Geology of the Elkton area Virginia

GEOLOGICAL SURVEY PROFESSIONAL PAPER 230

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By PHILIP B. KING

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A detailed report on an area containing interesting problems of stratigraphy, structure, geomorphology, and economic geology

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GEOLOGY OF THE ELKTON AREA, VIRGINIA

By Philip B. King

ABSTRACT

The Elkton area lies in eastern Rockingham and southern Page Counties, Virginia, and includes the northwestern edge of the Blue Ridge and the southeastern edge of the Appalachian (or Shenandoah) Valley.

The rocks of the Elkton area include indurated rocks of pre-Cambrian, Cambrian, and Ordovician ages, and unconsolidated deposits of Cenozoic age. The indurated rocks have an aggregate thickness of about 15,000 feet. The oldest rocks occur in the Blue Ridge to the southeast, and successively younger rocks underlie the Shenandoah Valley to the northwest. The youngest indurated rocks near Elkton crop out in Massanutten Mountain, northwest of the area mapped.

The pre-Cambrian rocks, which occur mainly in the Blue Ridge, consist of an older injection complex, overlain unconformably by a thin sedimentary unit (Swift Run formation) and by a thick mass of lava flows (Catoctin greenstone). The pre-Cambrian rocks are overlain unconformably by sandstones, shales, and quarzites of Early Cambrian age (Chilhowee group), which form the outer foothills of the Blue Ridge. These are overlain in turn by limestones, dolomites, and some interbedded shales of Early Cambrian to Middle Ordovician age (Tomstown dolomite, Waynesboro formation, Elbrook dolomite, Conococheague limestone, Beekmantown dolomite, and limestones of Middle Ordovician age). These rocks underlie the southeastern part of the Shenandoah Valley. Northwest of the area mapped, the limestones are overlain by shales of Middle and Late Ordovician age (Martinsburg shale) and finally by sandstones of Silurian age which form the crests of Massanutten Mountain. Small dikes and sills of igneous rock occur at a few places in the area and are probably of Triassic age.

The Elkton area is within the Appalachian Mountains, and most of its structural features are characteristic of that region, and are probably of the late Paleozoic age. The Elkton area lies between the crest of the Blue Ridge-Catoctin Mountain anticlinorium to the southeast and the trough of the Massanutten synclinorium to the northwest. The structure is broadly homoclinal, with the younger formations succeeding the older toward the northwest. The homoclinal structure of the Elkton area has been modified by folding, flexing, and, to a certain extent, by faulting. However, in contrast to some other parts of the Appalachians, major overthrusts are lacking. The most conspicuous modifications of the homocline in the Elkton area are a broad upwarp and downwarp extending across the strike of the rocks—the Shenandoah Salient and Elkton Embayment. In the salient, the foothills of the Blue Ridge extend farther northwest into the Shenandoah Valley than elsewhere; in the embayment, the valley extends farther southeast into the foothills than elsewhere.

Overlying the pre-Cambrian and Paleozoic rocks of the Elkton area are residuum and various unconsolidated deposits that accumulated during the Cenozoic era. Most of these materials occur on the floor of the Shenandoah Valley. Of them, the oldest is the residuum, a mass of clay and other insoluble material left after the leaching and decay of the Cambrian and Ordovician limestones, dolomites, and shales. It probably accumulated during the time of formation of the Valley Floor peneplain, under humid conditions, and is of Tertiary age. The residuum is overlain unconformably by a succession of gravel deposits, laid down on several surfaces that stand above the level of present drainage. These deposits and surfaces were formed during a time of alternating dry and moist climates, and are probably of Pleistocene age. Coarse talus deposits that occur on the mountainsides are probably also of Pleistocene age. The youngest unconsolidated deposit is the alluvium along the South Fork of the Shenandoah River and its tributaries.

The Elkton area contains deposits of iron, manganese, ocher, building stone, and limestone. The only deposits that have been mined extensively are the iron and manganese ores. Iron ore was mined in the area almost continuously between 1836 and 1905, during which period it is estimated that about 350,000 tons of concentrates were produced. Manganese ore and manganiferous iron ore were mined intermittently between 1884 and 1941, during which period it is estimated that about 23,000 tons of concentrates were produced.

No systematic estimates of reserves of iron or manganese ore in the area can be made. The iron ore of the area was rather thoroughly exploited before 1905; it is probable that all the rich deposits for which there were obvious surface indications, or which were indicated by prospecting during that period, have now been mined out. The manganese deposits have been exploited on a smaller scale, and a number of rich deposits that were discovered by surface indications or by prospecting have been mined out. Other deposits may exist, but, if so, there are no surface indications of their presence.

The ores consist of iron and manganese oxides in residuum of the Tomstown and Waynesboro formations, and occur in irregular bodies of small to large size. The iron and manganese oxides were probably concentrated from original carbonate minerals disseminated in the bed rock. The ore bodies were formed nearly contemporaneously with the formation of the Valley Floor peneplain and the accumulation of the residuum, and are older than the gravel deposits that overlie the residuum.

INTRODUCTION

The district here termed the Elkton area is in eastern Rockingham and southern Page Counties, Virginia, and includes the northwestern edge of the Blue Ridge and the southeastern edge of the Appalachian (or Shenandoah) Valley (fig. 1). The district includes a small strip of the northwestern part of Shenandoah National Park. It lies mostly in the Elkton and Mount Jackson 15-minute quadrangles, but includes small parts of the

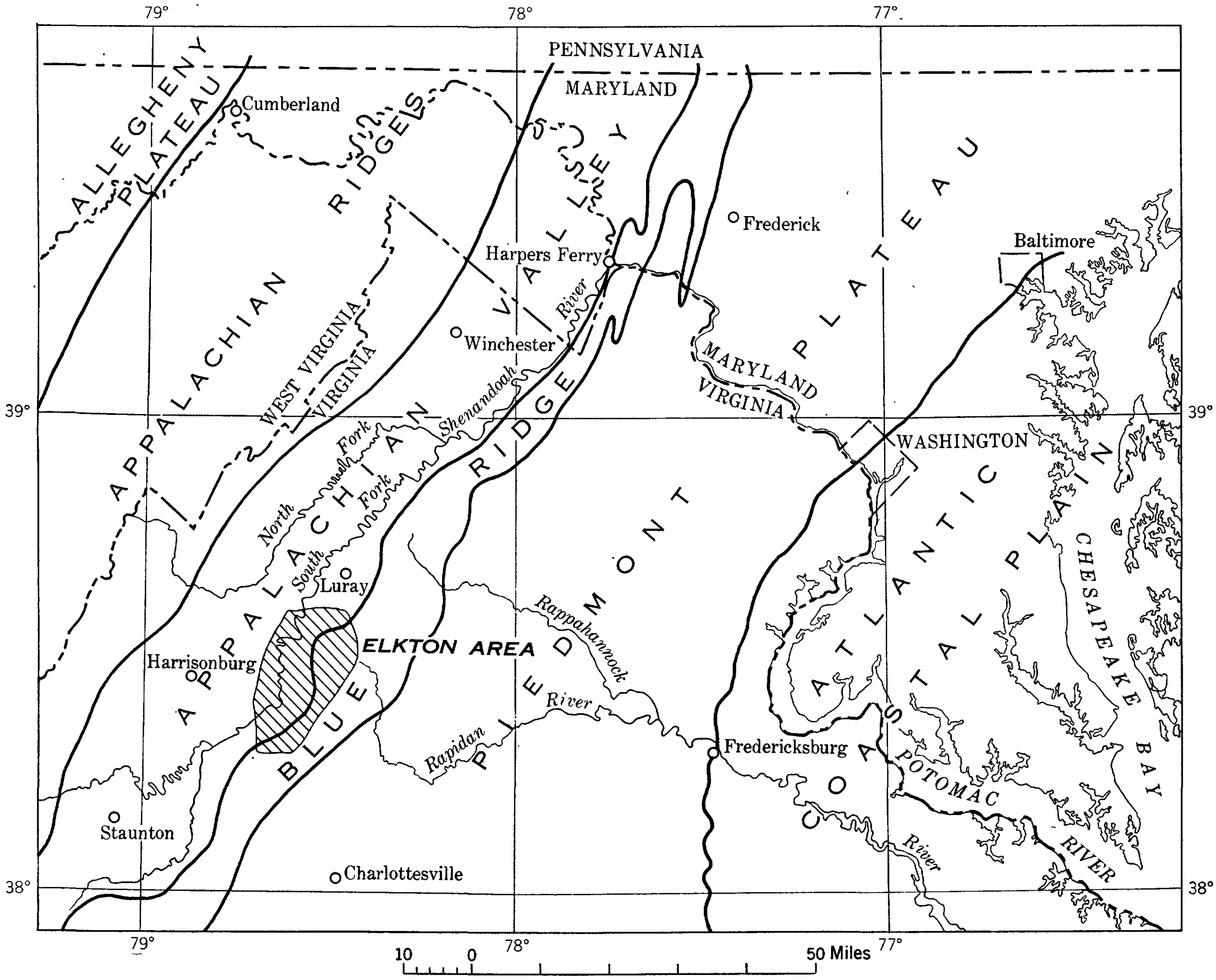

FIGURE 1.—Index map of northern Virginia and parts of adjacent States, showing physiographic provinces, and location of Elkton area.

Stony Man and Madison quadrangles. The district forms a belt that extends for 20 miles along the strike of the rocks, and from 5 to 8 miles across the strike, or from the pre-Cambrian rocks of the Blue Ridge to the base of the Martinsburg shale in the Appalachian Valley.

In the Elkton area large amounts of iron and moderate amounts of manganese ore were produced in the period between 1836 and the end of World War I. During the latter part of the nineteenth century the town of Shenandoah, within the area, was the center of a flourishing iron industry. The history of the area would thus seem to suggest the possibility of the presence of further ore reserves. During World War II the Elkton area was accordingly selected by the Geological Survey as one of those for investigation as a part of the Survey's strategic-minerals program.

The writer was assigned by the Geological Survey to make a geological investigation of the Elkton area, and to report on its manganese resources. The economic results of this investigation have been published as a strategic minerals bulletin. The present report reviews the economic resources at greater length, but also includes many results of general geologic interest that could not be included in the original bulletin.

PREVIOUS WORK

Before the present investigation in 1940 and 1941, no detailed geological survey had been made of the Elkton area, but sufficient general surveys had been made to indicate its broader geologic features. In reports of the first Virginia Geological Survey, between 1835 and 1838, Rogers (1884) described the general geologic conditions along the northwest foot of the Blue Ridge.

One of his structure sections crosses the northern end of the Elkton area, another the southern (Rogers 1884, pls. 7–8, secs. 6, 7); on these, the broader structural features are interpreted in much the same manner as they are today. Other early reports (Hotchkiss, 1878; Prime, 1880; McCreath, 1884) describe the geology of the iron deposits and other mineral resources of the Elkton area.

A report by Keith (1894, pp. 285–395) on the geology of the Catoctin belt north of the Elkton area set forth for the first time many of the fundamental geologic relations of the Blue Ridge-Catoctin Mountain province and has an important bearing on the interpretation of the geologic features of the Elkton area. A paper by Spencer (1897), published at about the same time, describes the geology of Massanutten Mountain northwest of the Elkton area.

During World War I, the Elkton area and other parts of the northwest foot of the Blue Ridge were studied by the Geological Survey (Stose and others, 1919) as a part of its investigation of manganese resources. The geology of the foothill belt was mapped, and individual manganese deposits were examined. The area was also included in the general survey of the Appalachian Valley in Virginia by Butts (1933, 1940). Districts adjacent to the Elkton area have been mapped for the Virginia Geological Survey. The Stony Man quadrangle was studied by A. S. Furcron and H. P. Woodward (1936, pp. 45–51), and Shenandoah National Park by A. S. Furcron (1934, pp. 400–410). Except for brief summaries, these results have not yet been published and were not available to the writer during either the field work or the preparation of this report.

Special features of the geology of the Elkton area have been mentioned by various authors. Manganese and iron deposits of the area have been listed by Watson (1907, pp. 244–245, 250–251, 431–434) and Harder (1910, pp. 56–57). The geology of the manganese deposits in the Neisswaner Shaft, near Elkton, was described by Hewett (1916, pp. 61–67). Ground-water resources of the area were noted by Cady (1936, pp. 82–98) and clay deposits by Ries and Somers (1920, p. 41). The limestone and dolomite resources of the area have been reviewed by Edmundson (1945, pp. 128–152).

Stratigraphic features of the Elkton area have been mentioned by Jonas and Stose (1938b, pp. 575–593) and by Cooper and Cooper (1946, pp. 35–113). Notes on the geomorphology have been given by Wright (1934, pp. 30–31). Gravity features of the area have been discussed by Hammer and Heck (1941, pp. 353–362).

Several publications by the present writer describe special features of the Elkton area. Besides the bulletin dealing with the manganese deposits (1943), papers have been published on the Cenozoic deposits and land forms (1949a) and on the problem of the base of the Cambrian (1949b).

PRESENT WORK

Present field work occupied about 6 months in the autumn of 1940 and the spring of 1941, during most of which time the writer was ably assisted by John Rodgers. Field mapping was done on topographic maps on a scale of 1:24,000. During field work, considerable use was made of air photographs by the Soil Conservation Service. Main attention was given to the Lower Cambrian clastic rocks (Chilhowee group), which form the foothills of the Blue Ridge. The adjacent underlying pre-Cambrian rocks and overlying Cambrian and Ordovician rocks were studied in somewhat less detail, but sufficiently to determine their character and relations.

As a result of the field work, much new information was obtained as to the areal distribution of the formations, their structure, and their stratigraphic relations. Considerable attention was also paid to the geomorphology and to the younger unconsolidated deposits, because of their relation to the occurrence of manganese. Owing to circumstances attending the field work, it was not possible to measure detailed stratigraphic sections, to collect fossils, or to make petrographic studies. At the close of the field work a number of problems were left unsolved that might have been cleared up by restudy of outcrops within the area, or extension of the work into surrounding areas. The results of the study are thus to some extent incomplete. It has not seemed feasible to spend further time on the project, and the results are therefore presented in their orginal form.

At the time of the field work, the United States Bureau of Mines was engaged in prospecting for manganese in two tracts along the northwest foot of the Blue Ridge in the Elkton area. The writer studied the results of their drilling and tunneling operations, and thereby obtained much information on the geology of this foothill area. This information is incorporated in the present report.

ACKNOWLEDGMENTS

Field work was carried on under the direction of D. F. Hewett, G. W. Stose, and H. D. Miser, who had participated in the investigation of manganese deposits in the region during World War I. These geologists joined the writer in a number of field conferences in the area. To Stose, the writer is particularly indebted for aid on stratigraphic problems; he indicated, for example, the proper horizon to be used as a boundary between the Weverton and Harpers formations. Miser

aided greatly in the interpretation of the manganese deposits.

The writer wishes to express his indebtedness to John Rodgers for his excellent field assistance, and for his stimulating discussion of the geologic problems. The geologic map is about equally the work of the writer and of Rodgers. Rodgers has also critically reviewed the manuscript, and has made many suggestions that are incorporated in the text.

The Virginia Geological Survey extended many courtesies. Arthur Bevan, former State geologist, and W. M. McGill, present State geologist, supplied many records and other facilities. Charles Butts spent a day in the field with the writer, in company with Bevan and R. S. Edmundson, and aided him in the discrimination of the Cambrian and Ordovician carbonate formations. The staff of the Bureau of Mines gave full cooperation during the writer's study of their prospecting operations in the area.

Numerous local residents contributed valuable information, especially R. F. Watson of Furnace, who has had long experience in prospecting for maganese in the region.

After the present report was written, the writer discussed the problems of Blue Ridge geology with two geologists who have worked in the region for the Virginia Geological Survey, A. S. Furcron and R. O. Bloomer; the writer has also been guided by Bloomer through parts of the Blue Ridge south of the Elkton area. The writer is grateful to Furcron and Bloomer for these discussions, and regrets that the results can be indicated in the present report only by short notes that were added to it while it was in proof.

GEOGRAPHY

The Elkton area lies partly in the Blue Ridge province and partly in the Appalachian Valley province. (See Fenneman, 1917, pp. 19–98). Its lowest point it at an altitude of 780 feet, on the floor of the valley where the South Fork of the Shenandoah River leaves the area on the north. The highest point is on Grindstone Mountain in the foothills of the Blue Ridge, at an altitude of 2,848 feet. The maximum relief in the area is thus about 2,000 feet. Nearby summits of Massanutten Mountain on the west rise to an altitude of 3,300 feet, and of the Blue Ridge on the east to 4,000 feet, so that the total relief of the region is more than 3,000 feet.

In the vicinity of the Elkton area the Blue Ridge is a single range about 10 miles wide, whose relatively straight, northeast-trending crest forms the divide between the Shenandoah River and Rappahannock River drainages. The ridge consists of high, rounded slopes, with occasional crags and lines of cliffs, and is generally carved from pre-Cambrian igneous rocks. Some of the steeper slopes and high summits are forested, but many are cleared of timber and used for pasture or cultivation. even well toward the summits.

Fringing the northwest base of the Blue Ridge are foothills carved from lower Cambrian quartzites (Chilhowee group). Regarding these foothills, Rogers (1884, p. 204) has written that:

> the sandstone of Formation I is occasionally met with high up upon the flanks of the Blue Ridge, * * * but throughout the greater part of its course we meet with the eastern limits of this formation much nearer to the base of the mountain. When lying upon the higher points of the declivity, its white siliceous strata form a conspicuous object in the scene, spreading downward to the valley with a western dip, at first gentle, but rapidly augmenting in steepness, until along the mountain base, or a little farther west, the highest strata of this formation are seen passing from their western dip into the vertical, and thence into an eastern and obviously inverted inclination. The latter attitude is that most commonly observed in the innumerable rocky passes by which the traveler obtains access to the main Blue Ridge.

The foothills form ridges that are generally sharper than those of the main Blue Ridge. Many of them have the form of cuestas or hogbacks, whose dip slopes (as recognized by Rogers) extend toward the Appalachian Valley to the northwest. In contrast to the main slopes of the Blue Ridge, the quartzite foothills are almost everywhere forested.

In the northern part of the Elkton area, the foothills project in a conspicuous salient near the town of Shenandoah. This feature is both topographic and structural and may appropriately be termed the Shenandoah Salient. Along the salient, the foothills in places extend to within a mile of the South Fork of the Shenandoah River, and to within 4 miles of Massanutten Mountain. The salient thus causes a conspicuous restriction in the southeastern branch of the Shenandoah Valley. North of the salient, and lying mostly north of the Elkton area, the foothills recede to the southeast, forming a broad lowland known as the Page Valley. South of the salient, in the vicinity of Elkton, the foothills likewise recede to the southeast, forming an embayment in the mountain front. Like the salient, this is both a topographic and a structural feature, and may be termed the Elkton Embayment.

In the region of the Elkton area, the Appalachian Valley, or Shenandoah Valley, is split into a southeastern and a northwestern part by the high, sharp-crested ridges of Massanutten Mountain. The northwestern part is drained by the North Fork of the Shenandoah River, and the southeastern part by the South Fork of the Shenandoah River. Massanutten Mountain is a synclinal area of Silurian sandstones, younger than the bedrock of the valley. The mountain ridges have a characteristic canoe-shaped form, and the southwesternmost ridge ends abruptly in a sharp peak west of the south end of the Elkton area, and north of the road from Elkton to Harrisonburg. Like the ridges of Lower Cambrian quartzite to the southeast, these ridges of Silurian sandstone are densely forested.

The southeastern branch of the Shenandoah Valley, within the area of this report, is a complex of gently sloping surfaces extending from the foothills of the Blue Ridge on the southeast and of Massanutten Mountain on the northwest to the axial stream in the center, the South Fork of the Shenandoah River. Regarding the sloping surfaces on the Blue Ridge side, along a line of section through the similar Waynesboro area to the south, Rogers (1884, p. 92) writes:

> The sectional line crossing this region * * * commences at a distance of 2 or 3 miles from the western base of the Blue Ridge, this being the position at which the rocks of the valley first become apparent. Of the character of the beds comprised on this interval we have no data enabling us to speak with certainty, inasmuch as the fragments of sandstone derived from the broken strata of that range, piled upon the subjacent beds of the valley, entirely conceal them from observation. * * * Future observations throughout this curious district are indispensable to an understanding of the true relation existing between the formations bounding it on either side, and will accordingly present subjects of geological, and even of practical interest in the prosecution of more detailed research.

Within the Elkton area, the valley surface consists of a series of flat-topped terraces or benches, rising steplike toward the mountains, and heavily mantled (as indicated by Rogers) by waste from the mountains on either side. The terraces are trenched to depths of 100 feet or more by lateral streams draining out of the mountains to the axial stream in the center. Along the latter, in the Elkton Embayment, are wide areas of alluvium; narrower strips of alluvium also extend up the valleys of some of the lateral tributaries. Farther north, near the Shenandoah Salient, the river is more deeply incised and the alluvium is narrower. In this area the river flows in a series of tightly looped, incised meanders.

The bed rock that underlies the valley is only intermittently exposed. Most of the rocks of the valley are Cambrian and Ordovician limestones and dolomites, but there is a thick body of shale, the Martinsburg, to the northwest. Besides being mantled by gravel washed from the mountains, the limestones and dolomites are in places deeply covered by residual clay produced by their own decay. The most extensive limestone and dolomite outcrops are in the deeply dissected area west of the Shenandoah Salient. However, sinkholes are common features in the valley, not only in the outcrop areas but in the gravel and clay areas, and are produced by solution and underground drainage in the limestone and dolomite bedrock.

Most of the surface of the Shenandoah Valley in the Elkton area is cleared and cultivated. Timber remains only in patches, mostly on the steeper valley slopes.

Historically, the Elkton area is of interest as probably being the first section of the Shenandoah Valley that was reached by the English colonists. In 1716, Governor Alexander Spotswood ascended Swift Run Gap on the Blue Ridge from the southeast, and beheld for the first time the great valley beyond the mountains.[1] This incident is commemorated by a monument at the gap, and by the name Spotswood Trail, applied to U. S. Highway 33, which extends through Swift Run Gap to Elkton and Harrisonburg.

The Elkton area was formerly the scene of mining, tanning, and lumbering activity. The chief center of iron mining was the town of Shenandoah, but mining was also carried on for many years near Elkton, and on a smaller scale elsewhere in the area. As with iron-mining operations elsewhere in the Appalachians, work ceased with depletion of reserves, and as a result of unfavorable competition with larger-scale operations elsewhere. The tanning industry formerly centered at Elkton, but like mining it is now moribund. Both mining and tanning depended to a large degree on timber resources in the nearby mountains—the mining for charcoal for the early furnaces, and the tanning for raw material for tanning fluid. Most of the timbered areas are now included in Shenandoah National Park, so very little lumbering is being carried on today.

At the present time the Elkton area is predominantly a farming community. The wide areas of rich cultivated land in the Shenandoah Valley are owned and farmed mainly by the people of Pennsylvania Dutch ancestry. The smaller and less productive farms of the foothills and the slopes of the Blue Ridge are farmed mainly by people of English or Scotch ancestry. The town of Shenandoah draws its income mainly from the Norfolk & Western Railway, which maintains shops and other installations there. Since 1941 Elkton has been the seat of the Stonewall plant of Merck & Co., an example of one of the newer industrial developments of the Shenandoah Valley.

The Elkton area is traversed by several main highways. U. S. Highway 33 (the Spotswood Trail) runs from east to west through Elkton, and crosses the Blue Ridge at Swift Run Gap. State Highway 12 runs from north to south along the Shenandoah Valley, through Shenandoah and Elkton. Secondary roads,

[1] Encyclopaedia Brittanica, 14th ed., vol. 21, p. 262. 1929.

which are well maintained and in part hard surfaced, extend into all parts of the area, making them readily accessible by automobile.

STRATIGRAPHY

The rocks of the Elkton area include indurated rocks of pre-Cambrian, Cambrian, and Ordovician ages, and unconsolidated deposits of Cenzoic age. The indurated rocks have an aggregate thickness of about 15,000 feet and have been greatly deformed. The oldest rocks occur in the Blue Ridge to the southeast, and successively younger rocks underlie the Shenandoah Valley to the northwest (pl. 1). The youngest indurated rocks near Elkton crop out in Massanutten Mountain, northwest of the area mapped.

The pre-Cambrian rocks, which occur mainly in the Blue Ridge, are largely of igneous origin, but include some sedimentary rocks. They are overlain by sandstones, shales, and quartzites of Early Cambrian age, which form the outer foothills of the Blue Ridge. These are succeeded in turn by limestones, dolomites, and some interbedded shales of Early Cambrian to Middle Ordovician age. As a result of weathering, the limestones and dolomites are in many places blanketed by a mass of residual material and are thus poorly exposed. Northwest of the area mapped the Middle Ordovician rocks are overlain by shales of Middle and Late Ordovician age, and finally by sandstones of Silurian age which form the crests of Massanutten Mountain.

The unconsolidated rocks of the area consist of gravel, sand, and clay that overlie the indurated rocks of the Shenandoah Valley. Such deposits are being laid down today by the South Fork of the Shenandoah River and its tributaries on their valley floors. Other deposits were laid down during several periods in the past on higher and older valley floors that have been deeply dissected by present drainage. Many of these deposits are probably of Quaternary age. The unconsolidated rocks are not described under the heading of "Stratigraphy", but under "Cenozoic deposits and land forms."

The table below summarizes the stratigraphic sequence in the area.

Geological formations of the Elkton area

Age		Name	Character	Thickness in feet
Quaternary	Recent	Alluvium (Qal)	Gravel, sand, and clay; on flood plains of present streams.	0–100
	Pleistocene	Talus (Q t)	Angular quartzite blocks, forming talus fields on foothills of Blue Ridge.	0–50
		Gravel deposits (Qg1, Qg2, Qg3)	Gravels, composed of pebbles and boulders, mainly of quartzite, grading into coarse, thick fanglomerate at edges of mountains. Laid down on three terraces or benches on floor of Shenandoah Valley; oldest unit on highest bench, intermediate and younger units on successively lower benches.	0–250
Tertiary		Ancient gravel unit.	Sand and gravel, unconformable below older gravel deposit. Present only in small areas and not mapped.	0–50
Triassic (?)		Intrusive igneous rocks. (R̄i)	Basic igneous rock, in dikes and sills near Elkton, on Long Ridge, and near Humes Run.	
Silurian		Sandstones of Silurian age.	Sandstone and quartzite in thin to thick beds; forms crest of Massanutten Mountain northwest of area mapped.	500
Ordovician	Middle and Upper	Martinsburg shale. (Om)	Shale and sandy shale; only basal part mapped.	2,800
	Middle	Limestones of Middle Ordovician age. (Olm)	Mostly dark-gray limestones; not subdivided.	200

Geological formations of the Elkton area—Continued

Age		Name		Character	Thickness in feet
Ordovician	Early	Beekmantown dolomite (Ob).		Thick-bedded dolomite, with some limestone. Includes Chepultepec limestone, undifferentiated, at base.	3000
Cambrian	Late	Conococheague limestone (Ꞓc)		Thick-bedded limestone, in part with agrillaceous and sandy beds; some dolomite.	2000
Cambrian	Middle and Late	Elbrook dolomite (Ꞓe).		Thin-bedded dolomite.	3000
Cambrian	Early	Waynesboro formation (Ꞓwy)		Red and brown shale, calcareous shale, and siltstone; some limestone.	1700
Cambrian	Early	Tomstown dolomite (Ꞓt)		Dolomite, argillaceous dolomite, and interbedded shale. Rarely exposed; generally represented at surface by residual clay.	1000
Cambrian	Early	Chilhowee group	Antietam quartzite (Ꞓau, Ꞓal)	Upper member of brown sandstone with some quartzite beds.	400
Cambrian	Early	Chilhowee group	Antietam quartzite (Ꞓau, Ꞓal)	Lower member of white, thick-bedded quartzite, with *Scolithus* tubes.	400
Cambrian	Early	Chilhowee group	Harpers formation (Ꞓh, Ꞓhs)	Thin-bedded, dark-gray to greenish siltstone. At base to south, a member of micaceous shale or phyllite.	900
Cambrian	Early	Chilhowee group	Weverton formation (Ꞓwu, Ꞓwm, Ꞓwl).	Upper member of ferruginous quartzite, white arkosic quartzite, and thin-bedded, greenish siltstone.	700
Cambrian	Early	Chilhowee group	Weverton formation (Ꞓwu, Ꞓwm, Ꞓwl).	Middle member of micaceous shale or phyllite.	100
Cambrian	Early	Chilhowee group	Weverton formation (Ꞓwu, Ꞓwm, Ꞓwl).	Lower member of conglomerate and interbedded soft arkose.	100–700
Cambrian	Early	Chilhowee group	Loudoun formation (Ꞓl).	Spotted purple or gray slate, probably representing altered volcanic tuffs and breccias; lava flows in a few places. Lies unconformably on Catoctin greenstone; passes out by overlap in places.	0–200
Pre-Cambrian	Late	Catoctin greenstone (pꞒc).		Altered basaltic lava, in part amygdaloidal, in part epidotized, with interbedded tuffaceous and sandy sediments.	0–1,000
Pre-Cambrian	Late	Swift Run formation (pꞒs).		Conglomerate, arkosic quartzite, and slate. Lies unconformably on injection complex.	0–100
Pre-Cambrian	Early	Injection complex (pꞒi).		Coarse-grained granodiorite, unakite, and other hydrothermally altered plutonic rocks, with gneissic structure.	

PRE-CAMBRIAN ROCKS

The pre-Cambrian rocks of the Elkton area resemble those elsewhere in the Blue Ridge-Catoctin Mountain anticlinorium, from South Mountain, in Pennsylvania, southward at least as far as the James River in Virginia. They have been described in numerous reports and their general character is well known, but some of the interpretations regarding them are still in controversy. Among the earlier papers on the pre-Cambrian, the most important is that of Keith (1894, pp. 296–318) which summarizes the older literature, and gives many geological details for northern Virginia, from the Potomac to the Rappahannock. Among the recent papers, the most important are those of Furcron (1934, pp. 400–410) and of Jonas and Stose (1938b, pp. 575–593). Another report by Stose and Stose (1946b, pp. 15–28) on the Maryland area immediately north of the Potomac gives many details of local outcrops, and includes notes

FIGURE 2.—View north-northwest from Devils Tanyard across northwest part of Shenandoah Salient. Cubbage Hollow in center, Lucas Hollow to left, Massanutten Mountain on skyline. Cleared areas in middle distance are on injection complex, wooded hills and peaks beyond are on Chilhowee group.

on these authors' observations in northern Virginia.

The pre-Cambrian rocks of the Blue Ridge-Catoctin Mountain anticlinorium are largely of igneous origin, but include some rocks of sedimentary origin. As has been known since the time of Keith's work, two main groups are represented, a series of plutonic rocks and a series of volcanic rocks. The plutonic rocks have long been interpreted as intrusive into the volcanic, but Jonas and Stose (1939b, pp. 592–593) have concluded that the volcanic rocks are actually younger than the plutonic, and lie unconformably upon them. In the Elkton area, the pre-Cambrian rocks are relatively less metamorphosed and folded than in other parts of the Blue Ridge-Catoctin Mountain anticlinorium, so relations can be worked out with considerable certainty. In this area at least (and disregarding other areas where different and often confusing relations have been reported), the volcanic rocks are younger than the plutonic rocks. In the Elkton area, the pre-Cambrian rocks are, accordingly, divided into an older pre-Cambrian series, termed the injection complex, and younger pre-Cambrian series comprising the Swift Run formation and the Catoctin greenstone.

