedimentary rocks of the Chilhowee Group were deposited. A period of weathering which formed a saprolite as much as 150 feet thick may have followed the end of Catoctin volcanism, but no proof of a major unconformity between the Catoctin and the Chilhowee has been found.

The greenstone of the Catoctin Formation is sometimes mentioned as marking volcanic activity associated with the early stages of formation of the Appalachian geosyncline (Bucher, 1933). The present study indicates, however, that the Catoctin lavas resemble basalt accumulations characteristic of stable areas and that they should not be considered as belonging to the Appalachian geosynclinal cycle. The Catoctin greenstones are probably remnants of a great basaltic plateau which foundered beneath the advancing Early Cambrian seas during the initial stages of formation of the Appalachian geosyncline.

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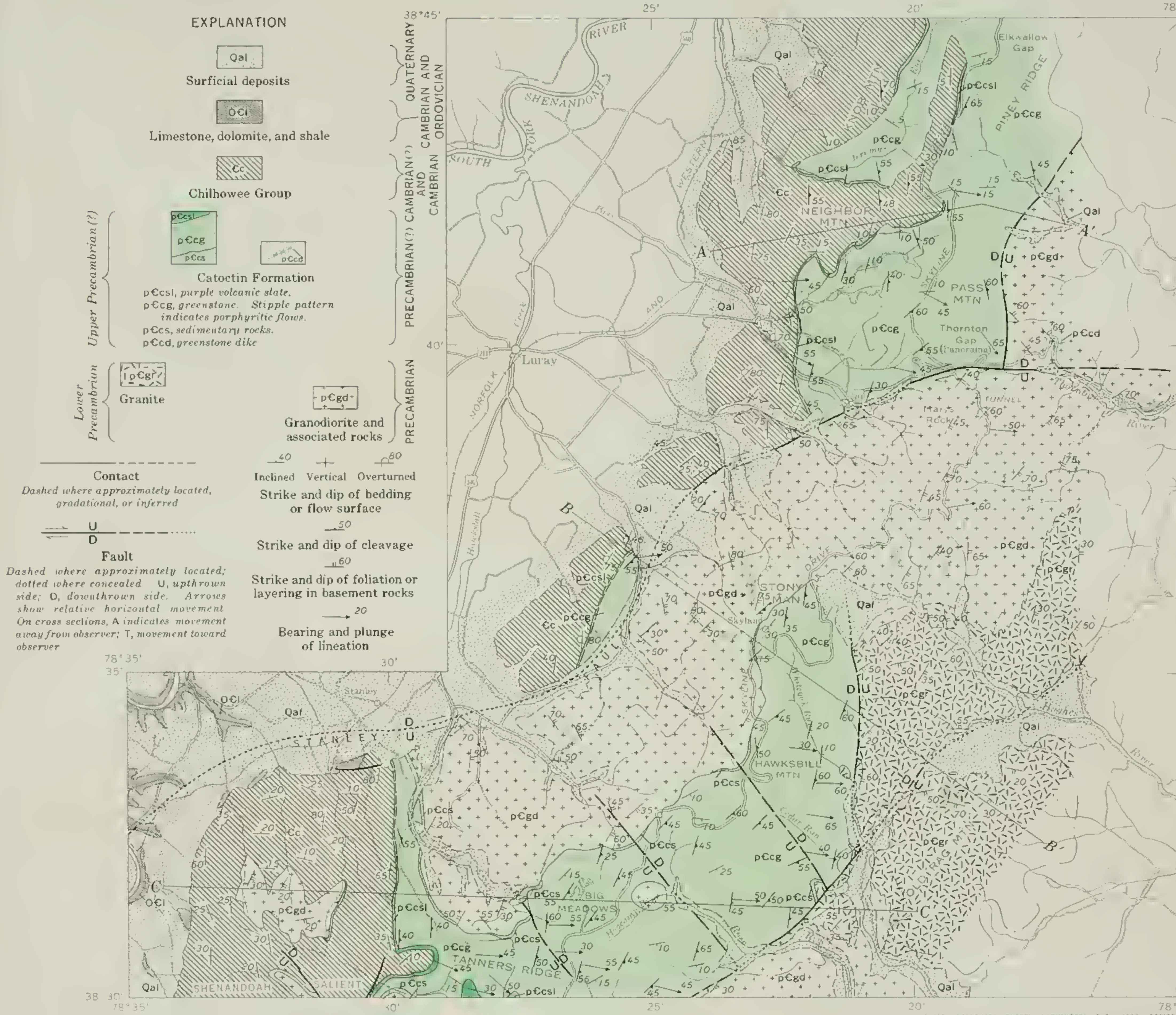

Base modified from U.S. Geological Survey 1:24,000 series Luray, 1965, Thorton Gap, 1965, Big Meadows, 1964, Old Rag Mountain, 1965, and Mount Jackson (1:62,500), 1942

Generalized from Reed (1955) with modifications and additions from King (1950) and Allen (1963)

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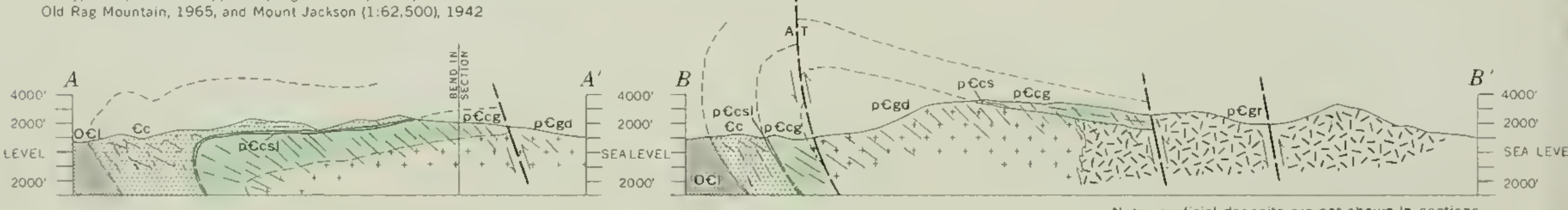
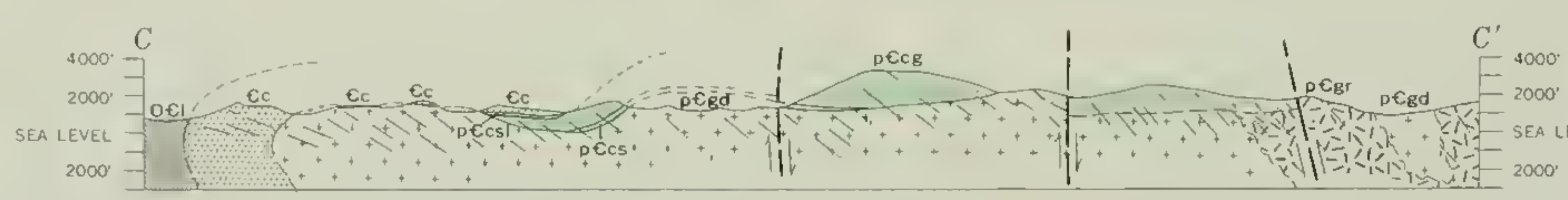


Note: surficial deposits are not shown in sections



GEOLOGIC MAP AND SECTIONS OF THE BLUE RIDGE NEAR LURAY, VIRGINIA

SCALE 1:125 000

2 0 2 4 6 MILES

2 0 2 4 6 KILOMETERS

Reed—ANCIENT LAVAS IN SHENANDOAH NATIONAL PARK NEAR LURAY, VIRGINIA—Geological Survey Bulletin 1265

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