The pre-Cambrian rocks of the Elkton area crop out in its southeast part, where they form the northwest slopes of the Blue Ridge. They also form numerous inliers farther northwest within the Shenandoah Salient. Toward the northwest they dip beneath the Lower Cambrian rocks, which overlie them unconformably.

INJECTION COMPLEX

NAME

The term "injection complex" was adopted by Jonas and Stose (1939b, pp. 580–581) as a general title for older pre-Cambrian rocks that had been shown on the geologic map of Virginia (Virginia Geological Survey, 1928) as Lovingston granite gneiss, Marshall granite, albitite, and hypersthene granodiorite. Within the Elkton area, the main unit represented appears to be the hypersthene granodiorite, but because of variations within the mass and the lack of detailed study by the writer, the more general title is employed.

OUTCROP

The injection complex crops out in numerous inliers in the Shenandoah Salient (pl. 1). It is present along the East Branch of Naked Creek east of Jollett, and the North Branch in Harris Cove, in both of which places it is overlain by younger pre-Cambrian rocks. It also forms an extensive inlier farther north in Dovel, Lucas, and Cubbage Hollows, where it is overlain unconformably by Lower Cambrian rocks (fig. 2).

CHARACTER AND ORIGIN

In the Elkton area, the rocks of the injection complex are coarse-grained gneiss, composed of gently dipping, alternating light- and dark-colored bands a quarter of an inch to an inch thick, the different bands being composed of quartz and feldspar, and of ferromagnesian minerals. In detail, the texture is exceedingly irregular, with spots and segregations of the light and dark minerals, and with none of the minerals showing definite crystal faces. The ferromagnesian minerals are to some extent altered to light green epidote, and this mineral also invades the margins of the feldspar grains. The feldspar forms bodies up to an inch across, many with conspicuous cleavage faces, but generally broken and veined; it is commonly pink or rose-red. Quartz forms smaller grains, generally clear and vitreous, but in part tinted blue or violet. Many details regarding rock of this type have been given by Phalen (1904, pp. 306–316) for the area near Fishers Gap, immediately east of the north end of the Elkton area.

Rocks of the sort described have clearly been subjected to a series of hydrothermal changes since consolidation. The hypersthene granodiorite of the Blue Ridge is considered by Jonas and Stose (1939b, p. 582) to have been formed by an intimate injection of earlier diorite by later granite. Jonas (1934, pp. 53–54) describes the process as follows:

> These changes include an addition of soda to form myrmekite and "chess-board" albite, of silica to form quartz, and, in part of the area, of lime-iron silicate epidote and ferric iron to form the fine hematite flakes that color the feldspars pink.

In irregular patches within the injection complex of the Elkton area, secondary alteration and introduction of epidote have proceeded so far that the rock is a unakite (Bradley, 1874, pp. 519–520). According to Phalen (1904, p. 312):

> This rock is an irregular crystallization of old-rose feldspar and green epidote, the latter generally occupying the space between the feldspar. The peculiar green of the epidote, together with the old-rose hue of the feldspar, make a striking and beautiful combination.

Specimens collected by the writer are similar, except that quartz also is present in many specimens. There appears to be no systematic distribution of the unakite, and it seems to be a local phase of the surrounding granodiorite. According to Jonas (1934, p. 53):

> Unakite is * * * largely secondary in its mineral content and composition. Original potash feldspar still remains, but its color has been changed from gray-green to pink. The epidote has replaced other minerals and the quartz is also secondary. Unakite preserves, however, the fine-grained or coarse-grained texture of the granodiorite from which it was derived.

JOINTING AND WEATHERING

The gneiss of the injection complex is cut by vertical joints which, with the nearly horizontal layering, cause it to break out in rectangular blocks. Here and there, it is traversed by quartz veins. The gneiss weathers to dull-brown or orange-red gritty soil, somewhat lighter-colored than that of the surrounding Catoctin greenstone. As the soil is fairly productive, areas of injection complex are extensively cleared, and are either cultivated or used for pasture land.

GREENSTONE INTRUSIVES IN INJECTION COMPLEX

In the northeast part of the Elkton area, greenstone intrudes the injection complex. At a locality on Tanners Ridge half a mile northwest of St. Luke Mission, greenstone dikes a few inches to 4 feet wide cross the gneisses of the complex. The exposures are near the overlying Catoctin greenstone where the Swift Run formation is locally absent. Some of the dikes have irregular margins, and some contain gneiss inclusions, whose layering is discordant with that of the country rock. Many of the dikes are bordered by a narrow zone of epidote and jasper, which may represent an alteration of an original chilled phase of the greenstone. These greenstone instrusives may be genetically related to the extrusives of the Catoctin greenstone, and their occurrence tends to confirm the interpretation that the Catoctin is younger than the injection complex.

OCCURRENCE OF BLUE QUARTZ IN ROCKS OF INJECTION COMPLEX

Many authors have noted that the vitreous quartz grains in the rocks of the injection complex are tinted blue or violet (Keith, 1894, p. 300, pl. 24). This so-called "blue quartz" may have acquired its color from the presence of minute included needles of rutile (Jonas, 1934, p. 53) or from the presence of parallel, secondary fluid pores resulting from metamorphism (Crickmay, 1936, p. 1385). Whatever the origin, these occurrences are of interest, because reworked clastic grains of blue quartz are a distinctive constituent of younger sedimentary formations. In the Elkton area, blue quartz has been noted at a few places in the immediately overlying Swift Run formation, and Stose and Stose (1946b, pp. 18–20) report it from the same unit elsewhere in northern Virginia and in Maryland. Its most conspicuous occurrence is, however, in the quartzites of the Lower Cambrian Weverton formation (Keith, 1894, pp. 329–330).

SWIFT RUN FORMATION

NAME

The name Swift Run was given by Stose and Stose (1946b, pp. 18–20) to a unit of sedimentary rocks lying unconformably on the injection complex and lying beneath the Catoctin greenstone. Its type locality (pl. 1) is 1.2 miles east of Swift Run Gap on U. S. Highway 33, a few miles southeast of the Elkton area (see Jonas and Stose, 1938b, pp. 583–585). The name is used in the Elkton area for sedimentary rocks in the same stratigraphic position, but because the tuffaceous element is subordinate, the unit is termed the Swift Run formation. In previous work in the Blue Ridge region, the Swift Run formation was commonly interpreted as representing narrow synclines of the Lower Cambrian Loudon formation, infolded along the contact between the injection complex and the Catoctin greenstone (Jonas and Stose, 1938b, pp. 585–586). However, field relations in the Elkton area prove that it is a nearly continuous bed that underlies the Catoctin.

OUTCROP

The Swift Run formation crops out in a narrow band around the inliers of the injection complex (pl. 1). In many places the unit is well exposed, and its quartzites stand in ledges or even cliffs. In a few places, especially where the formation is thin or consists largely of slaty rocks, outcrops are poor. The most accessible outcrop of the Swift Run formation is on the south bank of the East Branch of Naked Creek a mile east of Jollett, where its relations to the injection complex and Catoctin greenstone are well displayed.

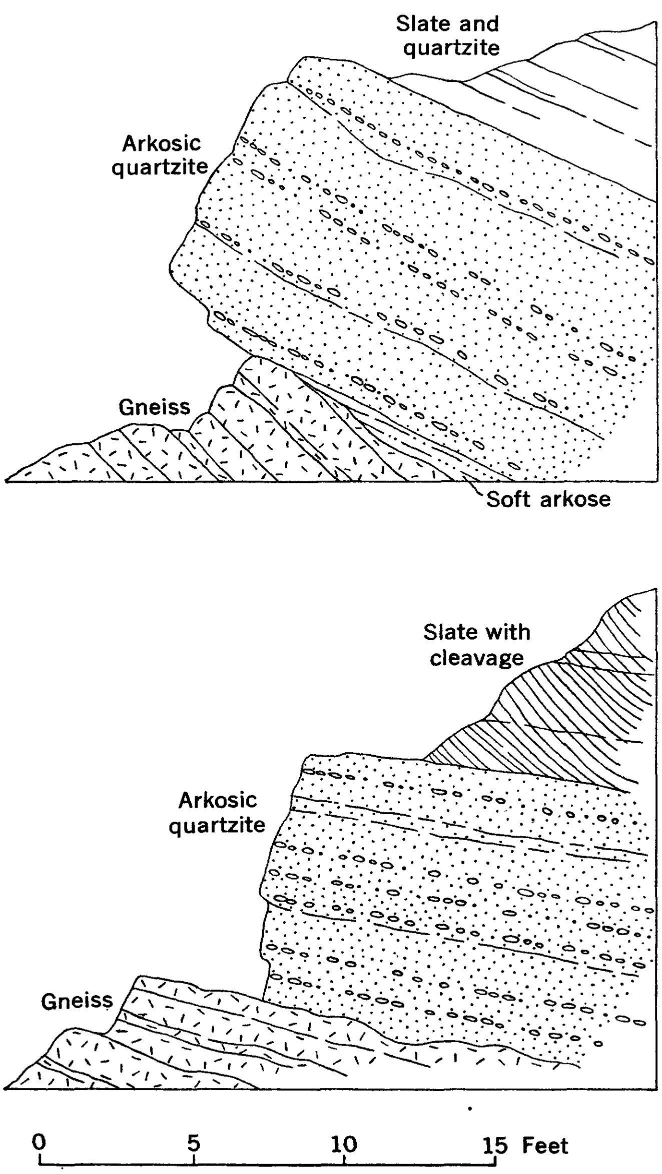

FIGURE 3.—Sections, based on field sketches, showing unconformable relations between Swift Run formation and injection complex. Upper figure, west slope of Devils Tanyard, in headwaters of Fultz Run. Lower figure, south side of East Branch of Naked Creek a mile east of Jollett.

GENERAL FEATURES

The Swift Run formation has a somewhat varied character. Its most conspicuous element is vitreous, well-bedded, arkosic quartzite, of gray, pink, or greenish color, composed of quartz, pink and white feldspar, and ferro-magnesian minerals. Much epidote is present in the matrix. In most outcrops the quartz grains are colorless and vitreous, but at a few localities blue quartz has been noted. Some conglomerate layers are present, and some beds of crumbly, poorly cemented arkose. Interbedded with the quartzite in places are red and gray slate, and green, blebby pyroclastic rocks. The contact with the overlying Catoctin greenstone is somewhat indefinite, due to the fact that greenstone of Catoctin type, perhaps of pyroclastic origin, is interbedded in the Swift Run formation in places, and that sedimentary rocks of the Swift Run type are interbedded in the overlying greenstone. The contact is considered to be at the base of the lowest massive greenstone.

The Swift Run formation is a thin unit, but has a considerable range in thickness within short distances. In many places it is between 10 and 50 feet thick, but at some localities it reaches 100 feet or more. Locally, it is absent, so the Catoctin greenstone lies directly on the injection complex.

LOCAL FEATURES

At the locality 1 mile east of Jollett, referred to above, the basal bed of the Swift Run formation is a 10-foot layer of quartzite, which at the east end of the exposure lies on the injection complex (fig. 3). The contact is clean-cut and slightly wavy, and is unconformable. The quartzite contains numerous rounded grains of clear quartz and a few of pink feldspar, mostly less than an eighth of an inch in diameter, but with some coarser, pebbly seams. The matrix is laminated by dark bands and is a fine-grained arkose, parts of which contain pale-green epidote. Above the quartzite at the west end of the exposure are about 10 feet of blue slate with strongly developed cleavage, containing dark-green or reddish blebs, probably of pyroclastic origin. This is overlain by massive ledges of Catoctin greenstone.

On the west side of Harris Cove about a mile west of Weaver School, the formation consists largely of quartzite, which forms two ledges with a total thickness of about 50 feet. The quartzite differs greatly from that of the Lower Cambrian Weverton formation, which lies not far above it in this vicinity. Unlike the Weverton, it does not contain large quartz pebbles, and has a high content of feldspar. The latter causes the rock to assume a pinkish cast, and to exfoliate in rounded surfaces. In some places it contains small quantities of greensh epidote. Bedding is shown by dark laminae and by textural varitions. Some of the layers are crossbedded.

Farther north along the same line of outcrop, the contact between the quartzite and the injection complex was observed on the west slope of Devils Tanyard, in the headwaters of Fultz Run (fig. 3). There, the basal quartzite ledge is 15 feet thick, and rests on a smooth surface of weathered, coarse-grained gneiss, whose layering apparently dips more steeply than the bedding in the quartzite. In places, a lenticular bed of soft arkose intervenes between the quartzite and the injection complex.

Near the head of the West Branch of Naked Creek, a mile southwest of St. Luke Mission, quartzites like those described are interbedded with greenstone of Catoctin type. Resting on the injection complex, which forms an inlier near creek level, is a thin, inconstant layer of quartzite. Above is nearly 100 feet of tough, fine-grained, blue-green rock, similar to metabasalt, but apparently of sedimentary origin because it forms stratified layers 2 to 5 feet thick, and contains tuffaceous pebbles. At the top is an 8-foot ledge of gray to pink quartzite. Greenstone of the Catoctin lies above, but this may also be in part sedimentary, as it shows rude strata 5 to 10 feet thick.

At some localities near those described, the Swift Run formation is composed largely of slate, rather than of quartzite. Near the southwest end of Long Ridge a mile north of Jollett, the unit consists of steel-gray, silky-lustered slate with dark bedding laminae, interbedded with medium-grained, dark-gray arkose that contains argillaceous pebbles. In both rocks cleavage is well developed.

In the northeast part of the Elkton area, the Swift Run formation consists dominantly of slaty rocks. North of St. Luke Mission on Tanners Ridge the formation is 30 to 100 feet thick. Pink arkosic quartzite forms thin, lenticular beds, and contains grains of blue quartz. Most of the formation is banded purple slate. The formation is overlain by and grades into slaty greenstone, probably of pryroclastic origin. In places near the mission, the formation is absent, probably by overlap.

Northward along this line of outcrop, east of Baileys store and Hawksbill Creek, some puzzling relations have been revealed by reconnaissance observations by John Rodgers. A thin band of sedimentary rock diverges northward from the top of the injection complex and the main belt of Swift Run sedimentary rocks, and is overlain and underlain by greenstone of Catoctin type (fig. 4, pl. 1). This suggests a southward overlap of the Swift Run formation and Catoctin greenstone on the injection complex, the lower greenstone to the north perhaps being older than either the Swift Run formation or the basal greenstone farther south on Tanners Ridge.

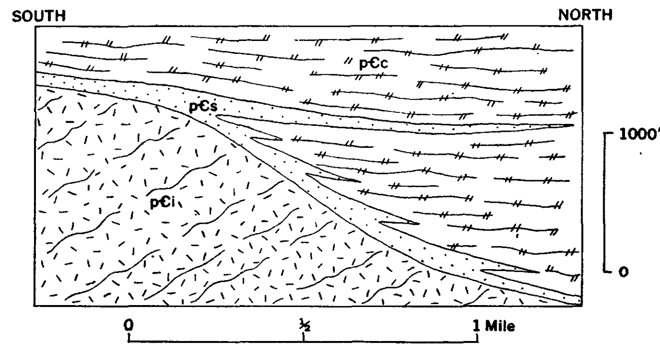

FIGURE 4.—Diagram showing possible interpretation of relations east of Baileys store, near Hawksbill Creek, in northeast part of Elkton area. Swift Run formation (p€s) and Catoctin greenstone (p€c) lie unconformably on injection complex (p€i), and apparently overlap its sloping surface.

STRATIGRAPHIC RELATIONS

The Swift Run formation appears to be younger than the injection complex, and to overlie it unconformably. Where the contact between them is exposed, it is a smooth surface which is probably of erosional rather than of intrusive origin. Moreover, the wide extent of this thin band of sedimentary material on the surface of the complex suggests that the sediments were deposited on the complex, and were not intruded by it. The blue quartz that occurs here and there in the deposit was probably derived from the erosion of the complex. Throughout most of the Elkton area, the Swift Run formation probably represents a single layer of about the same age throughout, but relations in the extreme northeast part suggest considerable overlap of the Swift Run and Catoctin formations against the surface of the injection complex.

The Swift Run formation is overlain by and is probably conformable with the Catoctin greenstone. The Swift Run contains tuffaceous sediments that were probably related to the eruptions of Catoctin age, and the Catoctin itself contains considerable bodies of altered pyroclastic sediments, especially in its basal part.

REGIONAL RELATIONS

Sedimentary rocks lying beneath the Catoctin greenstone and unconformably on the injection complex seem to be widespread in the Blue Ridge-Catoctin Mountain anticlinorium. Their general distribution has been summarized by Jonas and Stose (1938b, pp. 582–590). The Swift Run formation occurs in the northwestern and northern parts of the anticlinorium. On the southeast flank of the anticlinorium, in the Warrenton area, is the thicker Fauquier formation (Furcron, 1939, pp. 37–41), composed of slate with some limestone and sandstone. Toward the southwest, in the Buena Vista area, is the Oronoco formation (Bloomer and Bloomer, 1947, p. 95), composed of sandstone, slate, and volcanics. The Lynchburg gneiss on the southeast flank of the anticlinorium in southern Virginia may also be of about the same age.

These units all lie above the injection complex and below the Catoctin in their respective areas, and while they are in general of the same age, they may not be precisely so in detail, because they were laid down as transgressive deposits on a sloping, eroded surface of the injection complex. The Lynchburg and Fauquier on the southeast side of the anticlinorium are thus much thicker than the Oronoco and Swift Run on the northwest side of the anticlinorium, and at least their lower parts are probably older. The Oronoco formation may in turn be older than the Swift Run, as it differs lithologically from the Swift Run and seems to underlie a greater thickness of the Catoctin. The Swift Run more closely resembles "the two members composed of tuff, conglomerate, and arkosic sandstone" (Bloomer and Bloomer, 1947, p. 95) interbedded in the Catoctin some distance above its base in Augusta County, and well exposed west of Rockfish Gap, which were shown to the writer by R. O. Bloomer. That the Swift Run of the Elkton area may be younger than part of the Catoctin in other areas is further suggested by the apparent overlap relations observed east of Baileys store, in the northeast part of the Elkton area (fig. 4).

Under the circumstances, the current practice of designating the pre-Catoctin sediments in the different areas by local names seems advisable, although future work may demonstrate that some of the names should eventually be dropped as synonyms.

CATOCTIN GREENSTONE

NAME

The Catoctin schist was named by Keith (1894, pp. 306–309) for exposures in the Catoctin Mountain region of Maryland and Virginia. In most areas, however, it is not notably schistose. In many reports it has been termed a metabasalt (Stose and Stose, 1946b, p. 20), but Bloomer and Bloomer (1947, pp. 99–100), on the basis of work in the Buena Vista quadrangle southwest of the Elkton area, term it a propylite, or altered andesite. As opinions differ regarding its precise petrographic classification, and as it may vary in composition from place to place, it seems most appropriate to use for it the general rock term greenstone, which was employed on the geologic map of Virginia (1928).

The Catoctin greenstone (and associated metarhyolite and metaandesite) is one of the most characteristic units of the Blue Ridge-Catoctin Mountain anticlinorium, and extends from South Mountain in Pennsylvania, southward nearly to the James River in central Virginia. Throughout most of its extent in northern Virginia the Catoctin greenstone forms the crest and northwest flank of the Blue Ridge. Many details regarding the Catoctin in northern and central Virginia have been given by Furcron (1934, pp. 401–404) and by Bloomer and Bloomer (1947, pp. 94–106). Copper deposits that occur in the Catoctin at some localities in the Blue Ridge have been described by Phalen (1906, pp. 140–143) and by Watson (1907, pp. 504–511).

OUTCROP

The Catoctin greenstone crops out along the southeast edge of the Elkton area and forms the northwest slope of the Blue Ridge (pl. 1). Southeastward, beyond the Elkton area, it extends to the crest of the range. It also crops out in the Shenandoah Salient in the valleys of the East and West Branches of Naked Creek, and it forms Tanners Ridge in the northeast part of the area. In the northwest part of the Shenandoah Salient, the Catoctin greenstone wedges out beneath the Lower Cambrian rocks. Throughout its extent, the greenstone weathers to a vermillion-red, sticky clay soil, which commonly is cleared and grassgrown, rather than forested. Bouldery ledges crop out here and there in stream channels and on hill slopes. In places there are sizable cliffs of unweathered rock, as at Cedar Falls and Dry Run Falls, on the slope of the Blue Ridge 5 miles east of Elkton.

CHARACTER

The Catoctin greenstone consists of altered lava, largely basaltic in composition, and associated pyroclastic sediments.

Lava flows form the greater part of the formation, and are the typical greenstone. They are dense, tough, massive rocks, generally of dark-green or greenish gray color, but in part purplish or bluish gray. Parts are amygdaloidal, the amygdules filled by zeolites, quartz, jasper, or other minerals. Alteration features are common. Most outcrops contain patches of epidote, and in some ledges the original rock is largely replaced by this mineral. There are also irregular patches and vugs of quartz and dull-red jasper. Gash veins of quartz are common. Much of the rock is massive, but many parts show a poor cleavage, and in places the rock grades into a thinly cleaved schist that contains lenses of more massive rock.

In the greenstone area a mile northeast of Beldor a porphyry containing large feldspar phenocrysts was observed. This is probably an intrusive related to the flows.

A considerable but undetermined amount of the Catoctin greenstone consists of pyroclastic rocks, that is, rocks of sedimentary origin derived from the same sources as the flows. Interbedded with the massive greenstone are lenses and beds of spotted purple slate and silvery, sericitic schist, which were probably originally tuffs. Some of the massive greenstone itself is considered to be of sedimentary origin, because it contains blebs and pebbles of lava, shows faint bedding laminae, or forms rudely stratified layers a few feet to 10 feet thick. Pyroclastic rocks, both slaty and massive, were observed at many places immediately above the Swift Run formation, but they are also present higher in the Catoctin. The pyroclastic rocks are difficult to differentiate from the flows because exposures are poor and because the massive varieties resemble flows. No attempt was made to indicate them separately on the map (pl. 1).

THICKNESS AND STRATIGRAPHIC RELATIONS

The Catoctin greenstone is probably 1,000 feet or more thick on the slopes of the Blue Ridge in the southeast part of the Elkton area (fig. 11). In this region, because of the massive and homogeneous character of the formation, there is no clear evidence as to its stratigraphic relations with the overlying Loudoun formation. Where partings are present in the Catoctin they are approximately parallel to the bedding in the Loudoun and Weverton formations.

To the northwest, in the Shenandoah Salient, the Catoctin greenstone wedges out. The relations are well displayed on the west side of Harris Cove, where the Lower Cambrian Loudoun and Weverton formations cap the ridges to the west, and the injection complex, the Swift Run formation, and the Catoctin greenstone form the lower slopes to the east. A mile west of Weaver School the Catoctin is about 300 feet thick. Toward the north the quartzite ledges of the Swift Run formation rise on the slope, and within half a mile are overlain directly by slate of the Loudoun formation. Beyond, as in the ridges near the head of Fultz Run, there are a few lenticular bodies of greenstone between the two formations. At the head of Cubbage Hollow, 2 miles north of Weaver School, both the Catoctin and Swift Run formations are missing, and the Loudoun formation rests directly on the injection complex.

These relations suggest that the northwestward wedging out of the Catoctin greenstone in the Shenandoah Salient is the result of tilting of the Catoctin and older pre-Cambrian rocks before Early Cambrian time and of truncation of these rocks by erosion before the Loudoun formation was laid over them. In the northeast part of the Elkton area relations are somewhat different; there appears to be an overlap of the basal Catoctin on the surface of the injection complex (fig. 3A). It may be, therefore, that variations in thickness of the Catoctin are the result both of overlap at the base and of truncation at the top.

Evidence for erosion of the Catoctin before and during Chilhowee time is afforded by the occurrence of jasper pebbles in the conglomerate and quartzite of the lower member of the Weverton formation. As pointed out by Keith (1894, pp. 312–313) these were derived from amygdules in the lavas of the Catoctin greenstone.

REGIONAL RELATIONS OF UNCONFORMITY ABOVE CATOCTIN

The Catoctin greenstone is widely distributed in the Blue Ridge-Catoctin Mountain anticlinorium of northern Virginia, but at some places it is missing beneath the Chilhowee group in the same manner as in the Shenandoah Salient. North of the Elkton area, from Purcell Knob, Loudoun County, Va., northward into Frederick County, Md., Stose and Stose (1946b, pp. 28–29) report that the Loudoun formation of the Chilhowee group lies directly on the injection complex. They interpret this relation as due to uplift and erosion of the Catoctin greenstone. Southwest of the Elkton area, in the Lyndhurst-Vesuvius Salient in Augusta and Rockbridge Counties, Va., Knechtel (1943, pl. 29) has mapped the Catoctin greenstone as wedging out westward beneath the Weverton formation of the Chilhowee group. Farther southwest, in the Buena Vista area of Amherst County, Va., Bloomer and Bloomer (1947, pp. 95–97) report that the Catoctin and the underlying Oronoco formation are present toward the southeast, whereas toward the northwest the Chilhowee group lies directly on the injection complex. The northwest edge of the wedge of Catoctin and Oronoco is not exposed in this area, but Bloomer and Bloomer interpret the disappearance of the formations toward the northwest as resulting from overlap on the surface of the injection complex, and consider them to be essentially conformable with the Chilhowee group above.

It will be noted that at all places where the Catoctin greenstone has been observed to wedge out, it thins toward the northwest, and that all the occurrences are near the northwest edge of the Blue Ridge-Catoctin Mountain anticlinorium. This suggests that the northwest edge of the anticlinorium corresponds approximately to the present northwest limit of the formation. It is not certain whether this is because it originally ended in this direction by nondeposition and overlap, or whether it was once more extensive and has since been truncated by tilting and erosion. The regional northwestward thinning across the anticlinorium of the pre-Catoctin sedimentary rocks (of which the Swift Run is a part) suggests that the center of the basin in which these sediments were laid down was farther to the southeast. On the other hand, relations in the Shenandoah Salient of the Elkton area suggest that the wedging out was due to tilting and erosion. Possibly the latter relations are a feature of the margins of the original basin of accumulation.

Regional relations, as shown on plate 2, suggest that in northern Virginia the unconformity at the top of the Catoctin greenstone may represent a considerable time hiatus. The overlying Chilhowee group is much thicker in southwestern Virginia and northeastern Tennessee than it is in northern Virginia. Part of this thickening results from increase in volume of all units of the group, but a considerable part is caused by the existence of beds at the base (in the lower part of the Unicoi formation) that apparently are unrepresented in northern Virginia and in Maryland.

In the Elkton area, tuffaceous slates occur in the Loudoun formation at the base of the Chilhowee group (Elkton section, pl. 2). In the Buena Vista area to the southwest, tuffs and andesite flows occur in about the same position (basal part of Unicoi formation of Bloomer and Bloomer 1947, p. 103). In southwestern Virginia and northeastern Tennessee this volcanic horizon is seemingly represented by the amygdaloidal basalt flows of the middle part of the Unicoi formation (Konnarock and Iron Mountain sections, pl. 2). These lie at a comparable distance below the top of the Chilhowee group, but they overlie older sedimentary rocks that form the lower part of the Unicoi formation. On Iron Mountain, near the Virginia-Tennessee boundary, these are as much as 3,000 feet thick (King, Ferguson, Craig, and Rodgers, 1944, pp. 39–40).

The Loudoun formation of northern Virginia lies on the Catoctin greenstone. The pre-amygdaloid strata of the lower part of the Unicoi formation of southwestern Virginia and northeastern Tennessee lie on rhyolite flows and related volcanics of the Mount Rogers anticlinorium, which have been correlated with the Catoctin by Jonas and Stose (1938b, pp. 590–591). If the correlations are correct between the Loudoun and the amygdaloidal basalt of the Unicoi, and between the Catoctin and the volcanics of the Mount Rogers area, a time hiatus that separates the Catoctin and Loudoun in northern Virginia is represented by the deposition of the sediments of the lower part of the Unicoi in southwestern Virginia and northeastern Tennessee.

AGE

The writer considers the Catoctin greenstone to be late pre-Cambrian in age. It lies unconformably beneath Lower Cambrian rocks, which are themselves about 3,000 feet beneath beds containing the earliest Lower Cambrian fossils.

A different interpretation has been made by Bloomer and Bloomer (1947, p. 106), who state that "the relations and the lithologic similarity of the Oronoco, Catoctin, and Unicoi formations lead to the conclusion that these formations are a continuous stratigraphic series. If the Unicoi formation is Cambrian, then the Catoctin and Oronoco formations are also Cambrian." The Unicoi formation of their usage is equivalent to the Loudoun and Weverton formations of this report. As evidence for their conclusion, they cite the close lithologic similarity between the volcanics of the Oronoco, Catoctin, and Unicoi formations, and the sedimentary rocks of the Oronoco and lower part of the Unicoi; also the apparent lack of erosion of the Catoctin before Unicoi time, as indicated by the absence of detrital fragments of the Catoctin greenstone in the Unicoi formation.

Conditions in the Elkton area seem to be somewhat different, for the Catoctin greenstone is separated from the Chilhowee group by an angular and erosional unconformity, and the lower beds of the Chilhowee group contain detritus derived from the Catoctin (pp. 13, 18). Moreover, clastic sedimentary rocks beneath the Catoctin (Swift Run formation) are readily distinguishable lithologically from those in the overlying Weverton formation of the Chilhowee group (p. 11), which suggests considerably different environments of deposition. The tuffaceous slates of the Loudoun formation of the Chilhowee group closely resemble those interbedded in the Catoctin greenstone, but the several lava flows in the Loudoun formation are very different in appearance from those in the Catoctin (p. 17), and are probably of different composition. The writer concludes that, in the Elkton area, at least, the differences of the Catoctin and Swift Run formation from the overlying Chilhowee group are greater than the similarities, suggesting that the two units are parts of different geologic cycles, one of the pre-Cambrian and the other of Early Cambrian age.

CAMBRIAN SYSTEM

CHILHOWEE GROUP

NAME

The Chilhowee sandstone was named by Safford (1856, pp. 152–153; 1869, pp. 198–203) for exposures on Chilhowee Mountain in central-eastern Tennessee (pl. 2). The term Chilhowee group has been widely used in Tennessee, and was extended to the Virginia area by Butts (1940, pp. 26–27). The unit has also been termed the "Lower Cambrian quartzites and slates"

(U. S. Geol. Survey, 1933), the "basal quartzites" (Butts, 1933, p. 2) and the "basal clastic group" (King, and others, 1944, pp. 27, 28). The name is applied to clastic rocks in Tennessee and Virginia that lie unconformably on pre-Cambrian rocks and are overlain by the Shady or Tomstown dolomite.

DESCRIPTION BY ROGERS

The Chilhowee group was termed Formation I by Rogers (1884, pp. 167–168) in the work of the first Virginia Geological Survey, and was described by him as follows:

This rock, or group of rocks, which is frequently exhibited in extensive exposures along the western side and base of the Blue Ridge, more especially in the middle counties of the valley, is usually a compact, rather fine-grained, white or yellowish gray sandstone. * * * In Page, Rockingham, Augusta, and Rockbridge Counties this rock forms the irregular and broken ranges of hills lying immediately at the foot of the main Blue Ridge, and sometimes attaining an altitude little inferior to that of the principal mountain. A level region, sometimes of considerable breadth, and strewed profusely with fragments of this rock, in general intervenes between these rugged hills and the first exposure of the valley limestone; thus indicating at once the extent of the formation, and the violence of the forces to which it has been subjected.. In many instances two, sometimes three, ranges of hills are interposed between the limestone and what may be regarded as the termination of the rocks of the Blue Ridge, in which case the sandstone of those nearest the ridge exhibits peculiarities of composition and structure which distinguish it from the rock found in more remote positions. Talcose and micaceous matter make their appearance in it; its specific gravity is increased, and a jointed structure is developed to so great a degree that it becomes difficult to recognize its true plane of dip. * * * This micaceous and talcose variety is sometimes found in the same hill underlying the more purely siliceous rock.

The latter, in nearly all the exposures from Balcony Falls to Thornton's Gap, as well as in various other places, exhibits vague, fucoidal, and zoophytic impressions on the surfaces of the bedding, together with innumerable markings at right angles to the stratification, penetrating in straight lines to great depths in the rock [*Scolithus* of later authors] * * *. These markings are of a flattened cylindrical form, from one-eighth to one-tenth of an inch broad, giving the surface of the fractured rock a ribbed appearance, and resembling perforations made in sand which have been subsequently filled up, without destroying the distinctness of the original impression.

SUBDIVISIONS

The rocks of the Chilhowee group are a lithologic and depositional unit, and give rise to a distinctive topographic feature, the northwestern foothills of the Blue Ridge. Use of a group term for the unit is therefore desirable. The group characteristically consists of several types of clastic rock which are interbedded with each other vertically and interfinger with each other laterally (fig. 5). In a broad way, arkosic and conglomeratic rocks predominate in the lower part, argillaceous rocks predominate in the middle, and white, siliceous sandstones and quartzites predominate in the upper part, giving rise to a broad threefold subdivision. There is no assurance, however, that the boundaries between these lithologic types are everywhere of the same age. Definitions of the formations

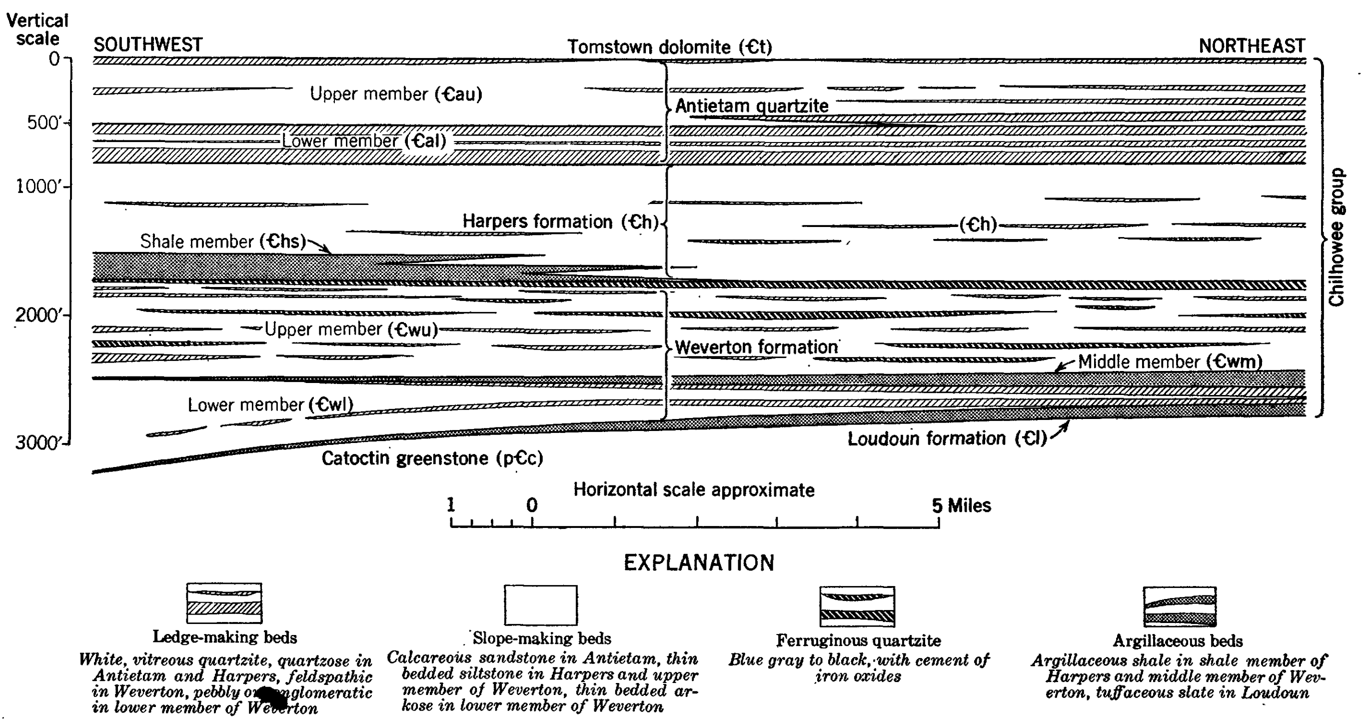

FIGURE 5.—Stratigraphic diagram of Chilhowee group in Elkton area.

should therefore be based more on the occurrence of traceable beds than on the gross lithology.

The Chilhowee group of northern Virginia and adjacent parts of Maryland was divided by Keith (1894, pp. 321–337), in ascending order, into the Loudoun formation, the Weverton sandstone, the Harpers shale, and the Antietam sandstone. In a report by Stose and others (1919, pp. 13–22) the Chilhowee group in both southern and northern Virginia was divided into the Unicoi formation, the Hampton shale, and the Erwin quartzite. The latter names had previously been applied to rocks of the Chilhowee group in northeastern Tennessee. By present usage the Tennessee terms are restricted to the region south of Roanoke in central Virginia. Farther north, in the Elkton area and elsewhere, the terminology used is that proposed by Keith for Maryland and northern Virginia.

LOUDOUN FORMATION

Name and correlation.—The Loudoun formation was named by Keith (1894, pp. 324–329) for exposures in Loudoun County, northern Virginia, but without designation of a specific type locality, and was applied to presumed basal Cambrian beds that intervened, or supposedly intervened, between the Catoctin and Weverton formations. Keith mapped the formation southward from Loudoun County in Virginia as far as Front Royal and Warrenton, and northward in Maryland into Frederick and Washington Counties. On the geologic map of Virginia (Virginia Geol. Survey, 1928), the term was applied to extensive areas of rocks believed to be basal Cambrian, lying southeast of the Blue Ridge, and extending as far southwest as Amherst County. Jonas and Stose (1938, pp. 588–589) indicated, however, that considerable areas of rocks hitherto called Loudoun in Virginia and Maryland were actually beneath the Catoctin rather than above it. In a subsequent report on Frederick County, Md., they (Stose and Stose, 1946 b, pp. 31–34) restricted the Loudoun formation to a unit about 200 feet thick between the Catoctin and Weverton, described as composed of arkose, conglomerate, and slate, the slate being in part of pyroclastic origin.

In the Elkton area a unit has been described by Furcron and Woodward (1936, pp. 45–51) as "a basal Cambrian lava flow", which is said to lie unconformably on the Catoctin greenstone and the injection complex, and to be overlain by the Loudoun formation. The writer's observations on this unit indicate that no beds overlie it which could conceivably be called Loudoun, and that the succeeding beds have the same character as the Weverton of its type area. The writer therefore has concluded that they are equivalent to the Loudoun as defined by Stose and Stose (1946 b, pp. 31–34) in Frederick County, Md. The unit in the Elkton area has an average thickness of 100 feet and consists mainly of slate of pyroclastic origin, but the differences between it and the Loudoun as described in Frederick County are considered to result from local variations in conditions of sedimentation. In this report, the unit in the Elkton area is therefore classed as the Loudoun formation.

Discussions by the writer with R. O. Bloomer, Ernst Cloos, and A. S. Furcron after this report was prepared have suggested that doubt exists as to whether the Loudoun formation is a valid unit. The original definition of Loudoun by Keith was ambiguous, as no type locality was designated, and as it was applied to beds in more than one stratigraphic position. Further confusion was created by the broad application of the term on the geologic map of Virginia. Moreover, Cloos (personal communication, 1949) questions the status of the unit in the area in which it was redefined by Stose and Stose. He interprets the Loudoun that was supposed to underlie the Weverton at the type locality of the latter on the Potomac River as consisting of overturned post-Weverton beds. It is therefore possible that the terminology herein adopted may not, in the end, prove to be the most satisfactory one, and that further consideration may have to be given to a name for the beds in the Elkton area here termed the Loudoun formation.

Outcrop.—The Loudoun formation extends across the Elkton area as a nearly continuous, narrow band, which lies between the outcrops of the pre-Cambrian and the younger Cambrian formations (pl. 1). In a few places it is missing, as in the northwest part of the Shenandoah Salient, and also perhaps in the extreme south part of the area. In some places the unit projects in prominent ledges, but in many it forms a sag on the hill slopes between more resistant formations below and above. Here, its presence is indicated by abundant chips of its characteristic slate in the soil.

Character.—The Loudoun formation of the Elkton area is dominantly a slaty unit, probably largely of pyroclastic origin. Most of the slate is dull purple or dull red, generally with a strong cleavage that forms lustrous, micaceous surfaces. The purple or red slate commonly contains numerous round or oval, light-green spots that range from an eighth of an inch to a quarter of an inch in diameter. The origin of this spotted slate is not entirely clear. Furcron and Woodward describe it as amygdaloidal lava at several localities in the northeast part of the Elkton area (as at Lucas Gap and Cubbage Hollow). However, part at least is of sedimentary origin, for some of the cleavage surfaces are crossed by bedding laminae different in color or texture from the enclosing rock, and part contains angular breccia fragments, probably of volcanic origin. Moreover, the unquestioned lava flows of the formation, described below, have different lithologic characters, are more massive, and have less cleavage.

Near the northwest end of Long Ridge, 3 miles northeast of Jollett, the formation includes a thin bed of amygdaloidal lava—a dark, dense rock with small white amygdules. This is very different in appearance from the underlying amygdaloidal lava of the Catoctin greenstone and, unlike the lavas in the Catoctin, contains no epidote. Near Allen Hollow, 2 miles southeast of Jollet, the Loudoun formation contains massive beds as much as 20 feet thick, of highly irregular texture, and consisting of hard jaspery masses in a gray, granular matrix. These rocks may be altered volcanic breccias.

In places, the spotted purple and red slate is interbedded with other slate of green or gray color, and with silvery, sericitic schist.

On the south side of the inlier of injection complex in the northwest part of the Shenandoah Salient, near the heads of Dovel and Cubbage Hollows, the formation contains thin interbedded layers of arkose and arkosic quartzite.

Thickness and stratigraphic relations.—Throughout most of the Elkton area, the Loudoun formation has a nearly constant thickness of 100 feet. In the vicinity of Long Ridge it appears to be much thicker, possibly 200 feet, or approximately the thickness reported for the Loudoun formation in Frederick County, Md. The Loudoun formation thins out northwestward in the Shenandoah Salient. It is present on the south and east sides of the inlier of injection complex in Dovel, Lucas, and Cubbage Hollows, where it lies directly on the complex, and has overlapped the Catoctin greenstone and the Swift Run formation. On the north and west sides of the inlier the Loudoun formation pinches out, so that the Weverton formation lies directly on the complex (pl. 1). The formation may also pinch out near the south edge of the area (fig. 4), for no outcrops of it were seen south of Beldor.

As indicated in the description of the Catoctin greenstone, the Loudoun formation probably lies unconformably on the Catoctin and associated pre-Cambrian rocks. The thinning and disappearance of the Loudoun itself in parts of the area might be due to erosion before the deposition of the Weverton formation, but it seems more likely that it was caused by overlap on the surface of the unconformity below. Such overlap is suggested by the presence of interbedded arkose and arkosic quartzite in Dovel and Cubbage Hollows, not far south of its point of disappearance in the Shenandoah Salient.

WEVERTON FORMATION

Name.—The Weverton sandstone was named by Keith (1894, pp. 329–333) for outcrops on South Mountain near Weverton, Md. In the Elkton area, the unit includes a considerable variety of other clastic rocks, and hence is termed the Weverton formation.

Outcrop.—In the Elkton area, the Weverton formation is widely exposed in the northwestern foothills of the Blue Ridge (pl. 1). Toward the north, it crops out across the Shenandoah Salient in a belt 4 miles wide. However, in much of this belt the outcrops of the formation have been split up by erosion, so it commonly forms the capping of ridges, with older formations exposed in intervening coves and valleys. At the northeast end of Long Ridge the formation reaches an altitude of 3,000 feet—the highest outcrop of the Chilhowee group in the Elkton area. Farther northwest in the salient, the formation rises in another conspicuous peak, Devils Tanyard, whose altitude is 2,832 feet.

South of the Shenandoah Salient, between Dry Run and Elk Run, the upper part of the Weverton formation is cut out for a distance of 2½ miles along the Huckleberry Mountain fault, and only the lower member is exposed. Southwest of Elk Run, where the entire formation is again present, it forms a single band of outcrop half a mile wide, made up of a number of parallel cuestas or hogbacks.

The Weverton formation stands in steep slopes, and in the Shenandoah Salient projects as high mountains. On the slopes, the sandy conglomeratic beds of the lower member project as ledges, but the less resistant beds of the middle and upper members are not as well exposed. Some steep slopes carved from these strata show nothing on the surface but chips and blocks of shaly and sandy float, and in places the blocks are gathered into small talus fields. The best exposures of this part of the formation are in creek beds, ravines, and artificial openings.

Outcrops of parts of the Weverton formation are fairly common, but continuous and well-exposed sections of the whole formation are relatively rare. Some good sections occur along the banks of creeks that cross its outcrop, most of them being near traveled roads and thus readily accessible. In the north part of the area, a nearly complete sequence is exposed along Stony Run, where it leaves Cubbage Hollow on the north. Another is exposed farther south, along Naked Creek southwest of Jollett. In the same vicinity, part of the formation is exposed in a stone quarry southeast of the creek and half a mile southwest of Jollett. In the south part of the area, the sequence is exhibited near U. S. Highway 33 in the valley of Swift Run. Exposures are discontinuous, but some of the beds are well displayed in highway cuts. Another section of the formation is exposed near the south edge of the area, where the Simmons Gap road crosses the ridge between Gap Run and Hawksbill Creek.

General features.—The Weverton formation is the first of the dominantly sandy formations of the Chilhowee group, but it is a rather complex unit, exhibiting considerable lithologic variation, both vertically and laterally (fig. 4). It can be divided into three members, which are traceable across the area. The formation is varied in thickness, and ranges from 1,000 feet in the Shenandoah Salient to 1,600 feet or more in the southeast and south parts of the area. These changes result mainly from variations in thickness of the lower member; the middle and upper members are more constant.

The most conspicuous beds in the lower member are of conglomerate and coarse-grained, feldspathic quartzite. These are interbedded with finer-grained sandy and silty strata. The middle member is a thin but persistent body of argillaceous shale. The upper member contains numerous beds of quartzite, many of which are dark and ferruginous; these are generally finer-grained than the quartzites of the lower member. Between are layers of thin-bedded siltstone and fine-grained gray sandstone.

Lower member.—In the north part of the Elkton area, the lower member of the Weverton formation includes two ledge-making beds of thick-bedded, pebbly quartzite 5 to 25 feet thick, one near the base and one at the top. These quartzites are irregularly sorted and textured. Conglomerate occurs as seams or lenses, and locally forms entire beds. It contains rounded quartz grains and pebbles an eighth of an inch to half an inch in diameter, some clear and vitreous, others tinted blue or violet. In places it contains chips of slate and grains of red jasper. As pointed out by Keith (1894, pp. 312–313, 329–330), the blue quartz and the jasper were probably derived from the injection complex and the Catoctin greenstone, respectively. The matrix is fine- to medium-grained and feldspathic, with bedding indicated by dark laminae, or by textural variations. In a few places, as near Allen Hollow, the ledge-making beds are white vitreous quartzite without pebbles, not unlike many beds in the younger Antietam quartzite.

Interbedded with the quartzite are less resistant, finer-grained rocks. They form a considerable body near the middle of the member, but also wedge in at the base toward the southeast. Some are thin-bedded quartzite and sandstone, but most of them are friable, fine-grained, arkosic siltstone, commonly of pale-greenish color. In some exposures, bedding is indicated in the siltstone by lighter or darker laminae, but in many places the siltstone is transacted by strong cleavage, and all traces of bedding have disappeared. At some localities in Allen Hollow the lower siltstone contains embedded, rounded quartz pebbles.

In the Shenandoah Salient, the lower member of the Weverton formation is about 100 feet thick, and in places even less. Such thicknesses were observed near the inlier of injection complex in Dovel, Lucas, and Cubbage Hollows; also on the west side of Harris Cove, and near Naked Creek west of Jollett. Farther southeast, the unit is thicker. It is about 250 feet thick on the ridge east of Harris Cove, and it apparently thickens to nearly 500 feet on Powell Mountain.

In the central part of the area, between Dry Run and Elk Run, where the upper part of the Weverton formation is cut out by faulting, the lower member consists largely of fine-grained, greenish siltstone, with occasional interbedded layers of dark, ferruginous quartzite. Southwest of Elk Run, near U. S. Highway 33 and elsewhere, coarse-grained quartzites reappear, and the sequence resembles that in the north part of the Elkton area. In this vicinity, the member is probably about 200 feet thick.

At the south edge of the area, the member is much thicker, and coarse-grained beds are indistinct or lacking. Along the Simmons Gap road at the head of Gap Run it is about 700 feet thick, and consists largely of greenish, fine-grained sandstone, siltstone, and silty slate. Coarser materials are rare, but gritty and pebbly layers occur.

Middle member.—The middle member of the Weverton formation is a body of shale with a rather constant thickness of about 100 feet. It consists largely of argillaceous shale, but contains some beds of arkosic siltstone and fine sandstone. It is generally strongly marked by cleavage, the cleavage surfaces having a lustrous sheen caused by the presence of minute flakes of sericite or mica. The rock has a greenish color when fresh, but commonly weathers to a bronze or light-brown color. In some outcrops, bedding has been obliterated by cleavage, in others it stands out as strong partings that cross the cleavage, or as bands of color or texture different from the enclosing rock. The contacts of the middle member with the members above and below are generally sharp and well marked.

The best exposures of the middle member of the Weverton formation are in ravines and along creek banks. Elsewhere, it is expressed by a sag or bench in the topography, and outcrops are poor. At such places, however, the unit can invariably be recognized by its characteristic float, which forms smaller fragments than that of adjacent units, and is made up of shale with a micaceous sheen on cleavage surfaces. At other horizons in the Weverton such float is rare and is nowhere extensive or persistent.

The middle member is extensively exposed in the Shenandoah Salient, but is cut out by the Huckleberry Mountain fault in the central part of the area. South of Elk Run it reappears in characteristic facies, but beyond Beldor it becomes indistinct, owing partly to increasing sandiness of the shale, and partly to increasing shaliness of the enclosing sandstone. This situation is further complicated by the fact that in the same region there is another shale member at a higher level, at the base of the Harpers formation (fig. 4). During a part of the field work this upper shale was correlated with the middle member of the Weverton formation farther north, which resulted in considerable misapprehension as to the stratigraphy and structure. The true relations are established by outcrops between Lee Run and Hawksbill Creek, where both shales are present and lie gently dipping in normal stratigraphic order.

Upper member.—The upper member of the Weverton formation consists of interbedded layers of quartzite and of finer-grained, thinner-bedded sandstone and siltstone. Sandstone apparently dominates in the southern exposures and siltstone in the northern, but the top of the unit is marked in nearly all places by one or more ferruginous quartzite ledges. These are a convenient marker for the top of the member and formation, but are not everywhere well exposed. The contact between the Weverton and Harpers formations is therefore shown as a broken line on parts of the geologic map. Despite its lithologic variations, the upper member throughout the Elkton area has a nearly constant thickness of about 700 feet.

The most characteristic rock in the upper member of the Weverton formation is ferruginous quartzite. This is fine- to medium-grained, vitreous quartzite, and is dark bluish, dark purplish, or even black, the color being caused by the presence of iron oxide in the cement. The ferruginous quartzite forms beds a foot to five feet or more thick, the most prominent in many places being at the top.

Light-colored quartzite is also present in some places, but is irregularly distributed, and at no place forms continuous, traceable beds. Some of it is brown and resinous, some creamy, and some nearly white. Most of the quartzite is medium grained, and all is more or less feldspathic. At two localities, on the west slope of Devils Tanyard and on the east slope of Grindstone Mountain near its south end, indistinct traces of *Scolithus* were seen in light-colored quartzite of the upper member.

A considerable part of the upper member of the Weverton formation, especially in the Shenandoah Salient, consists of dark-greenish, fine-grained sandstone and siltstone, generally in beds a few inches thick, and commonly marked by dark, narrow, argillaceous laminae. On weathering, the beds are characteristically discolored by brown, rusty spots. The siltstone of the upper member slightly resembles the greenish, arkosic siltstone of the lower member, but is probably of considerably different character and origin. It contrasts with the siltstones of the lower member in that bedding is well displayed in nearly every exposure, and cleavage is indistinct or rare.

Stratigraphic relations.—The Weverton formation is conformable with the overlying Harpers formation, and the two units are not separated by an abrupt change in sedimentation. The argillaceous shale of the middle member of the Weverton formation is very similar to the shale member at the base of the Harpers formation in the south part of the Elkton area. Ferruginous quartzite is a characteristic component of the upper member of the Weverton formation, but also occurs as thinner and rarer beds in the overlying Harpers formation. The greenish, thin-bedded siltstone of the upper member is identical with the rock that makes up a great part of the mass of the Harpers formation.

Changes in sedimentation took place from Weverton to Harpers time, but they were gradual. Coarse, pebbly quartzite with lenses of conglomerate is prominent in the lower member of the Weverton formation, but is rare in higher members, and does not occur in the Harpers formation. Quartzite in both the lower and upper members of the Weverton formation is distinctly feldspathic, or even arkosic, but the Harpers contains no prominent feldspathic material. These pebbly, feldspathic, and arkosic sediments are the poorly sorted products of the erosion of pre-Cambrian rocks, and were perhaps deposited rapidly in an unstable environment. Their disappearance upwards records a gradual change to quieter, more stable conditions of sedimentation in Harpers time (Keith, 1894, p. 335).

HARPERS FORMATION

Name.—The Harpers shale was named by Keith (1894, pp. 333–335) for exposures near Harpers Ferry, W. Va. In the Elkton area shale constitutes only a small part of the formation, the remainder being largely siltstone and fine-grained sandstone, so it is designated the Harpers formation.

Outcrop.—The Harpers formation crops out extensively in the Elkton area, and like the formations of the Chilhowee group below and above it, forms part of the foothills of the Blue Ridge (pl. 1). It forms a relatively narrow band that encircles the Shenandoah Salient on its north, west, and southwest sides. Its outcrop is somewhat interrupted by faults in the central part of the area, between the South Branch of Naked Creek and Swift Run, but at least a part of the formation is present in nearly all sections. In the south part of the area, its narrow band of outcrop is resumed beyond Swift Run, but inliers of the formation also occur to the northwest, along the Hanse Mountain anticline.

As the Harpers formation is relatively less resistant to erosion than the formations below and above, it commonly forms a sag in the topography of the foothill belt or lies on the southeastern slopes of the cuestas and hogbacks of Antietam quartzite. Because of its proximity to the Antietam it is in many places concealed by talus fields made up of quartzite blocks derived from that formation. Well-exposed sections of the Harpers formation are accordingly somewhat rare but occur along the banks of the larger creeks. In the north part of the area Stony Run and Naked Creek (already mentioned in connection with sections of the Weverton formation) provide sections of the Harpers. One of the best sections is in the south part of the area, along Hawksbill Creek on the northwest flank of the Hanse Mountain anticline. The top of the Weverton formation is exposed along the creek in the core of the anticline, and to the northwest nearly every bed of the Harpers up to the base of the Antietam quartzite can be seen.

General features.—Throughout the area the Harpers formation has a nearly constant thickness of about 900 feet. It consists dominantly of dark, thin-bedded strata, but these are mainly fine-grained sandstone and siltstone, rather than shale. Rocks of this type, incidentally, form a large part of the nearly equivalent Hampton formation in its type area in northeastern Tennessee (King and others, 1944, p. 36) and have been rather commonly referred to as "shale" in older reports on the Appalachians. True argillaceous shale does, however, form a relatively thin basal member in the south part of the Elkton area. This unit disappears to the north (fig. 4) and is absent in the Shenandoah Salient.

Shale member.—The shale member at the base of the Harpers formation crops out as a narrow belt from the south edge of the area as far northeast as Elk Run, beyond which it is cut out by faulting. Where the base of the Harpers formation reappears in the Shenandoah Salient, the member is missing, and close study of good exposures of the basal beds of the formation in that area fails to reveal any truly shaly material. This is probably due to lateral gradation from shale into the thin-bedded siltstone, rather than to pinching out of the shale body, for the formatoin as a whole is about 900 feet thick in both areas.

Where typically developed in the south part of the area, the member reaches 200 feet in thickness, and consists of very fissile, argillaceous shale of olive-green or dark-green color, weathering bronze or brown. Cleavage is strongly developed and cleavage surfaces are coated by fine mica flakes; in places the cleavage is contorted. Bedding is indicated by darker laminae and thin sandy seams. Like the shale member in the middle past of the Weverton formation, this shale member is poorly exposed on hill slopes, although its presence is generally indicated by shale chips in the float.

Main part of Harpers formation.—The main part of the Harpers formation consists of dark-greenish fine-grained sandstone or siltstone, generally in beds a few inches thick, and commonly marked by argillaceous laminae. Such beds closely resemble those in the upper member of the Weverton formation beneath, but contain less interbedded sandstone and quartzite. In places, some bedding surfaces are ripple marked and some of the surfaces exhibit faint animal trails. Cleavage is generally poor. The rock weathers to drab or brown colors, marked in places by brown rusty spots and splotches.

Interbedded with the thin-bedded sandstone and siltstone are a few thicker beds of earthy sandstone. Here and there, also, are thin beds of ferruginous quartzite, but these are nowhere as prominent as those in the underlying Weverton formation. In a few places, as on the north side of Dry Run just west of the Huckleberry Mountain fault, thicker and lighter-colored quartzite beds are present. At the locality mentioned, beds of cream-colored, resinous quartzite up to four feet thick are interbedded in the siltstone. These are not persistent, and lens out within a short distance.

Stratigraphic relations.—The Harpers formation is succeeded by massive white ledges of the basal Antietam quartzite. In the Elkton area, the contact is concealed by talus in most places, but where it is exposed there are few or no transition beds. The contact is thus one of the most abrupt in the area, but it results from a sudden change in sedimentation rather than from an unconformity. In the Lyndhurst-Vesuvius district (Knechtel, 1943, p. 168) to the south, in Virginia, and in the Mercersburg-Chambersburg area (Stose, 1909, p. 4) to the north, in Pennsylvania, the Harpers formation contains beds of white quartzite with *Scolithus*, like those in the Antietam quartzite. Thus, in regions near the Elkton area, conditions of sedimentation like those during Antietam time began during Harpers time.

ANTIETAM QUARTZITE

Name.—The Antietam sandstone was named by Keith (1894, pp. 335–337) for outcrops near Antietam Creek, immediately north of the Potomac River, in

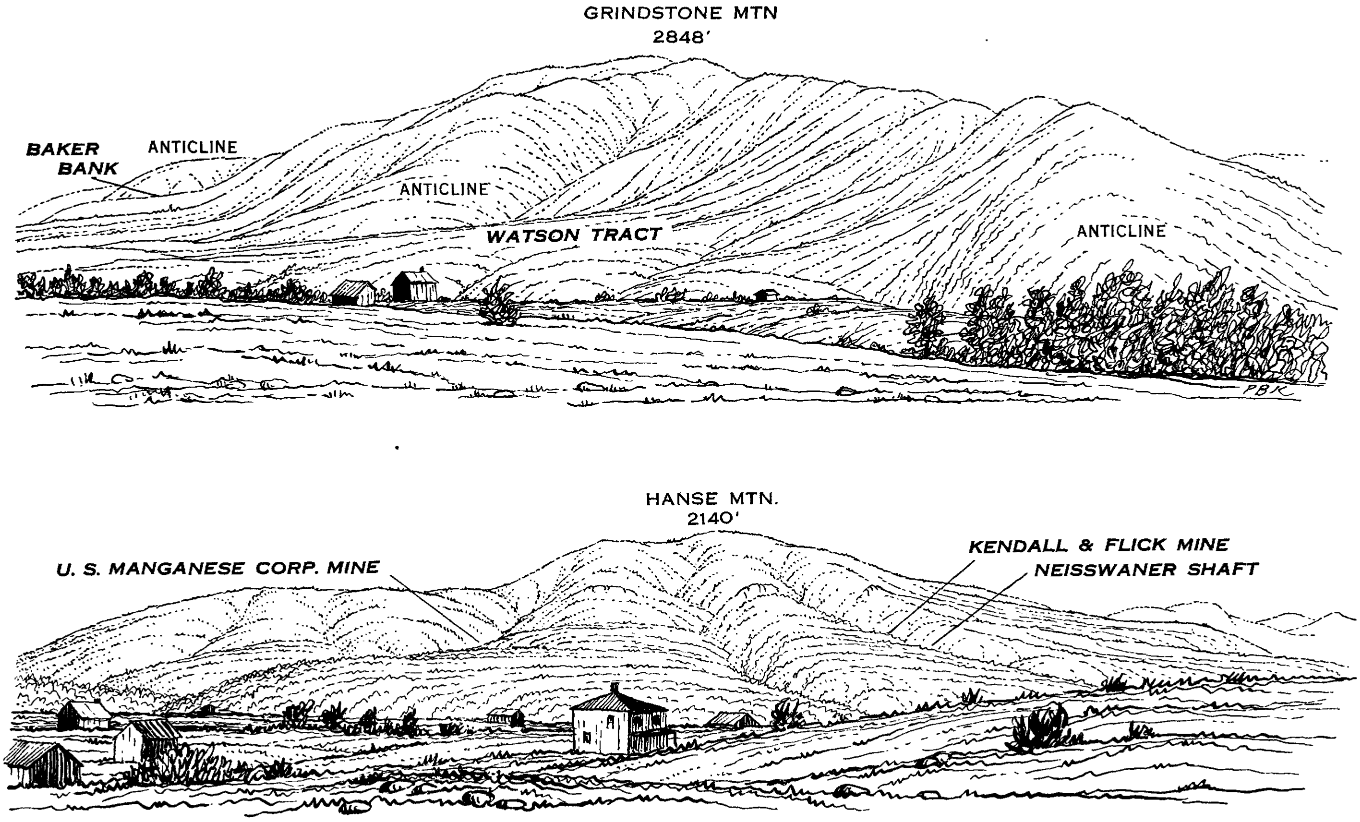

FIGURE 6.—Ridges of Antietam quartzite that form outer foothills of Blue Ridge. Upper view: Grindstone Mountain from south, from opposite side of Naked Creek valley; quartzite is folded into a series of anticlines and synclines, plunging toward observer. Lower view: Hanse Mountain from northwest, from top of terrace in south part of town of Elkton; quartzite is folded into an anticline which follows crest of mountain. In both views, note benches capped by Quaternary gravels at foot of mountains.

Maryland. In the Elkton area, most of the sands of the formation are so well cemented and the rock is so vitreous that the unit is termed the Antietam quartzite.

Outcrop.—The Antietam quartzite forms the outer or northwestern margin of the foothills of the Blue Ridge, and crops out as a sinuous band entirely across the Elkton area (pl. 1). Throughout its course, the formation stands as a series of high crests and jagged ridges, many of which have the form of cuestas or hogbacks, with dip slopes extending down to the Shenandoah Valley. These ridges are broken at intervals by valleys, through which streams drain from the Blue Ridge to the South Fork of the Shenandoah River. Each ridge or mountain in the belt outcrop of the Antietam quartzite is thus separate from the next, and bears a different local name. Of these, the most conspicuous are Grindstone Mountain east of Shenandoah, with an altitude of 2,848 feet, and Hanse Mountain south of Elkton with an altitude of 2,140 feet (fig. 6).

On the ridges, the Antietam quartzite forms massive, persistent white ledges, which are especially prominent in the lower member of the unit. These are the most conspicuous rock outcrops in the Elkton area, and, unlike the ledges of other formations, they may readily be traced on aerial photographs. Outcrops are less prominent in the upper member, as the quartzite and sandstone of the member tend to break down and cover the surface with blocks of float.

Conspicuous features of the Antietam quartzite ridges are the vast fields of talus which strew their sides, made up of angular blocks derived from the quartzite ledges (pp. 62–63). Rounded, water-transported boulders derived from the Antietam are also spread over the floor of the adjacent Shenandoah Valley where they form a part of the fanglomerates, gravel deposits, and alluvium. Similar material occurs in gravels now being transported by all the rivers that drain the area. Quartzite cobbles containing *Scolithus* have been observed in deposits of the Potomac River as far away as Washington, D. C.

General features.—The Antietam quartzite in the Elkton area has a rather uniform thickness of about 800 feet and is divided into two members of about equal thickness (fig. 4). The lower member is composed of white, vitreous quartzite; it contains abundant worm tubes, or *Scolithus*, and forms prominent ledges up to 100 feet thick. Between the ledges are thinner-bedded sandstone or quartzite, mostly poorly exposed. The upper member also contains ledges of white, *Scolithus*-bearing quartzite, but the greater part is formed by relatively less resistant buff or brown sandstone, probably in part calcareous.

Structural features.—The Antietam quartzite has been considerably deformed. It has been steeply tilted and thrown into numerous anticlines and synclines, but because of the competency of the unit, these folds are broad and open (pl. 4). Small-scale contortion and metamorphic features are generally lacking. The quartzite has been formed by the thorough cementation of sandstone by silica, perhaps during diagenesis, and is not the result of dynamic metamorphism, as implied by Butts (1940, p. 39). In many places, the quartzite is strongly jointed, and at a few localities, as along the axes of the steeper anticlines, a coarse fracture cleavage has developed.

Study of the Antietam quartzite aids in working out the structural geology of the Elkton area, because it forms a long belt of good outcrops whose folds and faults can readily be determined. It thus serves as a clue for interpreting adjacent and less well-exposed formations, such as the overlying and immediately adjacent carbonate formations of the Shenandoah Valley, which are largely concealed by wash and residual clay. As the manganese and iron deposits along the west foot of the Blue Ridge are closely related to these carbonate formations, close attention was given to the structure of the Antietam quartzite during the manganese investigation.

Lower member.—The lower member of the Antietam quartzite consists of several bodies of massive, cliff-making quartzite, separated by slope-forming beds. In the north part of the Elkton area, from Fultz Run around the north flank of the Shenandoah Salient, there are three main cliff makers. The lower two are especially massive, and near the north end of Dovel Mountain they merge into a nearly continuous sequence of quartzite. The upper ledge is not as strong, and in places fails to crop out. For some miles south of Fultz Run, four cliff makers are present; perhaps the basal ledge has here split into two parts. In the south part of the area, south of Naked Creek, there are two cliff makers in the lower member. These may correspond to the lower pair of cliff makers farther north; if so, the boundary between the two members of the Antietam has been placed lower in the southern part of the area than in the northern.

The quartzite of the cliff-making beds is white, pink, or light buff. It is so thoroughly cemented by silica that sand grains are seldom visible, and the rock breaks across them. Most of the grains are of quartz, although a few grains of white feldspar were noted in the basal beds. Grains of dark minerals are very rare. Where the quartz grains are visible they are mostly small, of uniform size, and well rounded. Occasionally somewhat larger grains form seams in the quartzite.

The quartzite of the cliff-making beds commonly contains worm tubes, or *Scolithus*, which are cylindrical structures an eighth of an inch to a quarter of an inch in diameter, filled by sand of the same character as the enclosing rock. The tubes originate on the surfaces of the bedding planes and extend downward, normal to the bedding, for a foot to 3 feet or more. In most places they are closely spaced, and some are less than an inch apart. On bedding surfaces the ends of the tubes appear as nodes. The presence of *Scolithus* is of some value in field work, for it aids in locating the bedding, where this is indistinct or obscured by joints. It is also useful in determining tops and bottoms of beds and whether the beds have been overturned. Where the quartzite has been strongly deformed the tubes have provided lines of weakness that have guided the directions of cleavage and jointing.

Scolithus ordinarily occurs only in evenly bedded layers, and these typically form the upper part of the cliff-making quartzite bodies. The tubes fade out downward in each layer, and as they do so the rock becomes very massive or assumes a cross-bedded structure. Strong cross bedding is a common feature in the lower parts of the ledges. In the third ledge from the base on the west slope of Roundhead Mountain single cross beds attain a thickness of 5 feet and a sweep of 25 or 30 feet. Elsewhere the dimensions are smaller.

Few of the slope-making beds are well exposed, as they are generally covered by float or talus from the beds above. Rare outcrops indicate that they consist mainly of thin-bedded, rusty sandstone, probably with an original calcareous cement. There are, however, some thin beds of fissile buff siltstone containing scattered sand grains.

The types of rock described seem to have been laid down during sedimentary cycles that were repeated a number of times in the lower member. A cycle would be initiated by deposition of cross-bedded quartzite, probably under conditions of strong scouring action. Later, during slower and less agitated conditions of deposition, *Scolithus* lived in great abundance. During the closing stages of the cycle thin-bedded sandstones were deposited, probably accompanied to some extent by lime precipitation. In places cycles did not reach completion; in some cliffs *Scolithus*-bearing quartzite is overlain by cross-bedded quartzite along a surface of scour and thin-bedded sandstones are absent.

Upper member.—The upper member of the Antietam quartzite contains fewer ledge-making beds than the lower member, and these are thinner, more lenticular, and less persistent. The greater part of the material in the upper member is similar to the slope-making beds of the lower member. In the north part of the area, around the north side of the Shenandoah Salient, a ledge a few feet above the base forms a distinct topographic bench, but fails to crop out for considerable distances. Locally, another ledge is present somewhat higher up, and at most places there is another at the top of the formation. South of Naked Creek, ledges are present here and there in the member, but are not persistent.

The rocks of the upper member are generally thinner bedded than those below, and weather to rusty and friable blocks. Some of the ledges are as white and vitreous as those in the lower member, but others weather brown. *Scolithus* is common in the ledges, including those at the top, and occurs in the thinner intervening beds as well. *Scolithus* in beds near the top of the formation is well displayed in cuts on State Highway 12, a mile and a half south of Elkton, just north of the bridge over Hawksbill Creek. Probably many of the beds in the upper member had an original calcareous cement, but this has largely been leached during weathering. In some beds, especially those toward the top, rounded quartz grains an eighth of an inch or more in diameter are embedded.

Stratigraphic relations.—The Antietam quartzite is overlain by the Tomstown dolomite, so that on passing from the Antietam to the Tomstown there is a lithologic change from dominantly arenaceous to dominantly carbonate sedimentary rocks. The contact is probably transitional. The apparently calcareous nature of the upper sandstones of the Antietam is a precursor of Tomstown conditions. No unweathered outcrops of the basal Tomstown have been seen in the Elkton area, but from the nature of its residuum one may infer that the lower 10 to 50 feet of the dolomite contained interbedded layers of sandstone and shale (p. 28). No evidence of unconformity between the two formations has been reported in areas where the contact is better exposed.

Despite the evidence of transitional features just noted, the change in gross lithologic character from the Antietam quartzite to the Tomstown dolomite is abrupt and striking. The same lithologic change takes place at the top of the Chilhowee group along its whole course in Virginia and Tennessee, as well as farther north and south (Butts, 1940, p. 41). This change in a conformable sequence of beds is probably of about the same age everywhere. It may mark a significant time zone within the Lower Cambrian, expressive of a change of environment of broad dimensions, but the causes of the change are largely problematical.

Fossils and age.—No fossils other than *Scolithus* have been seen in the Antietam quartzite in the Elkton area. Elsewhere, small collections have been made in the uppermost beds which have yielded, according to Butts (1940, p. 40), species of *Olenellus*, *Hyolithes*, and *Obolella*, of Early Cambrian age. A few recent collections from this zone have been reported by Stose and Stose (1946b, p. 42), and by others, but the greater part of the material was obtained years ago by Walcott (1892a, pp. 52–57; 1892b, pp. 469–482). Walcott's principal localities were along the James River near Balcony Falls, in central Virginia, and on the west flank of South Mountain, in Maryland. The fossiliferous beds are reported to be crumbly, thin-bedded sandstone, probably originally calcareous. Such beds also occur near the top of the Antietam in the Elkton area, but were not carefully searched for fossils during the present investigation. It is entirely likely that further scrutiny of these beds would yield fossils in this area also.

BROADER RELATIONS OF CHILHOWEE GROUP

Correlation of formations within the Chilhowee group.—The Chilhowee group has been mapped along the southeast side of the Appalachian Valley throughout Virginia and Tennessee, and the general distribution of the constituent formations has been shown on some published maps (Virginia Geological Survey, 1928). However, except for scattered areas, little is actually known of the details of this distribution, or of the precise character and limits of the formations. On plate 2 the writer has assembled some of the better-known sections, from Chilhowee Mountain in central eastern Tennessee, to South Mountain and Catoctin Mountain in Maryland. In Tennessee, where the stratigraphy of many areas has been studied in detail, there is considerable variation, so relations are actually more complicated than indicated on the diagram. In Virginia, where fewer areas have been studied in detail, a similar degree of complexity no doubt exists but remains to be discovered.

As has been indicated above, the top of the Chilhowee group is probably of about the same age everywhere, so the correlation line at the top of the group may be regarded as a time boundary. Correlations beneath have a less definite basis, but are capable of solution by detailed work. On the basis of such work, the relations between the rocks of Chilhowee Mountain, Tennessee, and Glade Mountain, Virginia, seem fairly certain; and also those of the Vesuvius area, Virginia, and of the South Mountain-Catoctin Mountain area, Maryland. On the relations in the intervening area, little information is available. As the formations in the southern and northern areas resemble each other in a broad way, the Erwin has commonly been correlated with the Antietam, the Hampton with the Harpers, and the Unicoi with the Loudoun and Weverton. However, differences also exist, and there is no assurance that the boundaries of the formations actually agree. It therefore seems undesirable ever to extend the northeastern Tennessee names into northern Virginia (Stose and others, 1919, pp. 13–22), or to follow the rules of priority and apply the name Antietam to the Erwin (Resser, 1938, pp. 4–5, 20).

Base of Cambrian.—In this report, as in most others on this general region, the Chilhowee group is classed as of Early Cambrian age, and the base of its lowest formation is considered to be the base of the Cambrian system. However, alternative interpretations have been made by some authors.

Resser and Howell (1938, pp. 199, 206; see also Resser, 1938, p. 20; Howell and others, 1944) place the base of the Cambrian at the base of the Antietam and Erwin quartzites, because these formations contain the lowest diagnostic Cambrian fossils. They assign the underlying Harpers, Weverton, and Loudoun formations of the northern area and the Hampton and Unicoi formations of the southern area to the "Beltian" or pre-Cambrian. A similar practice is recommended by Snyder (1947, pp. 146–152), who advocates placing the base of the Cambrian at the base of the lowest fossiliferous formations. Wheeler (1947, pp. 157–159) restricts the base of the Cambrian still further, and would place it immediately beneath the lowest occurrence of diagnostic Cambrian fossils.

By contrast, Bloomer and Bloomer (1947, pp. 94–106) suggest that the Catoctin greenstone beneath the Chilhowee group is closely related to the lower part of the Chilhowee group and is probably of early Cambrian age.

These proposals in regard to the base of the Cambrian involve fundamental problems of stratigraphic procedure on which there is as yet no general agreement. The writer has discussed the problem insofar as it relates to the southern Appalachians in another paper (1949b) and the details need not be repeated here.

It is sufficient to say that in the Elkton area and elsewhere in northern Virginia the lowest diagnostic Cambrian fossils occur at the top of the Antietam quartzite, at the top of the Chilhowee group, and that beneath are two unconformities, one at the base of the Chilhowee group and the other at the base of the Catoctin greenstone and Swift Run formation. The rocks of the Chilhowee group, down to the first unconformity below the lowest diagnostic fossils, seem to form a natural depositional unit, no part of which is greatly different in age from any other part. The rocks of the Catoctin greenstone and Swift Run formation, between the base of the Chilhowee group and the second unconformity, are different in lithologic character and were formed under different conditions.

It appears, therefore, that the most logical position at which to place the base of the Cambrian is at the base of the Chilhowee group, and the unconformity beneath it thus separates early Cambrian from late pre-Cambrian rocks. The still lower unconformity, between the Swift Run formation and the injection complex, lies within the pre-Cambrian and divides late pre-Cambrian from early pre-Cambrian rocks.

TOMSTOWN DOLOMITE

NAME

The Tomstown limestone was named by Stose (1906, p. 208; 1909, p. 5) for outcrops near Tomstown, in the Mercersburg-Chambersburg area, Pennsylvania. In Virginia, the unit is ordinarily referred to as the Tomstown dolomite.

The Tomstown closely resembles in character and stratigraphic position the Shady dolomite, whose type area is in northeastern Tennessee (Keith, 1903, p. 5). The name Tomstown dolomite is now used in Virginia as far south as Roanoke, beyond which the name Shady dolomite is used for the same unit. Unlike the formations of the Chilhowee group, whose identity across the entire region is uncertain, the Tomstown and Shady are probably the same formation. At some future time, the name Tomstown may well be dropped as a synonym, and the name Shady substituted for it.

OUTCROP

In the Elkton area, the Tomstown dolomite is poorly exposed, being greatly leached by weathering, and hence blanketed thickly by residual clay. In many places it is, moreover, heavily covered by gravel washed out from the Blue Ridge foothills immediately adjacent. Similar conditions exist throughout a long belt of country from the headwaters of the Shenandoah on the south to Front Royal on the north, in all of which the Tomstown is scarcely exposed (Butts, 1940, p. 53). It has even been suggested that the Tomstown is largely missing in this region, from faulting of other causes. The nearest extensive exposures of the Tomstown are in Clarke County, about 60 miles northeast of the Elkton area (Edmundson, 1945, pp. 179–183).

The present investigation has demonstrated that the Tomstown is probably present across the entire Elkton area. Exposures of the dolomite have been found in two localities, near Fultz Run and Crooked Run, in a deeply dissected district in the north part of the area (pl. 1). The dolomite has also been identified in test holes drilled by the U. S. Bureau of Mines in 1941 on the Watson tract five miles northeast of Elkton, and on a tract south of Giants Grave three miles south of Elkton (fig. 15). Elsewhere, the unit can be recognized by its characteristic residuum. These features suggest that the Tomstown occupies a belt 1,000 to 2,000 feet wide along the southeast margin of the Shenandoah Valley, between the Antietam quartzite of the foothills of the Blue Ridge, and the outcrops of the Waynesboro shale farther out in the valley.

GENERAL FEATURES

The apparent width of outcrop of the Tomstown dolomite and the structure of adjacent and better-exposed formations suggest that it is about 1,000 feet thick in the Elkton area, which agrees with the estimate of 1,000 to 1,500 feet made for it in Clarke County (Edmundson, 1945, p. 180). Information on the character of the Tomstown is fragmentary. Localities where fresh rock of the formation has been observed are widely scattered geographically, and the rock at these places represents small sections of different parts of the formation. Elsewhere, however, deductions as to the original character of the formation can be made from the nature of the residuum.

The formation apparently consists principally of fine-grained light-gray to dark-gray dolomite, with some coarser-grained, more saccharoidal dolomite. Layers of limestone are also present. Much of the dolomite appears to be impure and argillaceous, the insoluble component constituting 3 to 25 percent of the rock. There may also be many interbedded layers of calcareous shale in the Elkton area, although none have been reported in the more extensive outcrops in Clarke County (Edmundson, 1945, pp. 179–183). The large argillaceous content of the dolomite and the presence of shale layers explain the great volume of residual clay that is produced by the weathering of the formation. The formation contains many chalcedonic chert nodules and concretions, and the basal 50 feet includes interbedded sandy layers. The cherts and sands are preserved in the residual clays after the enclosing dolomites have been leached.

AGE

In the Elkton area, a single reefy mass was observed in the Tomstown which may be a *Cryptozoon*, but otherwise no fossils were found. Fossils are not abundant in the Tomstown and Shady of other areas, except at certain localities. Those fossils that have been collected are of Early Cambrian age (Butts, 1940, pp. 54–56; 1941, pls. 64–65).

TOMSTOWN DOLOMITE IN OUTCROPS

One of the outcrops referred to (p. 24) is on the west side of the valley of Fultz Run, or Steam Hollow, a mile and a half south of the South Fork of the Shenandoah River (pl. 1). The largest exposure is at the foot of the valley wall on the west, but ledges also occur in the bed of the run nearby. On the valley wall, about 100 feet of rock is exposed; in the run, about 30 feet. These outcrops seemingly represent the top of the formation, as shale of the Waynesboro formation lies adjacent to them toward the northwest. However, the structure is complicated by folds or faults, so part of the beds dip away from the Waynesboro, at angles of 30° or less.

The outcrops on the valley wall consist of light-gray to buff, finely and evenly crystalline dolomite in 6-inch to 1-foot beds, with some thicker beds of dark blue-gray dolomite, and thin interbedded layers of shaly, earthy dolomite. Most of the dolomite is characterized by thin laminae, which project on weathered surfaces and evidently contain considerable amounts of insoluble material. Some of the beds contain nodules of white, chalcedonic chert.

In the stream bottom, the lower part of the exposure is gray, fine-grained limestone, in part laminated and platy, and the upper part is thick-bedded dolomite (fig. 7). Near the base of the exposure is a very hummocky, knobby layer, which projects a foot or more into the overlying strata. This may be a *Cryptozoon* reef.

The other exposure referred to is half a mile to the south, near the head of the valley of Crooked Run, 2 miles from the South Fork of the Shenandoah River and a quarter of a mile east of Comertown (pl. 1). Here again, only the topmost beds are exposed, and are overlain by shales of the Waynesboro formation, but the strata are vertical and the structure is simpler. However, the rocks in Crooked Run do not resemble those in Fultz Run, and include considerable bodies of shale similar to that in the Waynesboro formation. These rocks may represent a lower unit of the Waynesboro, but as the beds of the Waynesboro formation above have a thickness normal for that formation, this exposure is more probably a part of the Tomstown dolomite.

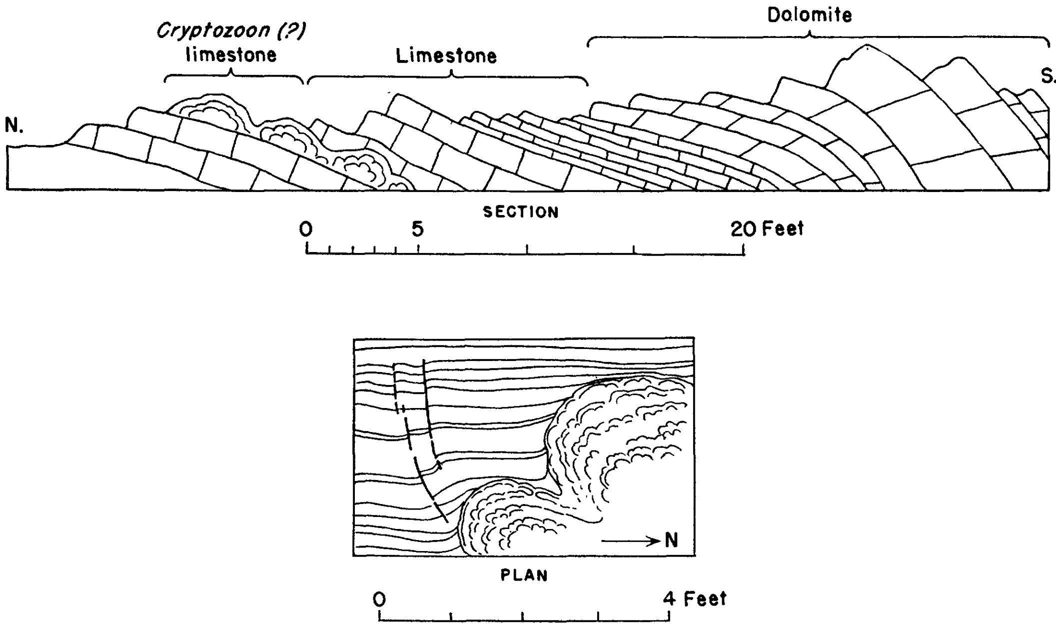

FIGURE 7.—Sketches showing stratigraphic details of Tomstown and Elbrook dolomites. Upper figure: section of outcrop of Tomstown dolomite in bed of Fultz Run a mile and a half south of South Fork of Shenandoah River. Lower figure: plan of outcrop in nearly vertical beds of lower part of Elbrook dolomite in valley of Crooked Run a mile and a quarter south of South Fork of Shenandoah River.

At this locality, a total of 742 feet of beds was measured, as indicated in the table below.

Stratigraphic section of upper part of Tomstown dolomite near head of valley of Crooked Run

Shale of Waynesboro formation at top of section (see table, p. 31).

Tomstown dolomite:	*Thickness in Feet*
5. Dark-gray, finely crystalline dolomite, full of cavities, weathers to rounded boulders. Much of rock is massive, but some contains argillaceous seams that weather to ribs on surface	47
4. Shale, in part poorly exposed, with thin interbedded sandstones in upper part and a poorly exposed bed of dolomite in middle	170
3. Rotten, thinly laminated buff dolomite, and blue-gray, compact, brittle limestone. Some chalcedonic chert on weathered surface. Some interbedded shale	260
2. Fine-grained, dark-gray dolomite, mottled and lumpy, forming reticulated ridges on weathered surface. Forms massive beds 5 to 10 feet thick	75
1. Hard, dull-brown or gray siliceous shale	190
Total thickness of measured section	742

Base concealed by terrace gravel.

Several small outcrops of Tomstown are also shown on the geologic map east and northeast of Ingham (pl. 1). These are ledges of brown or reddish shale, identical in appearance with the shales of the Waynesboro formation. They lie, however, within 700 feet of outcrops of the Antietam quartzite, and if they are Waynesboro, the Tomstown is very thin in this vicinity. More probably they represent shale members in the Tomstown, similar to those found on outcrops or in drill holes in other places, where the interbedded dolomite has been destroyed at the surface by weathering. The presence of carbonate beds above these shales is indicated by a sink hole on the ridge top a mile northeast of Ingham.

SUBSURFACE TOMSTOWN DOLOMITE

On the Watson tract, 5 miles northeast of Elkton, unweathered dolomite was encountered in U. S. Bureau of Mines test hole No. 2 (section R–R′, fig. 15). The drill hole was put down near the axis of a shallow syncline that plunges southwestward away from the outcrops of Antietam quartzite toward the head of the first ravine southeast of Mudhole Run, at an altitude of 1,460 feet (pl. 1). The base of the Tomstown dolomite was not reached in the drill hole, but from the nearby structural relations the rocks are obviously in the lower part of the formation. Other test holes and shafts on the northwest flank of the syncline encountered only residual clay above the Antietam quartzite, the clay in these holes commonly extending much deeper than the top of the dolomite in hole No. 2.

In hole No. 2 superficial gravel extends to a depth of 32 feet, and residual clay from 32 feet to 144 feet. Between 144 feet and 178 feet the rock is fine-grained gray dolomite, in part laminated, in part breaking into hackly fragments, with many beds of argillaceous dolomite and dolomitic shale. Here and there bodies of brown, waxy residual clay are encountered, which suggests that the surface of the dolomite is pinnacled and honeycombed. Between 178 feet and 201 feet, the total depth of the hole, the rock is fine-grained, light-gray, laminated dolomite, that grades down into coarsely crystalline or saccharoidal gray dolomite.

The table below shows the results of tests made by J. M. Axelrod on two samples of dolomite broken from cores from hole No. 2.

Results of tests on dolomite from U. S. Bureau of Mines drill hole No. 2 on Watson Tract

Chemical analyses (in percent)

Depth (feet)	CaO	MgO	Fe	Mn	Inorganic insoluble
178–182½	30. 93	19. 45	0. 36	0. 039	3. 33
182½–188	30. 71	21. 53	0. 19	0. 054	0. 09

Composition of insoluble residues (in percent)

Depth (feet)	Quartz	Clay	Ortho-clase	Minor constituents
178–182½	25	65	5	Chromite, garnet, tourmaline, tremolite, leucoxene.
182½–188	Some	Mostly	Some	Opal, leucoxene, magnetite, brown garnet, brown hornblende.

On the tract south of Giants Grave, 3 miles south of Elkton, three test holes were drilled on an approximate east-west line near the first run southwest of Giants Grave. Unweathered dolomite was encountered in each test hole (section T–T, fig. 15). There is no evidence as to what parts of the Tomstown dolomite were penetrated, but hole No. 3 is nearest the Antietam quartzite, and the section penetrated is thus probably lower in the formation than the sections penetrated in holes No. 2 and No. 1.

Hole No. 1 is at an altitude of 1,140 feet, and encountered only quartzite gravel and sandy wash to a depth of 260 feet. Unweathered dolomite lies directly beneath, and no residual clay is present. Dolomite extends to 290 feet, the total depth of the hole. The dolomite is drab gray, fine-grained, in part laminated, in part highly argillaceous. There are also many beds of buff or brown, dolomitic shale.

The table below shows the results of tests made by J. M. Axelrod on cable-tool cuttings from hole No. 1.

Results of tests on dolomite from U. S. Bureau of Mines drill hole No. 1 on tract south of Giants Grave

Chemical analyses (in percent)

Depth (feet)	CaO	MgO	Fe	Mn	Inorganic insoluble
265	24. 45	18. 60	0. 61	0. 049	12. 64
270	24. 90	16. 89	0. 67	0. 040	18. 64
275	17. 37	12. 03	1. 24	0. 044	40. 20
280	15. 33	10. 41	1. 37	0. 050	46. 60
285	23. 96	16. 24	1. 00	0. 045	20. 23
290	22. 04	15. 07	1. 21	0. 053	22. 04
275–290 [1]	30. 17	20. 29	0. 42	0. 030	3. 14

Composition of insoluble residues (in percent)

Depth (feet)	Quartz	Clay	Ortho-clase	Biotite	Minor constituents
265	59	40	1	------	Leucoxene, magnetite, chromite.
270	78	20	2	------	Brown garnet, leucoxene, tourmaline.
275	48	48	2	1	Plagioclase, chromite, leucoxene, garnet, opal.
280	30	65	5	------	Plagioclase, chromite, leucoxene.
285	30	50	20	------	Dark-green garnet, chromite, microcline, tourmaline, leucoxene.
290	32	55	5	7	Chromite, leucoxene.
275–290 [1]	35	60	2	------	Zeolite, chromite, tourmaline.

[1] Large fragments broken off when setting casing; exact depth unknown.

Hole No. 2 was put down about 500 feet east-northeast of hole No. 1, at an altitude of 1,170 feet. In this hole, surface sand and gravel are penetrated to 95 feet, and residual clay from 95 to 143 feet. Dolomite is encountered from 143 feet to 165 feet, the total depth of the hole. This rock is fine-grained, light-gray dolomite, and somewhat coarser dark-gray dolomite, with some beds of soft, gray, calcareous shale. The table below shows the results of tests made by J. M. Axelrod on a cable-tool sample from hole No. 2.

Results of tests on dolomite from U. S. Bureau of Mines drill hole No. 2 on tract south of Giants Grave

Chemical analysis (in percent)

Depth (feet)	CaO	MgO	Fe	Mn	Inorganic insoluble
143½	28. 17	19. 33	0. 44	0. 014	7. 60

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Composition of insoluble residue (in percent)

Depth (feet)	Quartz	Clay	Ortho-clase	Chro-mite	Minor constituents
143½	7	55	45	2	Magnetite, leucoxene, tourmaline, garnet, augite, opal.

Hole No. 3 was put down about 300 feet east of hole No. 2, near the National Park boundary, at an altitude of about 1,200 feet. In this hole, surface sand and gravel are penetrated to a depth of 145 feet, and residual clay from 145 to 177 feet. Dolomite is encountered from 177 to 190 feet, the total depth of the hole. This rock is fine- to coarse-grained, dark-gray dolomite, with some slightly argillaceous beds in the lower part. The table below, shows the results of tests made by J. M. Axelrod on cable-tool samples from hole No. 3.

Results of tests on dolomite from U. S. Bureau of Mines drill hole No. 3 on tract south of Giants Grave

Chemical analyses (in percent)

Depth (feet)	CaO	MgO	Fe	Mn	Inorganic insoluble
177–182	22. 37	19. 03	0. 83	0. 210	9. 31
182–187	29. 00	20. 05	0. 53	0. 085	3. 84
187–190	5. 87	5. 17	2. 39	0. 048	69. 34

Composition of insoluble residue (in percent)

Depth (feet)	Quartz	Clay	Ortho-clase	Leu-coxene	Minor constituents
177–182	10	78	10	1	Opal, magnetite.

BASAL BEDS OF TOMSTOWN DOLOMITE

No fresh outcrops of the basal part of the Tomstown dolomite are exposed in the Elkton area, although outcrops of decomposed beds next above the Antietam quartzite are rather common.

Such material was encountered in the U. S. Bureau of Mines incline on the Watson tract (pl. 3), and in adjacent test holes. In the Bureau of Mines incline, the basal 50 feet of residuum above the Antietam quartzite includes clay, silty clay, and sand. These form lenticular beds and show much disturbance, in part at least because of compaction during leaching and weathering. Some lenses of brecciated quartzite are present in the clay. On the South Branch of Naked Creek a mile and a half southeast of Furnace, the following section is exposed above the Antietam quartzite. The quartzite beds and the laminae in the interbedded clay are vertical.

Section of leached basal beds of Tomstown dolomite on east bank of South Branch of Naked Creek, 1½ mile southeast of Furnace

	Feet
Top not exposed	
Residuum of Tomstown dolomite:	
6. Residual clay, brown and waxy, with vertical laminae. Contains streaks of wad	?
5. Clay with fragments of brecciated quartzite; some wad	10
4. Massive, brown quartzitic sandstone	6
3. Breccia of quartzite fragments in clay matrix	5
2. Friable brown sand, with clay partings, passing up into silty gray and yellow clay	20
Antietam quartzite (top ledge):	
1. Brown quartzitic sandstone in 6-inch to 1-foot beds, containing *Scolithus*	30

Beds of the type described at these two localities evidently represent a heterogeneous deposit, perhaps transitional from the sandy beds of the Antietam to the carbonate beds of the Tomstown. Probably they originally consisted of interbedded dolomite, shaly dolomite, shale, and sandstone. A small thickness of such transition beds has been observed in unweathered outcrops of the contact zone in southwestern Virginia and northeastern Tennessee (Miller, 1944, pp. 19–20; King and others, 1944, pp. 18–19, 30–31).

RESIDUUM OF TOMSTOWN DOLOMITE

Residuum of the Tomstown dolomite is much more widely distributed at or near the surface than the unaltered rock, and is shown by a separate pattern on the geologic map (pl. 1). Natural outcrops occur in creek banks, in fields, and elsewhere. In many of them, the attitude of the laminae is sufficiently consistent to warrant placing a strike and dip symbol on the geologic map. The residuum has also been revealed artificially in mining operations, which cut through the overlying gravel deposits. At the mines, residuum is seen at the surface in open-cuts (fig. 8), and is known beneath the surface in mine shafts and drill holes. Considerable areas are thus proved to be underlain by residuum, although its actual surface outcrop may be rather small, and most of the surface is covered by gravel. In the mining areas the known extent of the residuum has been indicated schematically on the geologic map.

During the investigation, the writer studied the residuum of the Tomstown dolomite in detail in the underground workings and drill holes put down by the U. S. Bureau of Mines on the Watson tract. In older mine workings, much of the residual clay has slumped, but reasonably fresh exposures may be seen in the open-cut of the Stanley mine in the north part of the area. Natural outcrops are abundant along Naked Creek and the South Branch of Naked Creek east of Furnace. In test holes on the Watson tract, the clay attains thicknesses of 50 to nearly 150 feet, and lies either on An-

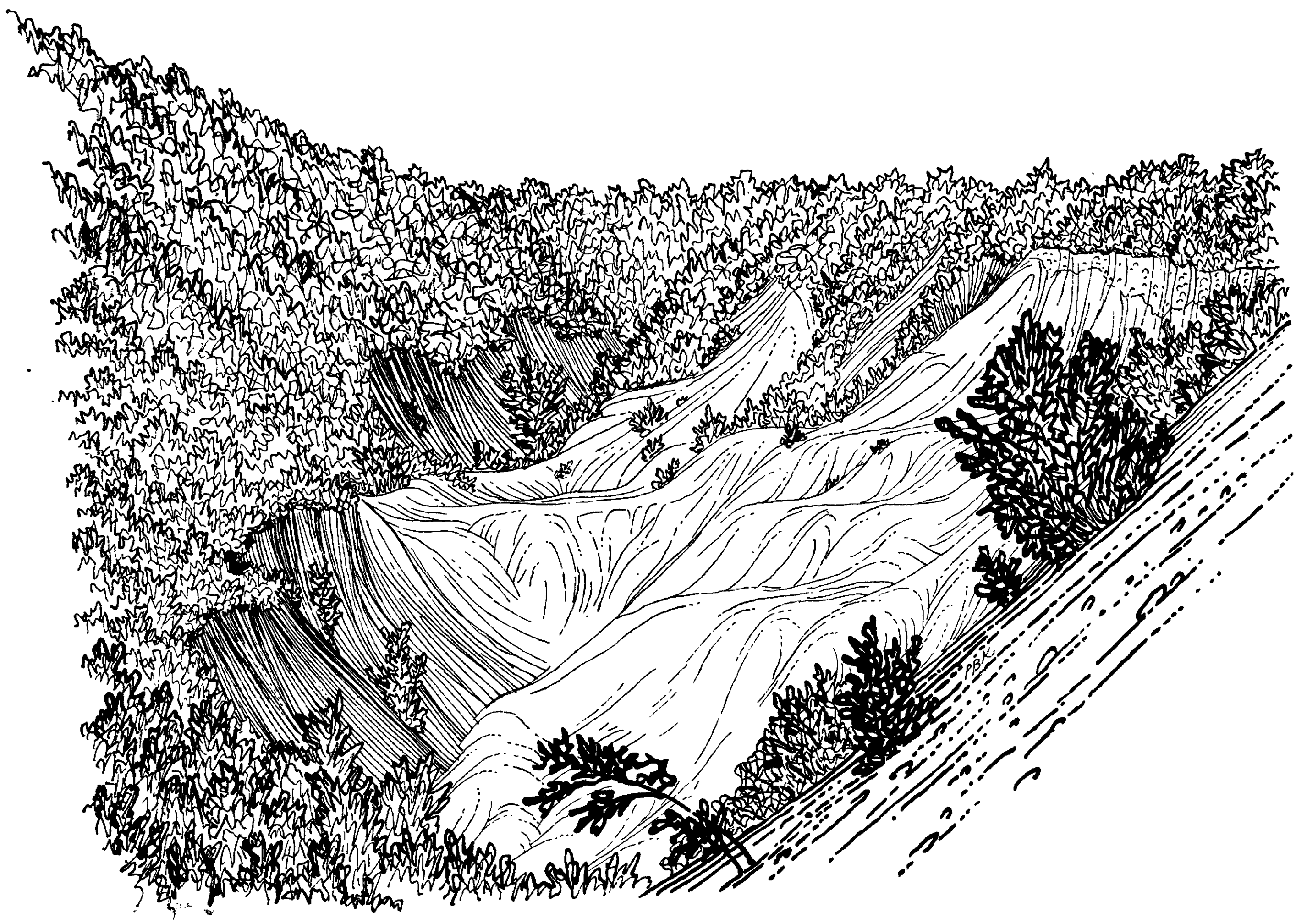


FIGURE 8.—Clay residual from Tomstown dolomite exposed in open-cut of abandoned iron mine. View of open-cut of Smith bank, 2½ miles northeast of town of Shenandoah, looking southeast. The cut exposes a thickness of more than 75 feet of residual clay and does not reach the underlying dolomite. Top of Antietam quartzite is near left end of view.

tietam quartzite or on unweathered dolomite (fig. 16). Similar great thicknesses undoubtedly exist elsewhere.

The residual clay is exceedingly varied in texture and color. The most common variety is tough, waxy, and dark brown, and is known to local miners as "buckfat." It is commonly interbedded with other waxy clays of red, orange, buff, pearl-gray, or white color. It includes dark gray or black streaks and seams, stained by wad or other manganese oxides. Other clay is silty and has a perceptible granularity to the touch. Such clay is commonly more fissile than the waxy clay, and is buff or light yellow. In the basal beds, sandy clay is present, and even lenses of unconsolidated sand. The waxy or "buckfat" clay was probably derived from the weathering of dolomite beds, and the silty clay was probably derived from weathering of shale or shaly dolomite.

The different varieties of clay are intermixed in a most complicated manner (pl. 3). Most of the clay is thinly laminated in light and dark colors, the laminae being uneven and contorted. Here and there are masses 5 or 10 feet thick, of uniform character and without laminae. Some clay is brecciated, with angular clay fragments of one texture or color embedded in clay of different character. As may be seen in larger outcrops, the clay laminae are sharply and irregularly folded, and broken by small faults. Layers pinch and swell, and are traceable for only short distances. Some of these features may have been inherited from original structure in the dolomite, but most of them were probably formed by slumping and compaction during leaching, and by creep during later periods of erosion.

Embedded in the residual clay are fragments of various insoluble substances. White or gray chalcedonic chert is common, and was derived from nodules and concretions in the original dolomite. Some chert fragments retain the rounded surfaces of the original nodules, but others are broken and angular. At the

Stanley mine and a few other places are fragments of jasperoid, a siliceous rock of dull luster and finely granular texture, believed to have been formed by replacement of dolomite during weathering (King and others, 1944, pp. 23–24). The sands in the basal residual clays have already been noted (p. 28).

The residual clay of the Tomstown dolomite also contains iron and manganese oxides, either as disseminated streaks, or as narrow veins, nodules, or irregular, massive lenses. These oxides were introduced after the formation of the clay, by processes of mineralization and replacement, but were probably derived from the weathering and concentration of iron and manganese minerals disseminated in the original dolomite. In places, the iron and manganese oxides are sufficiently concentrated in the residual clays of the Tomstown dolomite to produce workable ore bodies. These concentrations have been the principal source of the iron and manganese that have been produced in the Elkton area.

STRATIGRAPHIC RELATIONS

The Tomstown dolomite is overlain by the Waynesboro formation, also of Early Cambrian age. The Tomstown is mainly dolomite, but contains much shale; the Waynesboro is mainly shale, but contains limestone and dolomite. The two units are apparently conformable, and are parts of a single depositional sequence.

WAYNESBORO FORMATION

NAME

The Waynesboro formation was named by Stose (1906, p. 209; 1909, p. 5) for outcrops near Waynesboro, in the Mercersburg-Chambersberg area, Pennsylvania. The Waynesboro formation of the Elkton area was termed the Watauga shale in the report by Stose and others (1919, pp. 25–27), but this name has now been abandoned.

The Waynesboro formation closely resembles in character and stratigraphic position the Rome formation of the southern Appalachians (Hayes, 1891, p. 142). The name Waynesboro is now used in Virginia as far south as Roanoke, beyond which the name Rome is used for the same unit. At some future time, the name Waynesboro may well be dropped as a synonym, and the name Rome substituted for it.

OUTCROP

The Waynesboro is one of the formations of the Shenandoah Valley, and underlies the valley floor half a mile or more out from the foothills of the Blue Ridge (pl. 1). Its belt of outcrop enters the Elkton area from the northeast near Marksville, but south of Marksville it is offset about 2 miles to the west by the Stanley fault, so its next exposures are along Stony Run, a mile beyond Stanley. From Stony Run, its belt of outcrop is continuous to the southwest edge of the area, near Island Ford. Between Stony Run and Island Ford, the belt of outcrop is about 1,500 feet wide, but in the Elkton Embayment, between Naked Creek and Swift Run, it widens to 2 miles, probably as a result of local folding.

The Waynesboro, like the Tomstown, throughout most of its belt of outcrop is extensively masked by gravel washed from the mountains, and by its own residuum. Outcrops of fresh rock are few, and generally consist of small ledges of hard shale. The most extensive outcrops are in the vicinity of Ingham, where the South Fork of the Shenandoah River swings close to the foothills of the Blue Ridge, and valleys tributary to it from the southeast are deeply incised. The bottoms of these valleys extend below the zone of deep weathering, and contain many outcrops of unweathered rock. A complete section of the formation is exposed in the valley of Crooked Run, southwest of Ingham. East and southeast of Shenandoah are several patches of weathered shale, which have been exposed during iron-mining operations. Of these, the most extensive are at the Garrison bank of the Fox Mountain mine.

CHARACTER

The Waynesboro is dominantly a shaly formation. Some of the shale is maroon red or reddish brown, but red colors are less common than in the equivalent Rome formation of the southern Appalachians. Most of the shale is brown or tan, and some is greenish gray. Much of the shale is silty, and in places there are thicker interbedded layers of siltstone. As seen in the exposures near Ingham, the shales of the upper part of the formation are more calcareous than those below. Near Ingham, the formation contains interbedded limestone layers that range from a few feet to more than a hundred feet thick. Elsewhere, these have generally disappeared from surface outcrops, as a result of weathering and leaching.

A section of the Waynesboro formation was measured on Crooked Run southwest of Ingham, between 1 and 2 miles south of the South Fork of the Shenandoah River. The beds stand nearly vertically and are all exposed, except for some layers near the base. The measured thickness in Crooked Run is 1,685 feet. Judging from the width of outcrop elsewhere, this is close to an average for the thickness of the formation in the Elkton area.

Section of Waynesboro formation in valley of Crooked Run

Elbrook dolomite at top.

Waynesboro formation:	*Feet*
6. Dolomitic shale and thin beds of blue limestone. Shale is steel gray when fresh, but surfaces of ledges are brown and earthy, with argillaceous seams projecting as ribs. Residuum is soft, punky, and ferruginous	90
5. Blue limestone, interbedded in middle with shaly limestone and calcareous or dolomitic shale. Part of limestone forms massive beds as much as 3 feet thick; part is ribboned, and consists of 1-inch layers of blue limestone, separated by seams of argillaceous brown limestone that project as ribs on weathered surfaces. The shale is thinly laminated and weathers buff or tan	265
4. Buff or light-brown calcareous shale; some interbedded siliceous shale and thinly laminated shaly limestone; residuum is soft and punky	550
3. Dark-gray or blue-gray limestone in 6-inch to 1-foot beds. Consists of lenses and lumps of compact limestone, separated by seams of argillaceous limestone that form ribs on weathered surfaces	100
2. Brown, buff, or maroon-red shale, in part hard and flaggy, in part soft, thin-bedded, and perhaps calcareous; some bedding surfaces micaceous. Interbedded layers of massive brown or red siltstone	290
1. Shale in scattered ledges, with float-covered intervals; a few ledges of fine-grained, pale-buff sandstone	390
Total thickness of Waynesboro formation	1,685

Tomstown dolomite at base (see table, p. 26).

AGE

No fossils were collected in the Waynesboro formation in the Elkton area. In the type area in Pennsylvania it has likewise yielded no diagnostic fossils, but it is there classed as of Early Cambrian age on the basis of general stratigraphic position (Stose and Jonas, 1939, pp. 72–73). The similar Rome formation of Tennessee and southwest Virginia contains trilobites and a few other fossils, and has been classed as partly of Early Cambrian and partly of Middle Cambrian age (Butts, 1940, pp. 63–67; 1941, pl. 65). Recently, the Middle Cambrian part of the Rome in Tennessee, or the top few hundred feet, has been separated as the Pumpkin Valley shale (Rodgers and Kent, 1948, pp. 7–8). The Rome formation as now defined is thus all of Early Cambrian age. In the Elkton area the equivalent of the Pumpkin Valley may lie in the Elbrook dolomite.

RESIDUUM OF WAYNESBORO FORMATION

Like the adjacent limestone and dolomite formations, the Waynesboro is extensively broken down by weathering. In weathered outcrops, all trace of the limestone beds disappears, and the shales change to clay. As with the adjacent formations, the residuum of the Waynesboro is thickest and most widely distributed on the uplands, whereas unweathered rock is likely to be exposed in the intervening valleys.

The residuum of the Waynesboro formation, being largely derived from shale, tends to be more silty than the residuum of the adjacent carbonate formations. Moreover, as the volume changes on weathering is smaller than in the adjacent formation, the clay tends to retain the bedding and other original structural features of the parent rock. Waxy clay, resembling the residuum of the adjacent formations, is present in places, and was probably derived from interbedded limestone or dolomite.

Silty clay, probably derived from shale, is well exposed at the Garrison bank east of Shenandoah, and along Stony Run southwest of Stanley. Here, the clay is brown or buff, with closely spaced red, white, or gray laminae that extend evenly across the exposures. These laminae evidently closely approximate the original bedding in the shale. The clay contains clean-cut joints, and is traversed in places by breccia zones. At the Fox Mountain mine, southeast of Shenandoah, waxy clays occur in greater volume and the laminae are much more chaotic and contorted. Much limestone was no doubt present in the parent rock of this area. At this locality there are also layers and lenses of sandy clay and fine sand.

The contact between the residuum of the Waynesboro formation and the unweathered shale beneath was observed in the valley of Crooked Run along the road from Crooked Run to Fultz Run, and in the south opencut of the Garrison Bank. Here, the contact between shale and clay is sharp and abrupt, and pinnacles of shale project into the clay. Unweathered shale was also encountered beneath the clay in the shafts and tunnels of the Boyer mine east of Shenandoah, but no record is available as to the relations. In the Neisswaner shaft south of Elkton, hard red shale was penetrated beneath the residuum at a depth of 270 feet (sec. S–S; fig. 15). Here, in contrast to the outcrops just described, the contact between the shale and the clay is not abrupt, and the two are separated by a zone of partly decomposed shale 60 to 90 feet thick (Hewett, 1916, pp. 63–64).

Part of the residuum of the Waynesboro formation is produced by the leaching of limestone, dolomite, and calcareous shale. However, the poorly calcareous and noncalcareous shales also have decomposed into clay upon weathering. Observations made by Hewett (1916, p. 66) in the Neisswaner shaft suggest that this change results from decomposition of the sericite of the unweathered shale into kaolin in the clay, probably with little change in volume. Decomposition of this sort would seem to account for many of the observed features in the residual clay of the Waynesboro formation.

Like the residuum of the Tomstown dolomite, the residuum of the Waynesboro formation contains iron and manganese oxides, which in places form workable ore bodies. At the Fox Mountain mine, large quantities of iron ore have been removed from the open-cuts, but little of the limonite that was originally present is now visible (p. 73). At the Garrison bank, manganese oxide forms seams and films along the bedding of the clay and also partly replaces the breccia zones (pp. 71–72). The residuum of the Waynesboro along Stony Run southwest of Stanley was at one time extensively mined for ocher (pp. 76–77) (Watson, 1947, p. 228).

STRATIGRAPHIC RELATIONS

The Waynesboro formation is overlain by the Elbrook dolomite, of Middle Cambrian age. The Waynesboro consists mainly of shale, and the Elbrook mainly of thin-bedded dolomite and limestone, but the Waynesboro contains thin beds of limestone in the upper part, and the Elbrook contains thin partings of calcareous shale similar to the shales in the Waynesboro. Where exposed in the valley of Crooked Run, the contact between the two formations is gradational and apparently conformable.

ELBROOK DOLOMITE

NAME

The Elbrook dolomite was named by Stose (1906, p. 209; 1909, p. 5) for outcrops near Elbrook, in the Mercersburg-Chambersburg area, Pennsylvania. In the Elkton area, the Elbrook dolomite has lithologic features similar to those in the type area, has a similar thickness, and occupies a similar stratigraphic position.

OUTCROP

The Elbrook dolomite is one of the formations of the Shenandoah Valley and underlies the valley floor in a belt of outcrop a mile or two out from the foothills of the Blue Ridge (pl. 1). The northeasternmost outcrops are near Marksville, north of the Stanley fault. South of the Stanley fault, the formation reappears 5 miles to the southwest, near Ingham, and from there forms a continuous belt to the southwest edge of the area, near Elkton.

The Elbrook dolomite, like the Tomstown and Waynesboro formations, is widely mantled by gravel washed from the mountains. It is exposed at more places than these formations, as it crops out along nearly every large stream or deep valley that crosses the gravel area. The most extensive outcrops are near Ingham and near Elkton, where the belt of outcrop of the Elbrook dolomite is crossed by the South Fork of the Shenandoah River. The most complete section of the formation is in the valley of Crooked Run, southwest of Ingham. There is a smaller outcrop along Naked Creek east of Verbena.

CHARACTER

The Elbrook is rather uniform consisting mostly of thin-bedded dolomite. The dolomite is light-gray and fine-grained, and contains laminae and partings a few inches apart. These persist within the rock, even where it stands in thicker ledges. Some blue-gray limestone is interbedded with the dolomite, especially in the upper half. Most of the limestone contains argillaceous seams that project as ribs on weathered surfaces. Some dolomitic buff or pink shale forms partings between the dolomite or limestone beds. These are well exposed at the Chesapeake and Western Railroad bridge over the South Fork of the Shenandoah River near Elkton. At some localities the formation contains small lenses and nodules of gray and brown chert.

In most outcrops of the Elbrook, dips are varied and the formation is crossed by so many small folds that continuous sections are difficult to measure. In the valley of Crooked Run southwest of Ingham, the structure is less complex and the outcrops are reasonably complete. The belt of outcrop here is about 3,500 feet wide, and the beds stand nearly vertical, except for some local folds near the top. No section was measured, but the formation is estimated to have a thickness here of about 3,000 feet. This is approximately the same as the thickness in the type area in Pennsylvania (Stose, 1909, p. 5), but it is greater than thicknesses reported farther southwest in Virginia (Butts, 1940, p. 78).

AGE

Near the base of the Elbrook in the valley of Crooked Run, the thin-bedded dolomite contains projecting heads of *Cryptozoon* a foot or more in diameter, composed of limestone with crinkled, argillaceous laminae (fig. 6). *Cryptozoon* is also common in the Elbrook elsewhere in Virginia. No other fossils were observed in the Elbrook dolomite in the Elkton area, and the formation is apparently very sparingly fossiliferous elsewhere. In the type area in Pennsylvania it has yielded a few trilobites of Middle Cambrian age (Stose and Jonas, 1939, pp. 73–74). At localities in Virginia, the lower part of the formation has yielded fossils of Middle Cambrian age, and the upper part has yielded fossils of Late Cambrian age, similar to those in the Nolichucky shale (Butts, 1940, pp. 78–79).

The Elbrook dolomite is apparently equivalent to interbedded shales and limestones in Tennessee and southwest Virginia that are known as the Rutledge limestone, the Rogersville shale, the Maryville limestone, and the Nolichucky shale, the first three containing Middle Cambrian fossils and the last Late Cambrian fossils. An intermediate facies also exists in that area in which the Nolichucky shale overlies dolomites similar to the Elbrook, known as the Honaker dolomite.

RESIDUUM OF ELBROOK DOLOMITE

The Elbrook dolomite, like the Tomstown dolomite and Waynesboro formation, forms residual clay on weathering. However, this is neither as thick nor as extensive as that formed on the older formations and in places is absent entirely. The Elbrook lies beneath terrace surfaces that are lower and younger than those overlying the older formations, and if thick masses of residuum ever accumulated on the formation, they have subsequently been removed by erosion. In the bluffs along the east side of the South Fork of the Shenandoah River at Elkton, no residual clay is present above the dolomite, which is overlain directly by the younger gravel deposits. Residuum of the Elbrook is well exposed in a cut on the Norfolk and Western Railway immediately west of Fultz Run. The base of the cut is in dolomite and dolomitic shale. This is overlain by 10 feet or more of punky, silty, ocher-brown clay which still retains the bedding of the rock from which it was derived.

STRATIGRAPHIC RELATIONS

The thin-bedded dolomite of the Elbrook is overlain by the thicker-bedded limestone of the Conococheague, but this lithologic change is not sharp, for limestones occur in the Elbrook and dolomites in the Conococheague. Apparently the contact between the two formations is conformable, and it may have been somewhat arbitrarily placed during field work. However, at two places where the contact is well exposed—west of the lower end of Crooked Run and on the west bank of the South Fork of the Shenandoah River south of Millbank—the change from one rock type to another is well marked and takes place within a few feet of beds.

CONOCOCHEAGUE LIMESTONE

NAME

The Conococheague limestone was named by Stose (1908, p. 701; 1909, p. 6) for outcrops along Conococheague Creek in the Mercersburg-Chambersburg area, Pennsylvania. In the Elkton area the Conococheague limestone has lithologic features similar to those in the type area, and occupies a similar stratigraphic position.

OUTCROP

The Conococheague limestone crops out near the center of the Shenandoah Valley (pl. 1). North of the Stanley fault it probably underlies some of the country near Stanley. It is not exposed here, but limestone has been penetrated in water wells at depths of 175 to 235 feet (Cady, 1936, pp. 80–81). South of the Stanley fault it crops out near Grove Hill and extends to the southwest in a belt 2,000 to 3,000 feet wide, which passes out of the Elkton area southwest of Millbank. Most of it lies near the South Fork of the Shenandoah River, so it is extensively masked by river flood-plain deposits and by terrace deposits. Excellent outcrops may be seen along the slopes of the river valley near Grove Hill, at the old flux quarry near State Highway 12 in the southeast part of Shenandoah, along the Norfolk & Western Railway immediately south of Shenandoah, on the north side of Naked Creek at Verbena, and along U. S. Highway 33 west of Millbank.

CHARACTER

The Conococheague is much more varied than the Elbrook dolomite below or the Beekmantown dolomite above, and in contrast to these two formations, it contains much more limestone. The limestone of the formation is fine-grained or dense, and light blue-gray. It weathers mouse gray, ashen, or buff. It forms beds several feet in thickness, but the beds commonly contain closely to widely spaced, crinkled, argillaceous seams, that project as ribs on weathered surfaces. Much of the limestone contains light-gray chert nodules and lenses. These are more abundant in the Conococheague than in either the Elbrook or the Beekmantown. The beds of sandy limestone and sandstone that are said to be a characteristic feature of the formation elsewhere in Virginia (Butts, 1940, p. 87) are not conspicuous in the Elkton area. However, scattered sand grains project here and there on the weathered surfaces of some of the limestone beds. Beds of very sandy limestone crop out in a few places, and disintegrate into small bodies of sand on weathered surfaces. Interbedded with the limestone in nearly all exposures are beds of dolomite a foot or two thick. The dolomite is finely and evenly textured, and more uniform than the limestones. Some beds are marked by straight, dark laminae.

The Conococheague limestone shows more local disturbance than either the underlying Elbrook or overlying Beekmantown, and nearly every outcrop is crossed by minor folds and crumples. Many of the limestone beds show evidence of flowage. The interbedded dolomite layers are more competent than the limestone, and where the limestone is folded and squeezed, the dolomite is broken by coarse fracture cleavage, or is cut by gash veins of quartz (fig. 9).

No complete sections of the Conococheague limestone are exposed in the Elkton area. Thicknesses are difficult to estimate because the exposures are discontinuous and individual outcrops are complicated by local folds. To judge from the width of outcrop and the broader structure, the formation is about 2,000 feet thick in the Elkton area. This agrees with the average thickness of the formation elsewhere in Virginia as given by Butts (1940, p. 89), but is somewhat greater than the thickness in the type area of southern Pennsylvania.

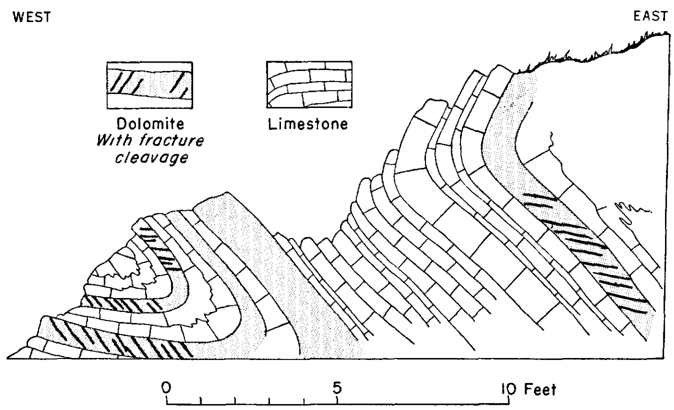


FIGURE 9.—Sketch section of outcrop of Conococheague limestone along South Fork of Shenandoah River in south part of town of Shenandoah, showing interbedding of limestone and dolomite. Folding has produced flowage in limestone and fracturing in dolomite.

AGE

No fossils were observed in the Conococheague limestone of the Elkton area. Elsewhere, the formation contains trilobites, brachiopods, and gastropods of Late Cambrian age (Butts, 1940, pp. 89–90; 1941, pl. 67; Stose and Jonas, 1939, p. 74). The Conococheague is equivalent to the Copper Ridge dolomite of Tennessee and southwest Virginia.

RESIDUUM OF CONOCOCHEAGUE LIMESTONE

The Conococheague limestone seems to be unusually susceptible to leaching on weathering, and must be relatively impure, as there is much residual clay over the bedrock in nearly every exposure. The areal extent of the residual clay at the surface is too small in most places to indicate separately on the geologic map.

The best exposures of the residuum of the Conococheague limestone are in the old flux quarry east of State Highway 12 in the southeast part of the town of Shenandoah, and in cuts on the Norfolk and Western Railway three-quarters of a mile south of the railroad station in Shenandoah (fig. 10). At these localities, most of the limestone beds are nearly vertical, but in places they are folded. The upper surface of the limestone is very irregular, with many projecting pillars and pinnacles. Overlying the limestone, and extending into deep pockets, hollows, and crevices, is buff or reddish, silty, punky clay. The clay is 10 to 25 feet thick, and is overlain unconformably by younger gravel deposits. The contact between clay and limestone is mostly sharp, although in places they are separated by a zone of rotten, earthy limestone a few inches thick. The clay was derived from the limestone, for it shows well-marked bedding that is accordant to that in the limestone, and contains calcite veins that are continuations of veins in the limestone. The absence in the clay of features resulting from slumping, and their punky, porous texture, suggest that during leaching there was little compaction or loss of volume, but only a reduction in mass by removal of soluble constituents.

STRATIGRAPHIC RELATIONS

During field work, the Conococheague limestone was distinguished from the Beekmantown dolomite above on the basis of a change from dominant limestone below to dominant dolomite above, a change that appears to be fairly constant and well marked. The boundary was so placed without the guidance of fossils and on the assumption that the Chepultepec zone of earliest Ordovician age probably formed a part of the lowest dolomites. Edmundson (1945, p. 144) has, however, tentatively assigned limestones to the Chepultepec near Shenandoah that were mapped by the writer as belonging to the upper part of the Conococheague. Until further work is done on this contact, the relations remain in doubt.

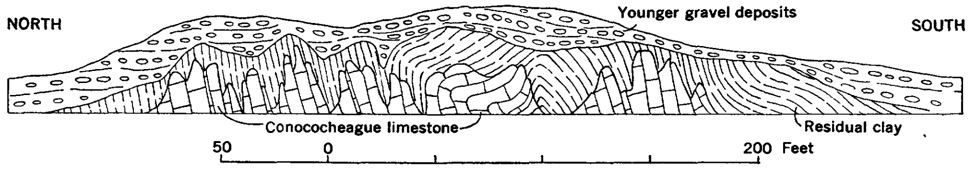


FIGURE 10.—Sketch section of cut on Norfolk and Western Railway, three-fourths of a mile southeast of railroad station in Shenandoah. Shows relation of residual clay to underlying Conococheague limestone, and to overlying gravel deposits.

ORDOVICIAN SYSTEM

BEEKMANTOWN DOLOMITE (INCLUDING CHEPULTEPEC LIMESTONE)

NAME

The Beekmantown is named for outcrops in Clinton County, N. Y., and has been widely used to denote beds of Early Ordovician age. The term Beekmantown group was used in Virginia by Butts (1940, p. 102), but he recognized the constituent parts of the group as zones, rather than as mappable formations. In the Elkton area, where the unit appears to be of rather uniform character, and where no subdivisions were recognized, it can appropriately be termed the Beekmantown dolomite.

Below the Beekmantown dolomite, and between it and the Conococheague, Butts (1940, pp. 95–96) mapped throughout Virginia a thin formation, the Chepultepec limestone. Edmundson (1945, p. 143) reports that diagnostic Chepultepec fossils have been collected 300 feet below the base of the Beekmantown dolomite along Dry Run near Luray, north of the Elkton area, and he gives a section farther north in which the unit is assigned a thickness of 321 feet. During field work the writer assumed that the unit was distinguished from the Beekmantown mainly on the basis of its contained faunas, and that it formed the basal part of the dolomites mapped as Beekmantown. However, its stratigraphic position in the Elkton area will remain in doubt until further work is done.

OUTCROP

In the Elkton area, the Beekmantown dolomite crops out near the axis or lowest part of the Shenandoah Valley (pl. 1). North of the Stanley fault, between Alma and Grove Hill, the formation spreads out over an area 2 miles or more wide, in which it shows relatively low dips in various directions. South of Grove Hill and south of the Stanley fault, the formation stands nearly vertical and strikes north-northeast. Here, it forms a belt about 4,000 feet wide, which can be traced to the west edge of the Elkton area in the vicinity of East Point.

The Beekmantown dolomite is the most extensively exposed formation of the Shenandoah Valley. Like the formations already discussed it is partly covered by gravels washed out from the mountains, but these lie principally on terrace surfaces on the uplands. In the intervening lowlands and valleys, the dolomite crops out widely. It forms prominent lines of cliffs along the South Fork of the Shenandoah River between Grove Hill and Alma. Its ledges are conspicuous at many places in and near the town of Shenandoah. The upper part of the formation is also well exposed in the Elkton Lime & Stone Co. quarry on Humes Run 2½ miles southwest of the town of Shenandoah.

CHARACTER

The Beekmantown is a rather monotonous sequence of thick-bedded dolomite. The typical rock is light-gray, fine-grained dolomite, weathering ashen gray. This forms prominent ledges 2 to 5 feet thick, commonly marked by faint to strong laminae within the beds. Some of the dolomite is more coarsely crystalline than the rest and has a saccharoidal appearance. When this rock weathers, the individual crystals tend to separate from each other, which gives the rock a falsely sandy appearance. Other dolomite beds are mottled, and are made up of purer nodules in a slightly argillaceous matrix. On weathering, the matrix projects faintly as reticulated ridges. Rarely, the dolomite contains lenses of black chert.

Limestone beds form a minor constituent of the Beekmantown. Much of the limestone resembles that in the underlying Conococheague, and is banded by argillaceous seams that project as ribs on weathered surfaces. Other limestone is faintly mottled. In some places, the limestone forms domical, reeflike bodies, perhaps of *Cryptozoon*. The largest of these are 10 feet across and 6 feet thick. Others are smaller and form chains of knobs rising from limestone beds and overlain by dolomite beds that were deposited on their irregular surfaces.

The upper part of the Beekmantown dolomite is exposed at the Elkton Lime & Stone Co. quarry (mss. pp. 303–304) (fig. 11). The top of the formation is at the west end of the quarry, where it is overlain by limestones of Middle Ordovician age. A detailed section of 1,196 feet of beds has been measured in the quarry and to the east by R. S. Edmundson (1945, pp. 131–134). Of the exposed beds in the section, 247 feet are classed as limestone, 276 as magnesian limestone, and 576 feet as dolomite. Limestone and magnesian limestone predominate above, and dolomite beds are increasingly thicker and more numerous downward.

Another section of the upper part of the Beekmantown dolomite was measured by Edmundson (1945, pp. 149–150) on the northeast side of the river bend a mile and a quarter north-northeast of Shenandoah. This showed a thickness of 1,033 feet, below the limestones of Middle Ordovician age, of which 795 feet are dolomite, 175 feet are limestone, and 63 feet are covered.

No complete sections of the Beekmantown dolomite were measured in the Elkton area. However, between Shenandoah and Grove Hill, several valleys cross almost the entire thickness of the formation and contain numerous outcrops. In this vicinity the beds stand nearly vertical and the belt of outcrop is 3,000 to 4,000 feet wide. The formation in this vicinity is doubtless 3,000 feet thick. At Rileyville, Page County, 14 miles

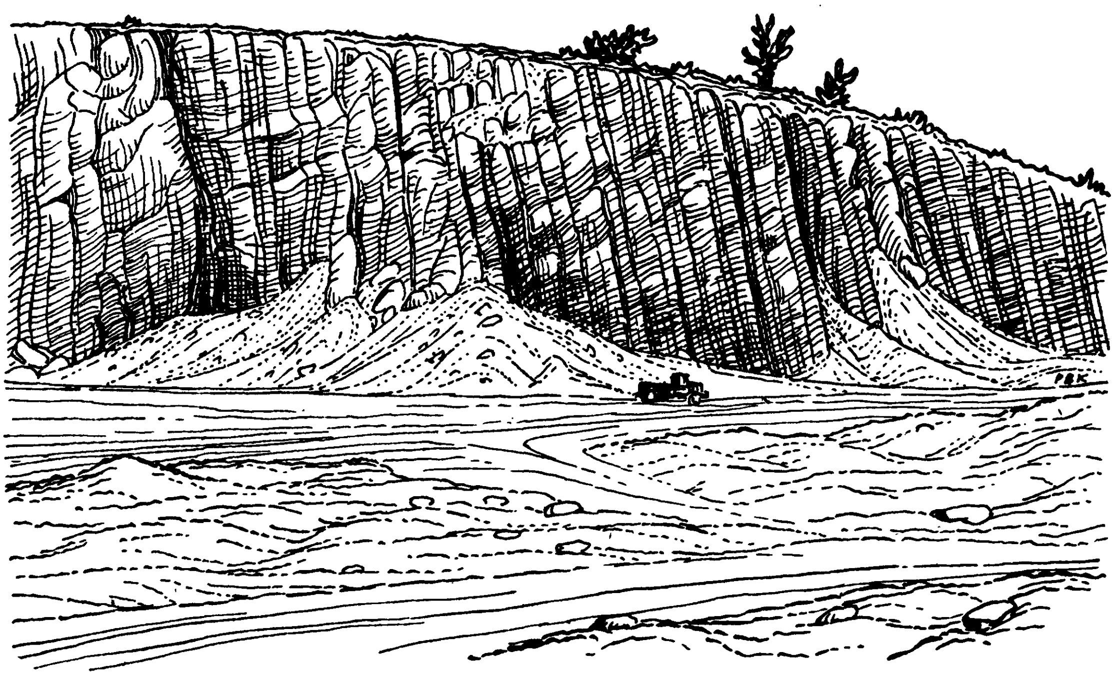


FIGURE 11.—Upper beds of Beekmantown dolomite exposed in face of Elkton Lime & Stone Co. quarry, 2½ miles southwest of town of Shenandoah. View is southward and shows face as it appeared in 1940. Exposure consists of interbedded layers of dolomite, magnesian limestone, and limestone, which dip steeply to west (right).

north of the Elkton area and in the same belt of outcrop, Edmundson (1945, pp. 147–148) has measured a thickness of 3,360 feet. Elsewhere in Virginia the formation is reported to be 2,500 to 3,000 feet thick (Butts, 1940, p. 116).

FOSSILS

The Beekmantown dolomite is more abundantly fossiliferous than any of the older formations. No fossils were, however, collected during the present investigation. In addition to the *Cryptozoon* reefs already noted, cross sections of gastropods and occasional cephalopods may be observed at many places in the limestone and dolomite. Gastropods and cephalopods are also preserved in many of the blocks of residual chert that strew the outcrop areas of the formation.

According to Butts (1940, p. 116; 1941, pls. 68–72), the fossils permit division of the Beekmantown into a lower and an upper zone, in addition to the Chepultepec zone at the base of the Beekmantown as here mapped. The lower is characterized particularly by *Lecanospira*, and by other gastropods such as *Ophileta* and *Hormotoma*. In the Elkton area, this zone was identified by Butts, when in company with the writer, in residual chert 500 feet southeast of the Shenandoah River bridge at Grove Hill, and perhaps 500 to 1,000 feet above the base of the formation as mapped. The upper zone is characterized by *Ceratopea* and various distinctive gastropods and cephalopods. This was not identified with certainty in the Elkton area, although numerous gastropods were seen near the top of the formation in the Elkton Lime & Stone Co. quarry.

WEATHERING FEATURES OF BEEKMANTOWN DOLOMITE

The Beekmantown dolomite weathers into a clay that is not conspicuous, and probably forms a relatively thin and discontinuous blanket over the formation.

The most conspicuous weathering feature of the Beekmantown is a widespread silicification. Chert nodules are not common in the outcrops of the formation, but mixed in the soil and spreading over the surface of the outcrop areas are numerous, small to large, angular blocks of dense to spongy brown chert. This is a replacement of the dolomite, for many of the chert fragments contain fossils. The chert has evidently formed during weathing by solution and concentration of the original silica content of the dolomite.

In places, the more deeply weathered ledges of dolomite have been entirely silicified. This is well illustrated on State Highway 12 about 2 miles north of Shenandoah. Highway cuts low on the hill slope to the south have exposed thick-bedded dolomite and interbedded limestone, without conspicuous chert bodies. At the crest of the hill to the north are ragged ledges of porous, slaggy, silicified rock, evidently an altered dolomite, still preserving the original bedding, joints, and slickensided surfaces of the original rock.

STRATIGRAPHIC RELATIONS

The Beekmantown dolomite is overlain with abrupt contact by the limestones of Middle Ordovician age. No detailed observations were made on the contact during the present investigation, but Cooper and Cooper (1946, p. 90) and others interpret it as unconformable, because of the absence of typical Chazy fossils in the succeeding beds, because of variations in thickness of the succeeding unit, and because of the presence of a basal conglomerate on the Beekmantown at many places. Near Leaksville in Page Valley, not far north of the Elkton area, they (Cooper and Cooper 1946, p. 98) describe a boulder and cobble conglomerate at the base of the Middle Ordovician succession that lies on the Beekmantown. This reaches 175 feet in thickness in places, but is of very small extent.

LIMESTONES OF MIDDLE ORDOVICIAN AGE

OUTCROP

Overlying the Beekmantown dolomite is a thin unit of limestones of Middle Ordovician age. The limestones crop out as a band 200 to 400 feet wide along the northwest edge of the Elkton area (p. 1). The limestones extend from Alma, at the north, through Newport, to the west of Grove Hill and Shenandoah, through Greenwood, to the west margin of the map area northwest of East Point. Throughout most of its extent the unit is poorly exposed and forms a sag on the slopes between the outcrops of the Beekmantown dolomite and the Martinsburg shale. The best exposures are at various places where it outcrop belt lies near the South Fork of the Shenandoah River.

CLASSIFICATION

As the limestones of Middle Ordovician age were incompletely studied during the prevent investigation, only their general character was ascertained. The description of the unit has been amplified from publications of Butts (1933, and 1940, pp. 119–201), Cooper and Cooper (1946, pp. 35–114), and Edmundson (1945, pp. 128–150). Interpretations that have been made of the limestones of Middle Ordovician age by these authors are varied and have resulted in two different classifications of the beds, as indicated in the table below.

Classifications of limestones of Middle Ordovician age

Lithologic character	Stratigraphic names			Age (Cooper and Cooper)
	Butts, 1940, and Edmundson, 1945 (1948)	Cooper and Cooper, 1946		
Shale	Martinsburg shale			Upper Ordovician
Argillaceous limestone	Chambersburg limestone	Oranda formation		Trenton
Cobbly limestone; black limestone and shale	Athens formation	Edinburg formation	Lantz Mills facies (cobbly limestone) Liberty Hall facies (black limestone)	Black River and possibly early Trenton
Granular cherty limestone	Lenoir limestone	Lincolnshire limestone		Post-Chazy (Black River ?)
Compact gray limestone	Mosheim limestone	New Market limestone		Chazy
Dolomite	Beekmantown dolomite			Beekmantown

These differences have resulted from differences in viewpoint. Butts believed that the stratigraphic units of Middle Ordovician age, although thin, are widely traceable through the Appalachians, maintaining about the same lithologic character throughout, and that they represent time-stratigraphic units formed during separate incursions of the sea. He accordingly introduced into Virginia the names "Lenoir," "Mosheim," "Athens," and others from Tennessee, and the name "Chambersburg" and others from Pennsylvania.

On the other hand, Cooper and Cooper conclude that "the generally accepted interpretation of the lower

Middle Ordovician in the Appalachian region confused time-stratigraphic divisions with purely lithogenic divisions, transcending faunal zones" (Cooper and Cooper, 1946, p. 37). Local names for units are therefore preferred to names introduced from other areas, and many lithologic units are believed to be lateral facies of other units.

CHARACTER

As a unit, the limestones of Middle Ordovician age are readily separable from the Beekmantown dolomite by their darker color, thinner bedding, and finer texture. They also contrast markedly with the Martinsburg shale, which overlies them with sharp contact.

The northernmost exposure of the unit in the Elkton area is on the west bank of the South Fork of the Shenandoah River and north of the bridge of State Highway 12. The rock here is black limestone, in part shaly, which is overturned and dips to the south, and shows evidence of considerable small scale deformation. These beds evidently belong to the Athens of Butts, or Liberty Hall facies of the Edinburg formation of Cooper and Cooper. The nature of the strata which are between them and the Beekmantown dolomite was not ascertained.

To the southwest, sections were studied by Edmundson (1945, p. 141, localities 164, 165) at Newport and Cub Run, and by the writer on the north and south sides of the South Fork of the Shenandoah River west of Grove Hill. Here, thin- to thick-bedded, dark, cherty limestone lies directly on the Beekmantown. This is probably the Lenoir of Butts or Lincolnshire of Cooper and Cooper, thus suggesting that the Mosheim or New Market of these authors is missing. At the localities cited, the cherty limestone is overlain by thin-bedded limestone without chert, probably the Athens or Edinburg of these authors.

Between Grove Hill and Shenandoah, according to Edmundson (pp. 141–142, localities 166, 167, and 168) compact, dove-gray limestone wedges in between the dark cherty limestone above and the Beekmantown dolomite below. This presumably represents the Mosheim of Butts or the New Market of Cooper and Cooper. On the north side of the river bend a mile and a half north of Shenandoah the compact limestone is 2 feet thick, but in the vicinity of Shenandoah it thickens to about 50 feet.

Southwest of Shenandoah, the uppermost beds of the unit were studied by the writer near Greenwood, where they are thin-bedded dark limestones, probably belonging to the Athens of Butts or the Edinburg of Cooper and Cooper. These are overlain directly by the Martinsburg shale. Regarding the lower beds in the same vicinity, Edmundson (pp. 128-129) reports that "North of the latitude of Elkton the rocks between the Beekmantown and the Athens are commonly thin and largely covered. At a few localities the Mosheim is missing, whereas at other places along the belt it is present but commonly shows considerable variations in thickness along the strike." Both Edmundson (pp. 129–130) and Cooper and Cooper (p. 99) give sections of the lower part of the unit near Montevideo, not far west of the Elkton area.

In the Elkton area, the belt of outcrop of the limestones of Middle Ordovician age is so narrow that evidently the unit is not much more than 200 feet in thickness. According to Cooper and Cooper (p. 38) the unit reaches a thickness of 400 to 1,000 feet elsewhere along the southeast flank of the Massanutten syncline. For Page County, in the same general area, Edmundson (1945, pp. 135–136) gives a thickness of 0 to 35 feet for the Mosheim, of 40 to 135 feet for the Lenoir, and of 400 to 600 feet for the Athens and Chambersburg.

STRATIGRAPHIC RELATIONS

The limestones of Middle Ordovician age are overlain by the Martinsburg shale, which is also of Middle Ordovician age in the lower part. In the Elkton area the contact is sharp, but the relations are somewhat problematical. According to Cooper and Cooper (1946, pp. 88–89) their Edinburg formation is overlain in places by the Oranda formation, of Trenton age. This is missing in the Elkton area, but it is uncertain whether this is owing to unconformity, or to gradation of the Oranda formation into the basal beds of the Martinsburg shale. If an unconformity is present, the time hiatus is small, for the top of the Edinburg is interpreted as Black River or younger age (Cooper and Cooper, 1946, p. 86) and the lower part of the Martinsburg is of Trenton age (Butts, 1940, p. 212).

MARTINSBURG SHALE

The Martinsburg shale was named for Martinsburg, W. Va. (Geiger and Keith, 1891, p. 161). The formation crops out in a belt 1 or 2 miles wide on the southeast slopes of Massanutten Mountain, northwest of the formations mapped in the Elkton area (pl. 1). Neither the Martinsburg shale nor the overlying sandstones of Silurian age were studied during the present investigation, but a few notes on them from other sources are included to complete the stratigraphic record.

The Martinsburg shale on the flanks of Massanutten Mountain has been described by Spencer (1897, pp. 8–9). The lower part is drab, argillaceous or calcareous shale, in part micaceous and ripple-marked. Higher up are bands of olive-green, ledge-making sandstone, composed of angular grains of quartz and other minerals. Above the sandy beds are fine-grained, carbonaceous shales, which near the top of the formation contain thin interbedded layers of earthy limestone.

According to Spencer, the Martinsburg shale is about 2,800 feet thick near Massanutten Mountain, but Butts (1940, p. 209) suggests that it may reach a thickness of 4,000 feet in this area.

According to Butts (p. 212) the Martinsburg is of Trenton, Eden, and Maysville age, or partly of Middle Ordovician and partly of Late Ordovician age. Butts (p. 202) believes that beds corresponding to the Oswego and Juniata sandstones, of Late Ordovician age, are absent in the Massanutten Mountain area, and that there is a hiatus between the Martinsburg shale from the overlying sandstone.

SILURIAN SYSTEM

SANDSTONES OF SILURIAN AGE

The crests of Massanutten Mountain are formed by sandstones of Silurian age, which were termed the Massanutten sandstone by Geiger and Keith (1891, pp. 156–163, pl. 4), but which Butts (1940, pp. 202, 237) has shown to correspond to the Tuscarora sandstone and Clinton formation of other areas. Beds of the formation project as massive ledges on sharp-crested ridges that rise above the slopes of the surrounding Martinsburg shale (pl. 1). Blocks derived from the sandstone are strewn over the shale slopes below, and obscure the outcrops of the underlying formation.

According to Spencer (1897, pp. 9–10), the sandstones of Silurian age are 700 to 1,000 feet thick, and consist of two members, a lower thin-bedded and fossiliferous sandstone, separated by a shale parting from an upper quartzite. According to Butts, the sandstones are overlain by the Silurian Bloomsburg formation, which forms parts of the valleys within Massanutten Mountain, along the axes of the synclinorium.

TRIASSIC (?) SYSTEM

INTRUSIVE IGNEOUS ROCKS

At three localities the rocks of the Elkton area are cut by small bodies of intrusive igneous rock. One locality is on the west bank of the South Fork of the Shenandoah River, 1,000 feet south of the bridge of U. S. Highway 33 at Millbank (pl. 1). Here a sill-like body and a dike cut the Elbrook dolomite and the Conococheague limestone. At the second locality at the east end of Chapman Mountain a mile west of St. Luke Mission, a dike a mile long cuts the Catoctin greenstone and the Loudoun formation. At both localities the intrusive rocks are finely crystalline, dark, and basic, and show none of the effects of deformation displayed by the invaded rocks. A third locality has been reported by Edmundson (1945, p. 134) 2½ miles southeast of Shenandoah on the south bank of Humes Run. This exposure was not seen during the present investigation.

These intrusives are probably of the same character, origin, and age as other small, basic intrusive bodies that cut the Paleozoic rocks elsewhere in the Valley of Virginia. The most abundant of these are near Monterey in western Virginia, but Butts (1940, p. 345) mentions two occurrences near Harrisonburg, not far west of the Elkton area. As Butts suggests, these intrusive igneous rocks are probably younger than the Paleozoic, and are perhaps of Triassic age.

TECTONICS

STRUCTURAL FEATURES OF PRE-CAMBRIAN AGE

The Elkton area lies within the Appalachian Mountains, and most of its structural features are characteristic of that region and are probably of late Paleozoic age. However, additional structural features are present in the pre-Cambrian rocks that are probably of pre-Cambrian age.

The injection complex, or oldest formation of the Blue Ridge, contains a gneissic structure that dips at low angles in various directions. This is evidently of pre-Swift Run age, as it is seen to be truncated by the unconformity at the base of the Swift Run formation. No systematic observations were made on this or other structural features in the injection complex.

RELATIONS OF PRE-CAMBRIAN ROCKS TO CHILHOWEE GROUP

Throughout most of the Blue Ridge province the contact between the Lower Cambrian Chilhowee group and the underlying pre-Cambrian rocks is exposed only along single bands of outcrop, so relations between the two groups of rocks are difficult to determine. In the Shenandoah Salient, in the north part of the Elkton area, the contact between the Chilhowee group and the pre-Cambrian can be observed at many exposures throughout an area 8 miles long and 4 miles wide. In this district it is possible to reconstruct the relations of the pre-Cambrian rocks to the Chilhowee group, and to infer the structure possessed by the pre-Cambrian rocks at the time when the Chilhowee group was deposited over them.

In the Shenandoah Salient the Catoctin greenstone wedges out northwestward as a result of the unconformity at the base of the Chilhowee group, the relations being particularly well exposed on the west side of Harris Cove west of Weaver School (p. 13). Northwest of the feather edge of the Catoctin the Chil-

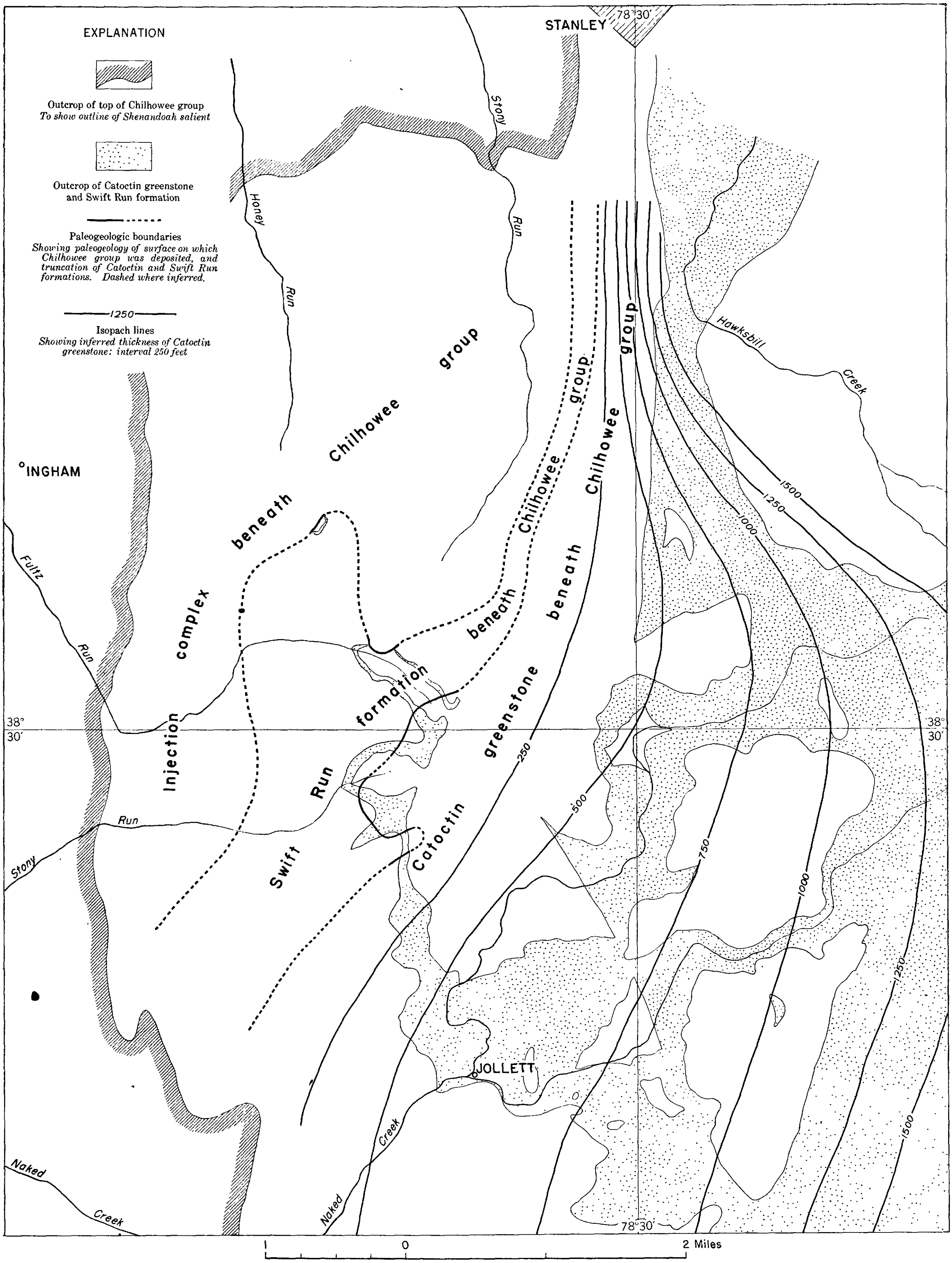


FIGURE 12.—Map of Shenandoah Salient, showing structural features of pre-Cambrian age. Shows paleogeology of surface on which rocks of Lower Cambrian Chilhowee group were deposited, and variations in thickness of Catoctin greenstone, which was beveled by an unconformity at base of Chilhowee group.

howee group lies on the Swift Run formation, and, finally, in the northwest part of the Shenandoah Salient, on the injection complex.

These relations are illustrated on figure 12. The paleogeology of the surface on which the Chilhowee group was deposited is indicated by two boundaries, one of which shows the northwest limit of the Swift Run formation and the other the northwest limit of the Catoctin greenstone. The thickening of the Catoctin greenstone southeast of its northwest limit is indicated by isopach lines.

INTERPRETATION OF STRUCTURAL FEATURES OF PRE-CAMBRIAN AGE

The northwestward truncation of the Catoctin greenstone and Swift Run formation, and the southeastward thickening of the Catoctin are interpreted as being due largely to tilting before Cambrian time and to erosion before the Chilhowee group was deposited. As indicated earlier (pp. 13–14) the northwestward truncation of these formations is part of a widespread feature that extends along the northwest flank of the Blue Ridge-Catoctin Mountain anticlinorium and may have resulted from local tilting and flexing on the margins of the original basin in which the Catoctin and Swift Run accumulated.

It is unlikely that any metamorphism resulted from this tilting and flexing. Furcron and Woodward (1936, p. 48) state that the slate of the Loudoun formation of the Chilhowee group is less metamorphosed than the Catoctin greenstone, but this appearance is probably illusory, and due to difference in competency of the beds during much later regional deformation. It is true that the Catoctin of the main Blue Ridge area shows more strongly developed slaty cleavage than do the rocks of the Shenandoah Valley to the northwest. However, in the Shenandoah Salient there is no major difference in degree of metamorphism between the Catoctin and the rocks of the overlying Chilhowee group. In fact, the writer's observations indicate that the more massive phases of the Catoctin show less cleavage and development of metamorphic minerals than do the tuffaceous slates of the Loudoun or the phyllitic shales of higher members of the Chilhowee group. The metamorphism of the Catoctin was therefore probably accomplished during the Appalachian Revolution.

To what extent the pre-Cambrian structural features of the area influenced or guided the development of the late Paleozoic, or Appalachian, structural features is a matter of conjecture. Paleogeologic and isopach lines drawn on the pre-Cambrian rocks have the same northeast trend as the fold axes and slaty cleavage of the Lower Cambrian rocks. This may be coincidental, as the northeast trend of the later structural features characterizes the whole of the Appalachian province, and thus extends far beyond the limits of the particular pre-Cambrian rocks and structures under discussion.

There is a possibility that the Shenandoah Salient owes its existence to the absence of the Swift Run formation and Catoctin greenstone in its northwest part, and the presence of the more competent injection complex directly beneath the Chilhowee group. This cannot be proved because the relations of the pre-Cambrian rocks cannot be observed in nearby and different structural units. It is considered unlikely, because the northwestward thinning of the Catoctin and Swift Run is probably a regional feature that extends far beyond the local area of the salient. A more likely possibility is that the northwestward thinning of the Catoctin and Swift Run in some way guided the configuration of the Blue Ridge-Catoctin Mountain anticlinorium when it was produced by the stresses of the Appalachian Revolution. It is at least a coincidence worth noting that all the localities where the thinning has been observed lie near the northwest flank of the anticlinorium.

STRUCTURAL FEATURES OF LATE PALEOZOIC (APPALACHIAN) AGE

GENERAL CHARACTER

The Elkton area lies between the crest of the Blue Ridge-Catoctin Mountain anticlinorium to the southeast and the trough of the Massanutten synclinorium to the northwest (fig. 12). Pre-Cambrian rocks form the surface in the anticlinorium, the Silurian rocks are preserved in the synclinorium. The intervening Elkton area, made up largely of Cambrian and Ordovician rocks, has a broadly homoclinal structure, in which the younger formations succeed the older toward the northwest.

The homoclinal structure of the Elkton area has been modified by folding, flexing, and to a certain extent by faulting. However, in contrast to some other parts of the Appalachian region, major overthrusts are lacking. On the other hand, metamorphism here is slightly greater than the average for the region. Shales have been converted into slates and phyllites, and the limestones and dolomites in places show the effects of flowage.

The most conspicuous structural features in the Elkton area are a broad upwarp and downwarp that extend across the strike of the rocks—the Shenandoah Salient and Elkton Embayment. As these warps affect the distribution at the surface of the ridge-making rocks of the Chilhowee group, the salient and embayment are topographic as well as structural features (pl. 1).

All the major structural features of the Elkton area were formed long after the Cambrian, Ordovician, and Silurian rocks were deposited there. These were probably produced during the Appalachian Revolution, and hence are of late Paleozoic age.

DISCUSSION OF ILLUSTRATIONS

The structural features of Appalachian age in the Elkton area are illustrated by the geologic structure map (plate 4), and by the structure sections on plate 5 and figure 13.

On the map, plate 4, the structure of the area of outcrop of the Chilhowee group is indicated by structure-contour lines. The preparation of a structure-contour map in an area of strong deformation such as this one involves greater possibilities of error than in areas of slight deformation. In an area of strong deformation, many of the features shown by contours must be based on extrapolation upward or downward to the horizon contoured, from the beds exposed at the surface. Folds are likely to increase or decrease in intensity or amplitude between the horizon contoured and the beds at the surface, and their positions will shift as a result of the dip of the axial planes. Such a shift has been suggested in the structure contours, for it will be noted that the reversals on the bed contoured are offset slightly from the traces of the fold axes as they occur at the surface.

Because of the hazards involved in extrapolation, the area of the Chilhowee group has been contoured on two horizons, the top of the Antietam quartzite in the outer foothills and the top of the lower member of the Weverton formation in the inner foothills. The contours were controlled partly by measurements taken from closely spaced structure sections and partly from elevations obtained from outcrops in the intervening areas.

Outside the area contoured on plate 4, areas of steeply dipping or vertical beds, and areas of overturned beds are indicated by patterns. The plate also shows the observed strikes and dips of the slaty cleavage. The significance of the cleavage, and its relation to the other structural features will be discussed later (pp. 50–51).

The 16 structure sections on plate 5 show the structure beneath the surface down to sea level, or as low as it may be inferred accurately from surface outcrops. Figure 13 shows a more speculative interpretation of two of the same sections (D–D′ and M–M′) with the strata restored as far down as 10,000 feet below sea level and as far up as 10,000 feet above sea level.

DESCRIPTION OF LARGER STRUCTURAL FEATURES

SHENANDOAH SALIENT

In the Shenendoah Salient, the rocks of the Chilhowee group and the underlying pre-Cambrian rocks crop out 2 or 3 miles farther northwest than they do elsewhere along the foothills of the Blue Ridge (pl. 1). This results from an upwarp across the strike of the rocks that has created a shelf or step intermediate between the trough of the Massanutten synclinorium and the crest of the Blue Ridge-Catoctin Mountain anticlinorium (sec. D–D′, fig. 13).

The Antietam quartzite around the edges of the salient is thrown into folds that plunge away from its crest (pl. 4). The folds on the north side plunge northward. In general, they are broad and open, but near Stony Run, a mile southwest of Stanley, a narrow anticline and two flanking synclines are asymmetrical toward the west (secs. A–A′ and B–B′, pl. 5). The folds on the southwest side plunge southwestward (pl. 4 and fig. 6). Between Stony Run, east of Shenandoah, and Naked Creek, 3½ miles to the southeast, are three anticlines arranged en echelon, each with steepest dips on the west flank (secs. F–F′ and G–G′, pl. 5). On the west side of the salient, between the north and the southwest sides, the Antietam quartzite is unbroken by folds and forms a nearly straight, north-trending outcrop (pl. 4). In this segment, the quartzite dips westward rather gently on the upper part of the slope, but more steeply toward the base, where the Antietam passes beneath the Tomstown dolomite (secs. C–C′, D–D′, and E–E′, pl. 5).

In the central part of the salient, the rocks are relatively little deformed over wide areas, and are even horizontal in places (pl. 4). There is little trace of the folds developed along the edges of the salient. The surface rocks in the central part of the salient are mainly Weverton formation, and those near the edges are Antietam quartzite, both competent units. They are separated by the relatively less competent Harpers formation, and there is a possibility that the disharmony in structure may be due to flowage in this unit. This seems unlikely for the Harpers itself shows little evidence of contortion, cleavage, or other unusual deformation. The folds at the edges, when traced into the salient, tend to flatten out, even within the outcrop area of the Antietam quartzite. Moreover, the rocks in the central part of the salient show evidence of strong deformation on the flexures described below (p. 43). It would thus appear that the salient is characterized not only by a rise in the plunge of the folds, but also by a general decrease in the intensity of the folding as compared with surrounding areas.

In the central part of the salient are two broad domes that correspond to two large inliers of pre-Cambrian rocks, the northern in Dovel, Lucas, and Cubbage Hollows, and the southern between Harris Cove and Jollet (pl. 4). The southern dome is broken on its northeast flank by the Harris Cove fault that trends northwest and is downthrown to the northeast (secs. D–D′, E–E′, F–F′, and G–G′, pl. 5). Its plane seems to stand nearly vertical, and it is probably a normal fault. Toward the northwest it dies out near Devils Tanyard, but toward the southeast it extends into the Catoctin greenstone of the Blue Ridge, where its continuation has not been traced.

On the southeast side of the salient the Chilhowee group and the pre-Cambrian rocks are bent upward along some sharp flexures (pl. 4). One flexure begins immediately south of Stanley and extends southward for 5 miles, passing to the west of Chapman Mountain (secs. *A–A′*, *B–B′*, *C–C′*, *D–D′*, and *E–E′*, pl. 5). Toward its south end the flexure is broken locally by a thrust fault, upthrown toward the east. East of the south end of the first flexure a second develops, beginning near Long Ridge and extending 9 miles to the southwest, or beyond the end of the Shenandoah Salient. Along this flexure the southeast edges of the Loudoun and Weverton formations are bent up sharply and in many places are overturned (secs. F–F′ and G–G′, pl. 5). On Powell Mountain tight local folds are present near the flexure. Because of this flexure the underlying Catoctin greenstone rises abruptly to the heights of the Blue Ridge.

AREA NORTH OF SHENANDOAH SALIENT

A short distance north of the quartzite foothills of the Shenandoah Salient the rocks of the Shenandoah Valley are broken by a large transverse fracture, the Stanley fault (pl. 4). To the southwest the fault has been traced into the area of outcrop of the Beekmantown dolomite near Grove Hill, where it apparently dies out. Toward the northeast it may be followed into the Stony Man quadrangle where its extension was not traced during the present investigation. Near Marksville in the northeast corner of the Elkton area the displacement on the fault is great, for the Waynesboro formation on the north is faulted against the Catoctin greenstone on the south.

Throughout much of its course the trace of the Stanley fault is covered by Quaternary gravels, but its existence can be inferred from outcrops of the bedrock or residuum near the trace (pl. 1). Toward its southwest end, near Grove Hill and Ingham, exposures are better, for the fault crosses the valley of the South Fork of the Shenandoah River in two places. The best outcrops are along the river a mile north of Ingham, where Elbrook dolomite on the southeast is faulted against Beekmantown dolomite on the northwest. The Elbrook is overturned and dips southeast at angles of 35° to 45°, but next to the fault on the west side of the river it is thrown into folds whose axis are parallel to the trace of the fault. The Beekmantown dolomite on the northwest side dips at angles of 20° or less in various directions, and a short distance north of the fault is horizontal. The beds of the Beekmantown dolomite next to the fault on the west side of the river form a massive cliff with no discernible bedding, cut by joints that give the rock a hackly appearance. The fault plane is obscurely exposed at the south end of this cliff, and apparently stands nearly vertical.

The apparent displacement of the Stanley fault is downward to the northwest, as older rocks form the southeast side and younger rocks the northwest side. This apparent displacement is indicated on the geologic and geologic structure maps (pls. 1 and 4) and on the structure-section sheet (secs. *B–B′* and *C–C′*, pl. 5). However, movements on the fault were undoubtedly complex, and the apparent movement may have little relation to the true movement. This subject is treated at greater length later (p. 47).

Northwest of the Stanley fault, as in the vicinity of Alma, Honeyville, and Newport, the Beekmantown dolomite spreads out over an area 2 to 3 miles wide, over much of which dips are low (pl. 1). However, the structure of the area is much more complex than would at first appear, for in an unnamed valley close to the Stanley fault and a mile and a half south of Honeyville are outcrops of limestone with all the characteristics of the Conococheague formation. These and adjacent beds of the Beekmantown dolomite dip southeast, and hence must be overturned. Unfortunately, part of this interesting area is masked by Quaternary gravels, but there are enough outcrops along the South Fork of the Shenandoah River and its tributary valleys to reveal the structural pattern. Toward the northwest, as near Newport, the Beekmantown passes beneath the overlying limestones of Middle Ordovician age with nearly vertical dips. To the southeast, the beds dip 25° to 50° NW., and in places are horizontal. Still farther southeast, they reverse to a dip of 10° to 50° SE., an attitude that extends into the outcrop areas of the Conococheague limestone. This belt of southeast-dipping beds apparently contains the axis of a recumbent syncline, as suggested on sections B–B′ and C–C′ of plate 5.

AREA WEST OF SHENANDOAH SALIENT

West of the Shenandoah Salient and south of the Stanley fault, the formations of the Shenandoah Valley dip steeply and strike north-northeast (pl. 1). Large parts of this area are masked by Quaternary gravels, but outcrops extend nearly continuously across the belt in the north, along the South Fork of the Shenandoah

River and its tributary valleys, between Grove Hill and Ingham. Farther south, as near the town of Shenandoah, only the higher beds of the sequence are well exposed.

The lower formations of the sequence, the Tomstown, Waynesboro, Elbrook, and Conococheague, or those nearest the Chilhowee group of the Shenandoah Salient, dip east-southeast at angles of 45° to 70° and are overturned (sections D–D′ and E–E′, pl. 5). The higher formations, the Beekmantown dolomite and the limestones of Middle Ordovician age, either stand vertically or dip northwest at angles of 60° to 80°.

ELKTON EMBAYMENT

As already indicated, the Elkton Embayment is a reentrant in the front of the Blue Ridge, by which the rocks of the Shenandoah Valley extend farther southeast into the foothills than elsewhere. The embayment lies between Naked Creek and Elk Run, a distance of about 4 miles along the strike. Most of the area of the embayment is masked by Quaternary gravels, but here and there are outcrops of residuum of the Tomstown and Waynesboro formation, as at the old Fox Mountain iron mine (pl. 1). The nature of the structure of these formations is obscure, but they are no doubt complexly folded.

The embayment is caused by a downwarp in the folds. To the northeast near Naked Creek, as already noted, folds in the Antietam quartzite plunge southwest toward the embayment from the Shenandoah Salient (pl. 4). Toward the southwest, near Hanse Mountain, other folds in the Antietam quartzite plunge northeastward. On this side, however, relations are complicated by faulting (see next column).

Southeast of the embayment the outcrop belt of the rocks of the Chilhowee group is uncommonly narrow. At one place between Dry Run and Elk Run the outcrop is less than a mile wide, a great reduction from its width of 5 miles in the Shenandoah Salient not far to the northeast. Much of this narrowing of the outcrop belt is due to cutting out of beds along a strike fault, the Huckleberry Mountain fault. Along this fault, between Dry Run and Elk Run, the lower member of the Weverton formation is faulted against the Harpers formation and the lower member of the Antietam quartzite (sections J–J′ and K–K′, pl. 5). The fault is obscurely exposed on the north side of the valley of Dry Run, where the Harpers formation on the downthrown side dips 35° SE., and the Weverton formation on the upthrown side dips 70° SE. In this vicinity the fault apparently dips at a high angle to the southeast, and is presumably a thrust fault. The Huckleberry Mountain fault apparently dies out northward in the Weverton formation in the valley of the South Fork of Naked Creek and has not been traced beyond (pl. 1). Northwest of the Huckleberry Mountain fault, the Harpers formation and Antietam quartzite are thrown into two or three narrow asymmetrical anticlines, plunging to the southwest (pl. 4).

The Elkton embayment may be considered to end at the southwest along a west-northwest trending zone of transverse faults that follow the valley of Elk Run (pl. 4). Two of these faults are termed the Niggerhead and Elk Run faults, but they appear to be merely the major breaks in a zone of slicing and brecciation about a third of a mile wide. On this zone, the rocks to the south have been shifted westward by strike-slip movements, relative to those on the north side. This movement, combined with the rise in the plunge of the folds to the southwest, causes the rocks of the Chilhowee group to crop out farther to the northwest in the Hanse Mountain area than they do in the Elkton embayment.

The faults in the zone along Elk Run have given rise to more brecciation than any others in the Elkton area. The Niggerhead, a conical hill between the Niggerhead and Elk Run faults, consists of quartzite of the lower member of the Antietam. Throughout the whole hill, bedding is obscure, and the quartzite is greatly shattered and broken. In places, the fractures are cemented by iron oxide. About three-quarters of a mile to the west, in the valleys of Elk Run and Wolf Run, are three or four large, bouldery ledges of quartzite breccia. On the Dean farm, on Wolf Run about half a mile above its mouth, a water well has encountered quartzite breccia, in which the fragments are cemented by manganese oxides (King, 1943, p. 53).

The Huckleberry Mountain strike fault joins the transverse fault complex from the north, and apparently dies out in it. It seems to be present between the Niggerhead and Elk Run faults, although offset to the west from its position in the north, for the Weverton formation lies against Antietam quartzite southeast of the Niggerhead (pl. 1). South of the Elk Run fault there is no displacement corresponding to the Huckleberry Mountain fault.

HANSE MOUNTAIN AREA

Southwest of the Elkton Embayment, in the vicinity of Hanse Mountain, the Chilhowee group crops out as much as 2 miles farther northwest than it does in the embayment. Relations are thus similar to those on the northeast side of the embayment, on the flank of the Shenandoah Salient. This area is, however, not an isolated salient, for the Chilhowee group crops out southwest from Hanse Mountain in nearly the same position to the vicinity of Waynesboro, Augusta County.

In this report, the segment of this outcrop belt of the Chilhowee group that lies in the Elkton area is termed the Hanse Mountain area.

A change in the structure of the Chilhowee group from that characteristic of the Elkton Embayment is immediately apparent south of the fault zone along Elk Run. Areas of brecciated rock are absent; there is no break comparable to the Huckleberry Mountain fault; nor are there any sharp folds in the Harpers and Antietam formations. Instead, the strata dip northwestward, in normal order, at angles of 10°–30° (sec. L–L′, pl. 5).

A short distance southwest of Elk Run, along Swift Run, the rocks of the Chilhowee group are broken by another transverse fault, the Swift Run fault (pl. 4), but it appears to be different in character from the faults near Elk Run. The Swift Run fault trends north-northwest rather than west-northwest. No brecciated rock was seen near it and its presence is indicated mainly by discontinuities between the outcrops on opposite sides of the valley of Swift Run. Movements along it are apparently nearly vertical; it may be a normal fault, downthrown to the west. In most places it lies in northwest-dipping beds whose outcrops on the east side are offset northward relative to those on the west side. However, near its north end the fault cuts the syncline southeast of the Hanse Mountain anticline. The synclinal axis is not greatly offset by the fault. On the west or downthrown side a small remnant of residuum of the Tomstown dolomite is preserved in the trough of the fold.

Southwest of Swift Run, the rocks of the Chilhowee group are folded into a number of open anticlines and synclines, somewhat asymmetrical to the northwest (pl. 4). The most prominent of these folds is termed the Hanse Mountain anticline. Its axis follows the crest of Hanse Mountain, whose northwest and southeast flanks are dip slopes of Antietam quartzite (sec. M–M′, pl. 5). Northeast of Hanse Mountain the anticline plunges toward the Elkton Embayment. To the southwest, the anticline is conspicuously exposed in the valley of Hawksbill Creek a mile above its mouth, where a small inlier of the Weverton formation is brought up along the axis (sec. N–N′, pl. 5). Beyond, the fold is less conspicuous, and it apparently dies out in the steeply dipping rocks of the Harpers and Weverton formations near Gap Run (pl. 4).

Northwest of the Hanse Mountain anticline is a lower and narrower anticline that follows the crest of the outlying foothill of Giants Grave (pl. 4). This anticline is doubly plunging, for the Antietam quartzite along its crest passes beneath the residuum of the Tomstown dolomite toward both the northeast and southwest. The syncline between the Giants Grave anticline and Hanse Mountain anticline has a similar double plunge. Along Hawksbill Creek the syncline is entirely in the Antietam quartzite (sec. N–N′, pl. 5), but to the northeast and southwest it encloses reentrant areas of residuum of the Tomstown dolomite. The Elkton mines, which were formerly worked for manganese and manganiferous iron ore, lie in the synclinal reentrant to the northeast (pp. 74–76). The synclinal reentrant to the southwest forms an embayment in the mountain front 2 miles long and a mile wide (sec. O–O′, pl. 5). At its southwest end, beyond Gap Run, the plunge of the folds is reversed, and the Antietam quartzite raised into the crest of Rocky Mount. Here, the structure is more complex than at Giants Grave, for instead of one anticline there are three or four (sec. P–P′, pl. 5).

AREA NORTHWEST OF HANSE MOUNTAIN AREA

The bedrock of the Shenandoah Valley northwest of the Hanse Mountain area is largely masked by Quaternary gravel and alluvium, but there are enough outcrops near the South Fork of the Shenandoah River from Elkton northwestward to suggest the general structure (pl. 1).

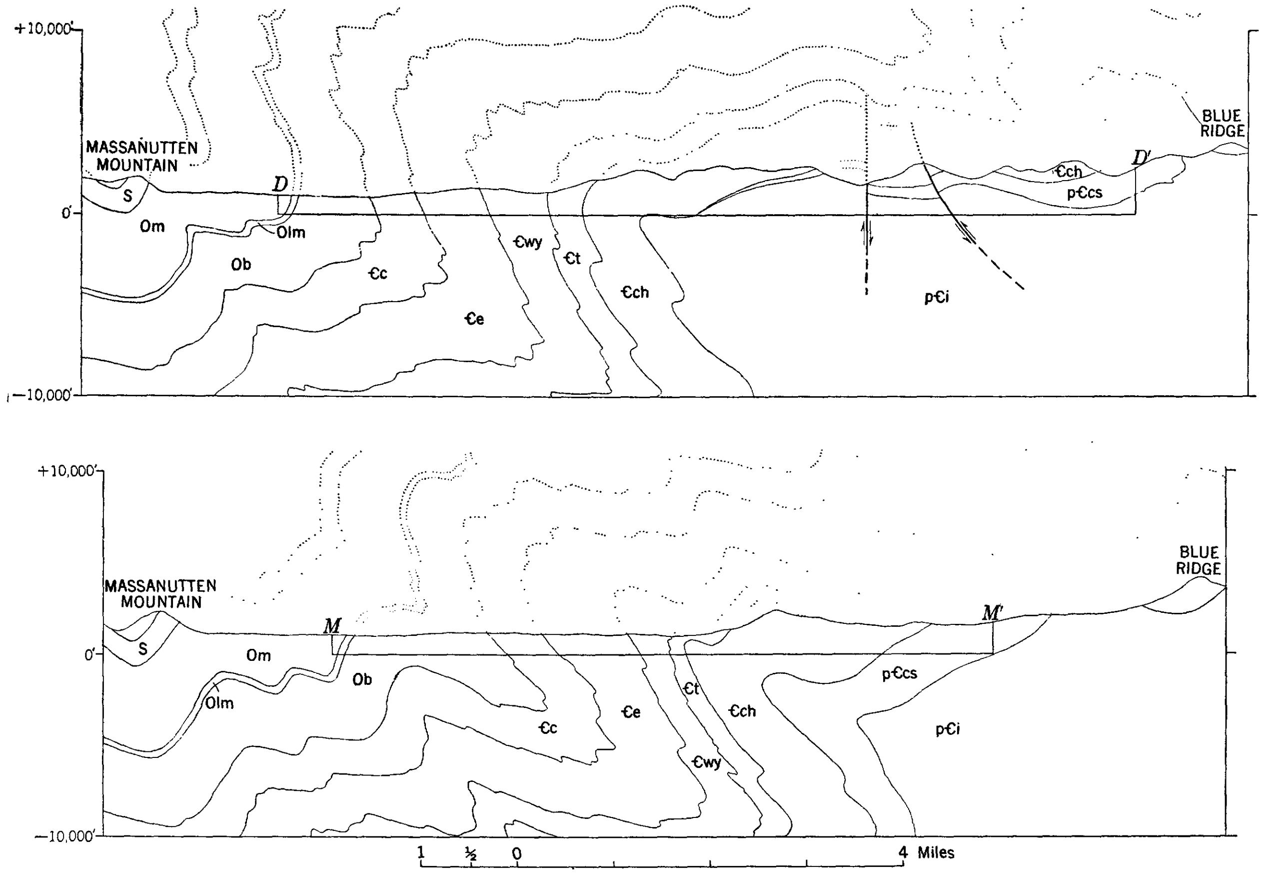
Near Elkton, the rocks of the Waynesboro, Elkbrook, and Conococheague formations are inclined in various directions and at various angles, but in most places dip to the southeast. Thus, over a wide area these formations may be overturned, as they are east of Grove Hill and Shenandoah (sec. M–M′, pl. 5). Farther northwest, the Beekmantown dolomite dips at angles of 25°–60° NW., but near East Point the strata have been arched into a low anticline. Beyond the anticline, the Beekmantown passes beneath the limestones of Middle Ordovician age at angles of 25°–40°.

INTERPRETATION OF LARGER STRUCTURAL FEATURES

RESTORATION OF STRUCTURE ABOVE AND BELOW SURFACE

The structural features just described are those which can be observed in outcrops, and those shown on the structure sections of plate 5 are ones that may reasonably be inferred by extrapolation for short distances above or below the surface. To determine the major structural features of the area, still greater extrapolation and interpretation is necessary.

On figure 13, sections D–D′ and M–M′ of plate 5 have been expanded to a depth of 10,000 feet below sea level and to a height of 10,000 feet above sea level; the ends have also been extended beyond the mapped area to the crests of the Blue Ridge and of Massanutten Mountain. Section D–D′ shows the inferred structure along a line passing through the Shenandoah Salient, and section M–M′ shows the inferred structure along



S, Sandstone of Silurian age; Om, Martinsburg shale; Olm, Limestones of Middle Ordovician age; Ob, Beekmantown dolomite; Ꞓc, Conococheague limestone; Ꞓe, Elbrook dolomite; Ꞓwy, Waynesboro formation; Ꞓt, Tomstown dolomite; Ꞓch, Chilhowee group; pꞒcs, Catoctin greenstone and Swift Run formation; pꞒi, Injection complex

FIGURE 13.—Expanded structure sections. Shows possible structure to a depth of 10,000 feet below sea level, and restored structure to a height of 10,000 feet above sea level, along lines of sections D–D′ and M–M′ of plate 5.

a line passing through the Hanse Mountain area. Because outcrops are poor, a similar section could not be prepared for the intervening area of the Elkton Embayment.

The outcrops along section D–D′ show an area of relatively open folding extending across the Shenandoah Salient. The top of the Chilhowee group at the northwest edge of the salient dips northwest in normal order beneath the rocks of the Shenandoah Valley, but the rocks of the valley immediately beyond are strongly overturned. Farther northwest, in the area of outcrop of the Beekmantown dolomite, the strata are vertical or dip steeply northwest, but nearer Massanutten Mountain the strata presumably dip at a lower angle toward the northwest.

These surface features suggest the presence of a great anticline and flanking syncline, both of whose axial planes dip at relatively low angles to the southeast. The gently dipping rocks in the Shenandoah Salient would form the upper limb of the anticline; the overturned rocks to the northwest would form its lower limb. The vertical rocks beyond would be nearer the axis of the succeeding and underlying syncline. This concept was used in preparing the expanded version of section D–D′. A similar interpretation was also made of section M–M′, where overturned beds likewise occur in the area of outcrop of the Elbrook and Conococheague formations. In section M–M′, however, relations are complicated by the presence of minor folds in the areas of outcrop of the Chilhowee group and the Beekmantown dolomite.

If considerable overfolding took place as indicated on figure 12, it would suggest considerably more crustal shortening in the Elkton area than may be inferred from superficial examination of surface outcrops. Such overfolding might account for the few faults in the area and the absence of any overthrust faults of regional extent. It might also account for the higher grade of metamorphism in the Elkton area, as compared to that in some other parts of the Appalachians. In the Elkton area stresses resulted in folding and overturning of the beds, unrelieved by rock breakage

The rocks themselves thus remained under high confining pressures and were subject to dynamic metamorphism.

INTERPRETATION OF STANLEY FAULT

In describing the Stanley fault it was pointed out that its apparent displacement is downward toward the north, for younger formations on the north side consistently lie against older formations on the south side. This empirical interpretation has been used in indicating the direction of displacement on plates 1, 4, and 5, but as already indicated (p. 43) the supposed movement may be merely apparent. The actual movement may have been quite different.

One possible alternative explanation is that the Stanley fault possesses a large component of strike-slip movement, by which the rocks of the Shenandoah Salient on the south side were moved to the west relative to those to the north. Such strike-slip movement occurred on a minor fault on Roundhead Mountain a mile south of the main fault and parallel to it (pl. 4). Strike-slip movement on the main fault is suggested by the truncation by it of the vertical edges of the Chilhowee group south of Stanley; the corresponding edges of the Chilhowee group north of the fault must lie some miles to the east, in the Stony Man quadrangle. If such strike-slip movements took place, there must have been considerable differences in deformation on opposite sides of the fault, as the fault dies out southwestward, near Grove Hill. Such differences are suggested west of the Shenandoah Salient where the rocks of the Shenandoah Valley south of the fault are vertical or overturned, and those north of the fault dip gently over wide areas. This explanation does not, however, account for the anomalous occurrence of Concocheague limestone north of the fault and south of Honeyville, nor of the probable overturned syncline in this vicinity. In this area, at least, it would be necessary to postulate a component of northward thrusting in the fault movement, as well as a strike-slip movement. This interpretation involves the assumption that movements on the Stanley fault were essentially contemporaneous with the folding of the rocks of the area.

Another, and radically different, interpretation of the movement on the Stanley fault is also possible. In section D–D′ of figure 12, a marked overfolding of the rocks along the west side of the Shenandoah Salient is postulated, resulting in an anticline along the edge of the salient and a syncline in the Shenandoah Valley to the west, with the axial planes of both features dipping at a low angle to the southeast. Could the syncline thus postulated correspond to the overturned syncline near the area of Conococheague limestone north of the Stanley fault? This suggestion is illustrated by figure 14, in which section B–B′ of plate 5 has been expanded upward and downward in a manner similar to that in sections D–D′ and M–M′ of figure 13.

By this interpretation, the rocks south of the fault, on the margin of the Shenandoah Salient, would form the upper flank of the great anticline, and the syncline would be beneath the surface. North of the fault, the syncline would lie at the surface, and the overlying anticline would have been removed by erosion. The north side of the fault would be upthrown about 7,500 feet with respect to the south side. Moreover, extensive rotational movements would be necessary, as the fault terminates about 4 miles to the southwest of this section. It will be noted that this interpretation involves the assumption that the folding of the rocks of the area had been largely or wholly completed by the time of the movement on the Stanley fault.

Evidence within the Elkton area does not permit final judgment as to the merits of the interpretations just discussed. Any final interpretation on the movements on the Stanley fault must be based not only on relations in the Elkton area, but on relations in the Stony Man area to the northeast, into which the fault extends.

PROBLEM OF "BLUE RIDGE OVERTHRUST"

In characterizing the Elkton area, it was stated that faulting is subordinate and that major overthrusts are lacking (p. 41). This interpretation is at variance with that which has been made by other geologists, for it has been widely supposed that in the Elkton area and elsewhere along the northwest foot of the Blue Ridge a great fault, the "Blue Ridge overthrust," separated the rocks of the ridge from those of the Appalachian Valley to the northwest (fig. 15). This interpretation now appears to be out of general favor among geologists but it deserves analysis as an example of the vague evidence on which some of the supposed major features of the Appalachians have been based.

The origin of the concept of a great fault along the northwest flank of the Blue Ridge is not entirely clear. No fault appears in this position on Rogers' sections (1884, secs. 7, 8; pls. 7, 8), and rocks of the Blue Ridge are shown by him as passing without break and in normal order beneath the rocks of the Shenandoah Valley to the northwest. Keith (1894, pp. 360–362, pls. 22, 32), in his geologic map and sections of the Catoctin belt, showed an overthrust at the northwest foot of the Blue Ridge from Harpers Ferry southwestward beyond Front Royal. He also showed an overthrust at the west foot of South Mountain in Maryland, but he apparently regarded this as a separate feature. With the discovery of other faults along the northwest foot of the

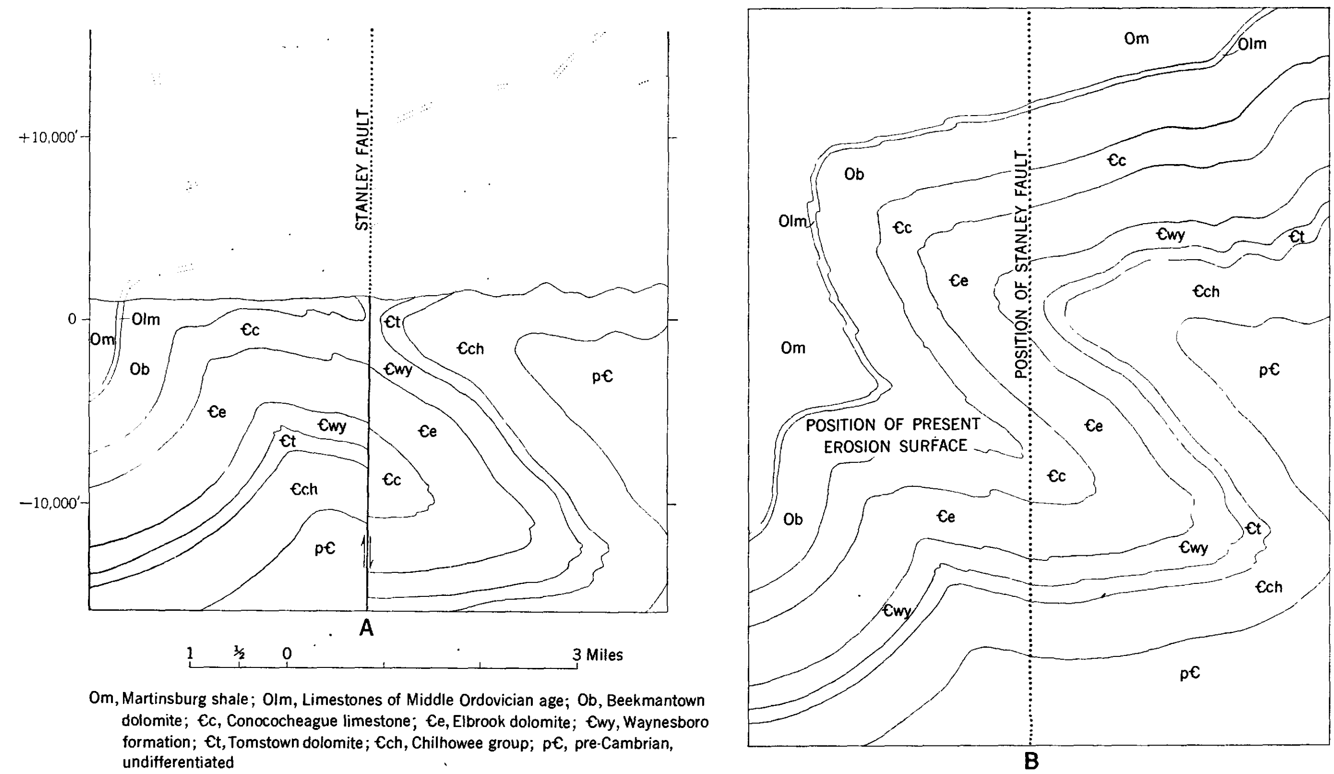


FIGURE 14.—Sections showing one possible interpretation of movements on Stanley fault. A. Expanded section, based on section B–B′ of plate 5, showing possible structure to a depth of 15,000 feet below sea level, and restored structure to a height of 15,000 feet above sea level. B. Possible structure before movement on Stanley fault.

Blue Ridge much farther to the southwest, as near Roanoke (Woodward, 1932, pp. 80–83), there was a natural temptation on the part of geologists to join these disconnected features into a single major fault.

In 1919, Stose and others (pp. 28–30, pl. 3) in their general reconnaissance of the northwest foot of the Blue Ridge concluded that "a great master fault apparently follows along the Blue Ridge throughout most of the region studied [from Front Royal to Roanoke], and lies within but generally close to the west front of the mountains" (p. 28). In the Elkton area, the fault was shown near the contact between the pre-Cambrian rocks and the Chilhowee group, but in other places it was indicated as being between the Chilhowee group and the rocks of the Appalachian Valley, and in still others as lying within the pre-Cambrian rocks of the Blue Ridge. Various indications of the existence of the overthrust are cited, including relations near Marksville in the northeast part of the Elkton area, where ridges of the Chilhowee group "are all cut off at their south ends by the great overthrust fault which thrusts the pre-Cambrian granite across the ends of all the siliceous rocks, and onto the limestone, a horizontal distance of over 4 miles" (p. 29). The fault cited is actually the Stanley fault, on which there were either strike-slip or vertical movements. Obviously, relations on the Stanley fault have little bearing on movements on an overthrust, even if one were present in the vicinity.

In 1932, Jonas (pp. 230–231) stated that "three great overthrusts form the major structural units of the crystalline belt of the southern Appalachians. They are the Martic, the Appomatox, and the Blue Ridge overthrusts." The Blue Ridge overthrust was represented as extending without interruption from Pennsylvania to Alabama.

Butts (1940, p. 440) also postulated an overthrust along the northwest foot of the Blue Ridge, and states that "one of the main structures of the Valley [of Virginia] is a great fault extending far along the Blue Ridge * * * probably its full length." On his map (1933) he shows it in the Elkton area as lying along the contact between the rocks of the Chilhowee group and those of the Appalachian Valley. This interpretation was apparently made to account for the supposed absence of the Tomstown dolomite in parts of this region. The Tomstown is, of course, very poorly exposed in the Elkton area, but evidence obtained during the present investigation indicates that the formation is actually present, and lies in normal order and without displacement on the Antietam quartzite.

A different interpretation has been suggested by Bucher (1933, pp. 174–176) from analysis of the results

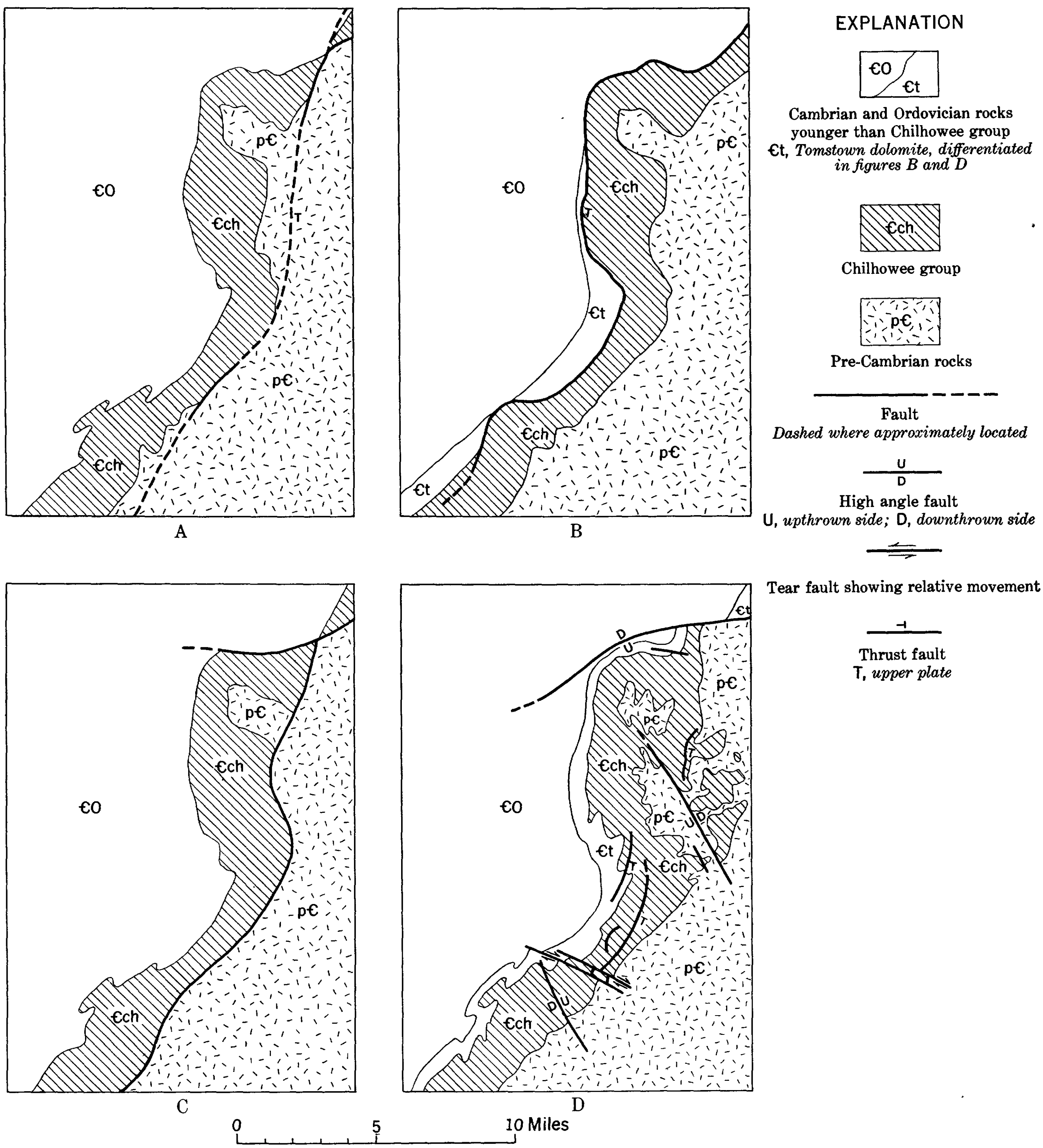


FIGURE 15.—Four geologic sketch maps of Elkton area, showing interpretations which have been made of its major structural features. A. By Stose and others, 1919; scale of original map, 1 : 125,000. B. By Butts, 1933; scale of original map, 1 : 250,000. C. By Jonas and Stone, 1939; scale of original map, 1 : 1,700,000. D. By King in this report; scale of original map, 1 : 31,250.

given by Stose and others. Bucher's map shows the faults at the northwest foot of the Blue Ridge as a series of disconnected features, separated by areas without faulting. The Blue Ridge-Catoctin Mountain anticlinorium is interpreted as a great "welt" rising southeast of the region of the Appalachian Valley, partly overfolded upon it and partly faulted against it.

From our sketch, it is evident that the reality of such a continuous thrust plane is not established. In less deformed welts we have seen thrust planes arise and die out in relatively short distances. It is entirely possible that the same is true here, and in even more intensely disturbed regions. * * * We have no means of deciding from the meager information at hand whether the thrust planes in the Blue Ridge are continuous or not. Even if they are, there still remains a great variation from point to point in the distance of forward movement beyond the edge. Such differential behavior implies a degree of "plastic" yielding which we do not associate habitually with the crystalline cores of welts.

This interpretation corresponds essentially with the views of the present writer as a result of his field work in the Elkton area.

In a recent publication, Stose and Stose (1946b, pp. 112–113) state that their Harpers Ferry overthrust (the fault first mapped by Keith from Harpers Ferry southwestward) "is not the result of breaking of an overturned anticline, but is a clean-cut break which originated in the basement rocks of the core of the uplift," and that it "is one of a series of clean-cut thrusts which originated in the injection complex and which border the west front of the Appalachian Mountains from Maryland southward into Virginia and Tennessee." If such "clean-cut breaks" exist within the basement rocks of the Elkton area, they do not extend to the surface as faults, but have passed into folds within the sedimentary cover. The sharp overfolds along the northwest foot of the Blue Ridge indicated in sections D–D′ and M–M′, figure 13, might have been the result of some such process.

SPECIAL STRUCTURAL FEATURES

SLATY CLEAVAGE

Slaty cleavage is conspicuous in parts of the Elkton area. It is best developed in the least competent beds, but it also increases in intensity southeastward toward the crest of the Blue Ridge (Keith, 1894, p. 363).

Slaty cleavage is best developed in shales of the Harpers formation and the middle member of the Weverton formation; in fine-grained arkoses of the lower member of the Weverton formation; and in tuffaceous slates of the Loudoun and Catoctin formations. In these rocks there is much recrystallization and reconstitution of the mineral constituents, and especially the formation of sericite and muscovite, resulting in an all-pervading cleavage that cuts across bedding, volcanic breccia fragments, and other original structural features in the rock. In places, cleavage is also present in siltstones of the Harpers formation and upper member of the Weverton formation; and in more massive phases of the Catoctin greenstone. In these rocks, the planes are coarser than in the rocks previously described, and the amount of recrystallization is apparently less. In areas of more extreme deformation, fracture cleavage is present in quartzites of the Antietam and lower member of the Weverton, but this appears to result from mechanical splitting rather than from mineralogical rearrangement of the constituents.

Numerous observations were made on cleavage during the present investigation and these are plotted on both the areal geologic map (pl. 1) and the geologic structure map (pl. 4). The plotting on the geologic structure map is designed to bring out the broader trends of the cleavage. It will be observed that throughout most of the area the cleavage trends northeast, and thus diverges in many places from the local strike of the rocks, although maintaining a rather constant parallelism to the trends of the folds. In the northern part of the area, along the east side of the Shenandoah Salient, the strike of the cleavage bends to the north, or even to the north-northwest, but this trend is again parallel to the folds and flexures in that area.

In the south-central part of the Shenandoah Salient in the vicinity of Jollet, a group of 12 cleavage observations in the pre-Cambrian rocks and rocks of the lower part of the Chilhowee group show an aberrant strike of east-northeast or east. This has no relation to any known folds. Moreover, some cleavage observed in the same area shows the normal northeast strike. No observations are recorded in which one set of cleavage crosses the other, but there is a strong likelihood that the two sets are of different ages, and that the east-northeast to east set was produced by forces different from those responsible for the regional deformation.

All the cleavage in the area dips east-southeast or east, but the angle of dip is far less consistent than the strike. No flat-lying or vertical cleavage has been recorded, but there are all angles of dip between the horizontal and vertical. A statistical summary indicates that most of the cleavage dips at angles between 30° and 60°, and that at the largest number of places it dips at an angle of 45°.

Slaty cleavage is generally believed to be parallel to the axial planes of the folds (Billings, 1942, pp. 224–230; Wilson, 1946, p. 269), and this observation seems to be confirmed by observations in the Elkton area. However, a seeming inconsistency exists in the central part of the Shenandoah Salient. In parts of the salient the rocks are apparently little deformed, and in places lie horizontal, yet cleavage is well developed in the less competent beds, and trends in a direction consistent with that elsewhere in the area. (On pl. 4 note the abundance of cleavage observations in the Shenandoah Salient, as compared with the gentle deformation indicated by the structure contours.) It seems plain that such cleavage is related, not to purely local anticlines and synclines, but to the larger folds of the region, such as the overturned anticline on the flank of the Shenandoah Salient indicated in section D–D′, figure 12.

A feature probably analogous to cleavage is observed in places in the carbonate rocks of the Shenandoah Valley, and especially in the Conococheague limestone and Beekmantown dolomite. Planes of flowage, apparently resulting from recrystallization of the carbonate minerals, cross the rock at an angle to the bedding and in places are more prominent than the bedding itself. Localities where measurements have been made on this feature are indicated by cleavage symbols on plates 1 and 4, but it has also been observed at other places. All these localities are in areas of overturned beds; in other words, on the lower limb of the overturned anticline shown in figure 12. At many other places in the area the limestones and dolomites show little evidence of internal reconstitution, even where folded or steeply tilted. Features resulting from flowage of the limestones and dolomites in the Elkton area are analogous to those studied exhaustively by Cloos (1947, pp. 856–910) in the South Mountain area of Washington County, Md., and adjacent parts of Pennsylvania. The features in the Elkton area are, however, apparently not as extensively developed as in the area studied by Cloos.

Curiously, the attitudes of the flowage planes where measured do not seem to correspond closely to the major structural features. In many places the strike is east-northeast and the dip south-southeast, whereas the regional strike of the enclosing beds and the trend of the fold axes is north-northeast.

JOINTING AND VEINING

Both joints and veins are common in the rocks of the Elkton area, but no systematic observations were made on them during the present investigation. Joints are conspicuous features in the more competent rocks, as for example the Antietam quartzite, but their arrangement and origin is undoubtedly complex, and it was not thought that study would be sufficiently rewarding to justify the time spent on them.

Both quartz and calcite veins are present at many places in the Elkton area, but all are narrow and discontinuous, and apparently were formed along gashes or fractures resulting from purely local causes.

ROCK FLOWAGE AND DISHARMONIC FOLDING

In the Elkton area, the rocks have been folded very much as a unit. Disharmonies between the structure of the different formations are not as marked as in areas where competent units are separated by incompetent units. Contrasts exist in the response to deformation of units in widely separated parts of the section, but the contrast in structure of adjacent beds is not striking.

The most competent rocks of the section are probably those of the basement—the gneisses of the injection complex. Almost equally strong are the massive flows of the Catoctin greenstone and the quartzites of the Chilhowee group. These are thrown into broad, open folds, without significant minor contortion. Somewhat less competent are the Cambrian and Ordovician limestones and dolomites of the Shenandoah Valley. Many of these units are thick and massive, but the rocks composing them are not as strong as the quartzites, for they are more susceptible to flowage under extreme deformation.

The least competent rocks are the shales. Those interbedded in the Catoctin greenstone and the Chilhowee group have largely been converted to slates or phyllites, and hence have been subjected to much flowage. However, they occur only as thin members and thus seem to have had little effect on the configuration of the broader structural features. Shales also occur higher in the section in the Waynesboro formation, and toward the top in the Martinsburg. Much local contortion and crumpling was noted in these units, but cleavage is not prominent and there is no certain evidence as to the amount of flowage that has taken place.

In the South Mountain area of Washington County, Md., Cloos (1947, pp. 901–910) believes that the greater part of the deformation has been accomplished by shear folding, due to laminar flow on subparallel planes. Cleavage is described as a nearly universal feature in the rocks, and microscopic studies of oolites indicates 100 percent or more distortion of the ooids parallel to the cleavage. This has resulted in great attenuation of beds and formations along the flanks of the folds, and great thickening of these same units along the axes.

In the Elkton area, the broader structure is similar to that in the South Mountain area described by Cloos (compare fig. 13 of this report with fig. 2, p. 857 of Cloos), and many of the same formations are involved, but the deformation does not appear to be as intense. Cleavage is not universal, but is well developed only in the shales, and in the limestones and dolomites of certain areas. The variations in competency between the different units, as discussed above, have exerted a modifying influence on the results of deformation. Thus, the quartzites of the Chilhowee group have yielded mainly by normal flexure folding, and in the limestones and dolomites shear folding has taken place mainly on the overturned limb of the major recumbent anticline.

Cloos (1947, pp. 910–911) continues his analysis with a discussion of stratigraphic thicknesses, and concludes that in the South Mountain area the original thickness of the formations was no more than half their apparent thickness after deformation. He raises the question as to "whether folding took place in troughs with thick sedimentation, or whether sediments may be thick due to folding." This would seem to require uniform shear folding, affecting all formations of the section over wide areas. In the Elkton area, only the less competent units seem to be thus deformed. It is worth noting that the thicknesses customarily given for formations in the Appalachians have been calculated in numerous sections, widely distributed geographically, and in diverse positions structurally, yet they fail to show the extreme variations that one would expect had they been greatly modified by deformation.

GRAVITY DATA

Information on the value of gravity in the Elkton area is given by Hammer and Heck (1941, 352–362), on the basis of a gravimeter profile that was made across the central Appalachians from Buckhannon, W. Va., to Swift Run Gap, Va. This profile reveals that there is a strong gravity low between the town of Elkton and the crest of the Blue Ridge at Swift Run Gap.

The cause of this gravity low is uncertain. The authors state that—

> the local gravity low at the eastern end of the profile is much too sharp to be the expression of the relatively broad sedimentary syncline adjoining the outcrop of the crystalline rocks.

Yet it is possible—

> that there may be a low density member in the Cambrian section. Station 15–3 is located near the eastern upturned edge of the Rome [Waynesboro] formation and the lithology suggests that this formation * * * may be lighter than the adjacent Tomstown and Elbrook dolomites.

They conclude that—

> the possibility that a higher density in the pre-Cambrian rocks is compensated by a low density member in the Cambrian section cannot be ruled out but does not seem to be supported by the shape of the gravity curves at the eastern end of the profile. Another possibility is that the pre-Cambrian crystallines are denser than the Paleozoic sediments and that the crystalline rock of the Blue Ridge is wedge-shaped and has overridden the Paleozoic sediments to a distance of some miles.

Discussing the general conditions along the line of the profile, they state that—

> While there is little doubt that the regional gravity picture is closely related to the general tectonics in the Appalachian area, it slowly has come to be realized that the gravity picture cannot be fully accounted for by simple considerations of lithologic changes and structures observed or deduced from surface geology. The present detailed data go much further as they prove an almost complete lack of local gravity anomaly associated with individual structure in the central Appalachians. This can hardly lead to any other conclusion than that practically none of the gravity picture arises within the sedimentary section and therefore that it must be due almost entirely to structural or lithologic changes below the sedimentary layer. * * * The absence of local gravity anomalies over the strong geologic structures can only mean that density-contrasts within the sedimentary section compensate or are lacking. * * * Another conclusion that can be drawn from the absence of local gravity anomalies is that either the basement rocks are not involved in the faults and folds observed at the surface or the density contrast between basement and sedimentary rocks is very small.

CENOZOIC DEPOSITS AND LAND FORMS

Overlying the pre-Cambrian and Paleozoic rocks of the Elkton area, whose stratigraphy and structure have been described, are residuum and various unconsolidated deposits that accumulated during the Cenozoic era. The Cenozoic was, however, primarily a time of terrestrial conditions and of erosion, and the Cenozoic residuum and deposits are materials formed during relatively brief episodes. To understand the Cenozoic era, reference must also be made to the land forms that were shaped during the time.

The land forms in the Appalachians of western Virginia (Blue Ridge, Appalachian Valley, and Appalachian Ridges of fig. 1) fall into several broad classes which are summarized by Wright (1925, p. 11): "There are five chief elements in the topography, which, beginning with the highest, are as follows: (a) Monadnocks on the Upland Peneplane; (b) remnants of the Upland Peneplane; (c) Monadnocks on the Valley Peneplane; (d) the Valley Peneplane; (e) trenches cut below the Valley Peneplane." In general, these correspond to forms seen in and near the Elkton area.

The history of the land forms in the Appalachians of Virginia has been variously interpreted. There has not been general agreement on the number of former erosion surfaces now preserved, nor on the ages of the respective surfaces. Some of the interpretations which have been made are indicated in the following table:

Interpretations of land forms in Appalachians of Virginia

Topographic position.	A. Keith, 1894, pp. 366–394.	G. W. Stose, 1919, pp. 34–40.	D. Johnson 1931, pp. 14–21.	F. J. Wright, 1934, pp. 1–43; also 1925, pp. 7–41.	A. J. Stose and G. W. Stose, 1946, pp. 6–10; also 1940, 461–476.	P. B. King, this report.
Above summits.			Fall Zone peneplane: pre-Cretaceous.		Rejected, same as Schooley peneplain.	
Summits.	Residuals on Blue Ridge.	Summit peneplain, pre-Kittatinny: pre-late Jurassic.		Residuals, no definite peneplane.		
Uplands.	Cretaceous or Catoctin baselevel; Cretaceous.	Upland peneplain, Kittatinny: late Jurassic or early Cretaceous.	Schooley peneplane: Middle Tertiary.	Schooley peneplane.	Schooley peneplain: pre-Cretaceous but not dissected until Miocene.	Not studied, may be Mesozoic.
Intermediate surfaces.	Weverton baselevel.	Intermediate peneplain, Weverton: Middle Cretaceous.		Doubtful.	Weverton peneplain, (minor).	Doubtful in Elkton area.
Valley floor.	Tertiary baselevel, =pre-Lafayette surface: Late Tertiary.	Valley-floor peneplain, Harrisburg: Early Tertiary.	Harrisburg peneplane: Late Tertiary?	Harrisburg peneplane, or Valley peneplane.	Harrisburg peneplain: Late Tertiary.	Valley-floor peneplain and residuum: older Tertiary.
Below valley floor.		Lower valley-floor terrace, Lafayette: Pliocene.	Somerville peneplane.	Part of Harrisburg surface.		Ancient gravel unit: Tertiary(?)
Along river valleys.	Upper baselevel and lower baselevel: Pleistocene.	Gravel-covered terraces: Pleistocene.		Terraces.	Gravel-covered terraces: Pleistocene.	Older, intermediate, and younger gravel units: Pleistocene.

In this report, some of the observations and interpretations, particularly those relating to features on the valley floor, are not consistent with earlier interpretations, and also imply modifications in our conception of the general history of the region. It has not seemed feasible in a report of limited scope to resolve these inconsistencies or to explore all the implications.

UPLAND AREAS

POSSIBLE HIGH-LEVEL PENEPLAINS

CHARACTER

Any remnants of former high-level peneplains near the Elkton area would lie on or near the crests of the Blue Ridge and of Massanutten Mountain (pls. 1 and 6). These areas were not studied during the present investigation, and the writer made no observations on them. The relations have been described and interpreted by Keith (1894, pp. 384–392), Stose (1919, pp. 37–38, pl. 1), and others.

The most elaborate treatment of the Blue Ridge area is by Stose, who recognizes both a "Summit peneplain" and an "Upland peneplain." Near Luray the Summit peneplain is considered to form broad flats and gentle divides at an altitude of 3,500 feet, with Stony Man and other peaks rising as residuals above it. Farther southwest, as between Elkton and Waynesboro, the broad rounded tops stand at altitudes of about 3,000 feet, and are considered to represent the Upland peneplain. The Upland peneplain is interpreted by Stose as equivalent to the Kittatinny (Schooley) peneplain of Pennsylvania and New Jersey; the Summit peneplain is therefore still older. In view of uncertainties in regard to evidence of former peneplains on the Blue Ridge, Fenneman's comment (1938, p. 168) is apt:

> Considerable stretches on the Blue Ridge in Virginia seem almost sure to have been peneplaned, but as these have different heights, much uncertainty remains as to the elevation of the old base level, the extent of former peneplaning, the amount of later warping, and even of the number of base levels represented.

In the Massanutten Mountain area to the northwest, both Keith (1894, p. 391) and Spencer (1897) have interpreted the crests of the narrow ridges as remnants of a former peneplain surface. These crests show considerable irregularity, and must therefore have been degraded somewhat below any former peneplain level, but their average altitude falls a little under 3,000 feet. This suggests that any former surface on Massanutten Mountain, if it existed, was equivalent to the Upland peneplain of Stose in the Blue Ridge to the southeast.

AGE

A full discussion of the age of the high-level peneplains is beyond the scope of this report; as indicated in the table on page 53, considerable diversity of interpretation exists. A widely accepted older interpretation, followed by Stose in 1919 (p. 38), is that the Schooley, or Upland peneplain is equivalent to the surface beneath the Cretaceous deposits of the Atlantic Coastal Plain, and hence is late Jurassic or early Cretaceous in age. Later writers, notably Shaw (1918, pp. 575–586), and Johnson (1931, pp. 14–21), express the opinion that the Schooley is much younger, and probably of mid-Tertiary age. The floor beneath the Cretaceous deposits of the coastal plain, the Fall Zone peneplain of Johnson, is supposed to have been represented in the Appalachians by a surface, now completely destroyed by erosion, that lay high above the Schooley level. Stose (1940, pp. 461–476) in a later paper reaffirms the continuity of the Schooley with the floor of the coastal plain sediments, but suggests that "the landward part of the peneplain was not uplifted sufficiently to be materially eroded until mid-Tertiary time" (p. 474).

POSSIBLE INTERMEDIATE PENEPLAIN

Along that part of the Blue Ridge near the Potomac, Keith (1894, p. 238) has recognized a younger surface below the Upland peneplain, which he terms the Weverton. Stose (1919, pp. 38–39) believes that in the Blue Ridge farther southwest this intermediate peneplain is poorly represented on some of the tops of the foothill ridges, spurs, and knobs, and in some of the low divides and wind gaps on the main ridge. Such a surface might once have been present in the Elkton area in the northwest foothills of the Blue Ridge, underlain by the clastic sedimentary rocks of the Chilhowee group. If so, it has now been entirely destroyed, for the foothills are a series of irregular crests of greatly varied form and height.

VALLEY FLOOR

In the Elkton area, the floor of the Shenandoah Valley is a complex of rock-cut surfaces, of residuum, and of gravel deposits, which stand at various levels, but in large part rise well above the flood plains of the present streams (pl. 6). The floor appears level only by contrast with the mountains that border it on either side; in places its relief exceeds 500 feet. The upland areas of the floor of the Shenandoah Valley have been termed the Valley Floor, Harrisburg, or Shenandoah peneplain, which has been described by Keith (1894, pp. 374–376), Stose (1919, pp. 39–40), Wright (1934, pp. 28–31) and others. In these descriptions, chief attention has been given to land surfaces, and little attention has been given to the materials of which the surfaces are composed. Study of these materials suggests that the history of the valley floor was probably more complex than has been supposed (King, 1949a).

Overlying the bedrock on parts of the valley floor are masses of residuum, formed as a result of the decay of the carbonate rocks. At one locality the residuum is overlain by ancient gravel deposits. Both the residuum and the ancient gravel unit were mineralized by iron and manganese oxides, and their upper surface was deeply eroded before the succeeding or main deposits of gravel were laid down over them. The main gravel deposits are divisible into older, intermediate, and younger units, deposited on successively lower erosion levels. These are in turn trenched by the present streams and higher than the Recent stream alluvium.

RESIDUUM

CHARACTER

The residuum resulting from the decay of the carbonate and argillaceous rocks of the Shenandoah Valley has already been described under the respective Cambrian and Ordovician formations (pp. 28–34, 36). The residuum consists of insoluble material, principally clay, which remains after the solution of limestone or dolomite, or after kaolinization of sericite in shale. Mixed with the clay are sand and silt, a residue of originally sandy or silty rocks, and chert, originally in the form of concretions in the carbonate rocks. Some of the clay also contains nodules, plates, and impregnations of iron and manganese oxides, which were introduced into the clay after its formation by processes of mineralization and replacement. Much of the clay has a chaotic structure (pl. 3), which resulted from collapse, compaction, and creep that took place during the reduction in volume of the original rock.

THICKNESS

The residuum is thickest over the Tomstown dolomite and Waynesboro formation on the southeast margin of the valley, and is thin or even lacking over the younger carbonate formations along the axis of the valley.

The volume of the residuum overlying the Tomstown and Waynesboro formations is indicated by test holes and mine workings. Test holes put down by the U. S. Bureau of Mines on the Watson tract in 1941 showed a thickness of residuum of the Tomstown dolomite of 100 to 150 feet (secs. Q–Q′ and R–R′, fig. 16). Test holes south of Giants Grave showed a thickness of residuum of the Tomstown dolomite of 50 to 100 feet (sec. T–T′, fig. 14). The Neisswaner shaft, put down a mile south of Elkton in 1913 to 1915 showed a thickness of residuum of the Waynesboro formation of nearly 200 feet (sec. S–S′, fig. 16, see also Hewett, 1916, pp. 61–67). The residuum in test hole No. 1 on the Watson tract extends down to the altitude of nearby Naked Creek, along which residuum is also exposed, and residuum in the Neisswaner shaft extends below the altitude of the nearby South Fork of the Shenandoah River.

The residuum of the younger carbonate formations farther out in the Shenandoah Valley is thinner. Thin bodies of residuum were noted above the unweathered Elbrook and Beekmantown dolomites in some outcrops, and somewhat thicker bodies were noted above the Conococheague limestone (fig. 10). Residuum may overlie the Elbrook and Conococheague over a considerable area east of the town of Shenandoah (sec. W–W′, pl. 6), as outcrops of it were seen here and there on creek banks. In other places residuum is absent, as along the east side of the South Fork of the Shenandoah River at Elkton, where unweathered Elbrook dolomite is overlain directly by gravels. The base of the residuum of the younger carbonate formations also seems to be higher with respect to present drainage than that of the Tomstown and Waynesboro formations. Near Elkton unweathered Elbrook dolomite and Conococheague limestone are 50 feet or more above river level, whereas the unweathered Waynesboro formation is below river level in the Neisswaner shaft not far to the southeast (sec. Y–Y′, pl. 6). North of the town of Shenandoah unweathered Beekmantown dolomite extends 100 feet or more above river level.

The Martinsburg shale northwest of the axis of the Shenandoah Valley seems to have produced only small amounts of residuum; ledges of unweathered shale extend 300 feet or more above river level (sec. W–W′, pl. 6).

The thickest masses of residuum are therefore on the Tomstown dolomite and Waynesboro formation. In part this is because these formations lie farthest from the axis of the valley. Their residuum would therefore be less subject to attack by later erosion than that of the younger formations. However, the base of the residuum in many places extends below the level of modern drainage (sec. Q–Q′ and S–S′, fig. 16), and lower than the base of the residuum of the younger formations near the axis of the valley. Very deep circulation of ground water evidently took place, for surface drainage at the time of formation of the residuum stood at a higher level than modern drainage. Along the belt of outcrop of the Tomstown dolomite and Waynesboro formation, circulating ground water may have been guided by the impervious beds of the Antietam quartzite which underlies the Tomstown. Similar relations have been found in northeastern Tennessee, where the thickest masses of residuum lie against quartzite dip slopes (Rodgers, 1948, p. 15 and fig. 3).

ORIGIN

Residuum is not being actively accumulated at present. Rock outcrops on valley slopes that have been cut below the uplands of the valley floor show little or no surface accumulation of clay. Clay is no doubt being released today by weathering of carbonate rocks on the valley slopes, but under present conditions it is carried away by erosion. The thickest accumulations of clay are beneath the upland surfaces of the valley floor, where removal by erosion would be even more effective at the present time. Moreover, the clays are mineralized by iron and manganese oxides, yet many such deposits, according to Hewett (1916, p. 44):

> are situated near the top or along the slope of isolated hills or spurs, so that since dissection of the peneplain began they have received very little of the surface drainage or ground water that might contain manganese in solution.

Most of the larger masses of residuum are overlain unconformably by deposits of the older, intermediate, or younger gravel units. The unconformity truncates, the contorted structure of the residual clay, indicating that the collapse, slump, and creep of the clay took place before the gravel was laid down. Moreover, the clay is mineralized by iron and manganese oxides, whereas the gravel is not mineralized, but contains fragments of iron and manganese minerals reworked from the clay. The gravel was deposited on several surfaces at different altitudes and presumably at different times. In a previous report (King, 1943, p. 22), it was implied that accumulation of residuum took place during each erosion period which preceded an epoch of gravel deposition. This is now regarded as unlikely; it is more probable that the main accumulation of residuum took place during a single epoch, and that this epoch was older than the deposition of the highest or older gravel unit.

The residuum seems to have accumulated during an epoch prior to the deposition of the older gravel unit, at a time when the upland areas lay near the grade of the streams that drained them, and at a time when erosion was not active enough to have removed the resid-

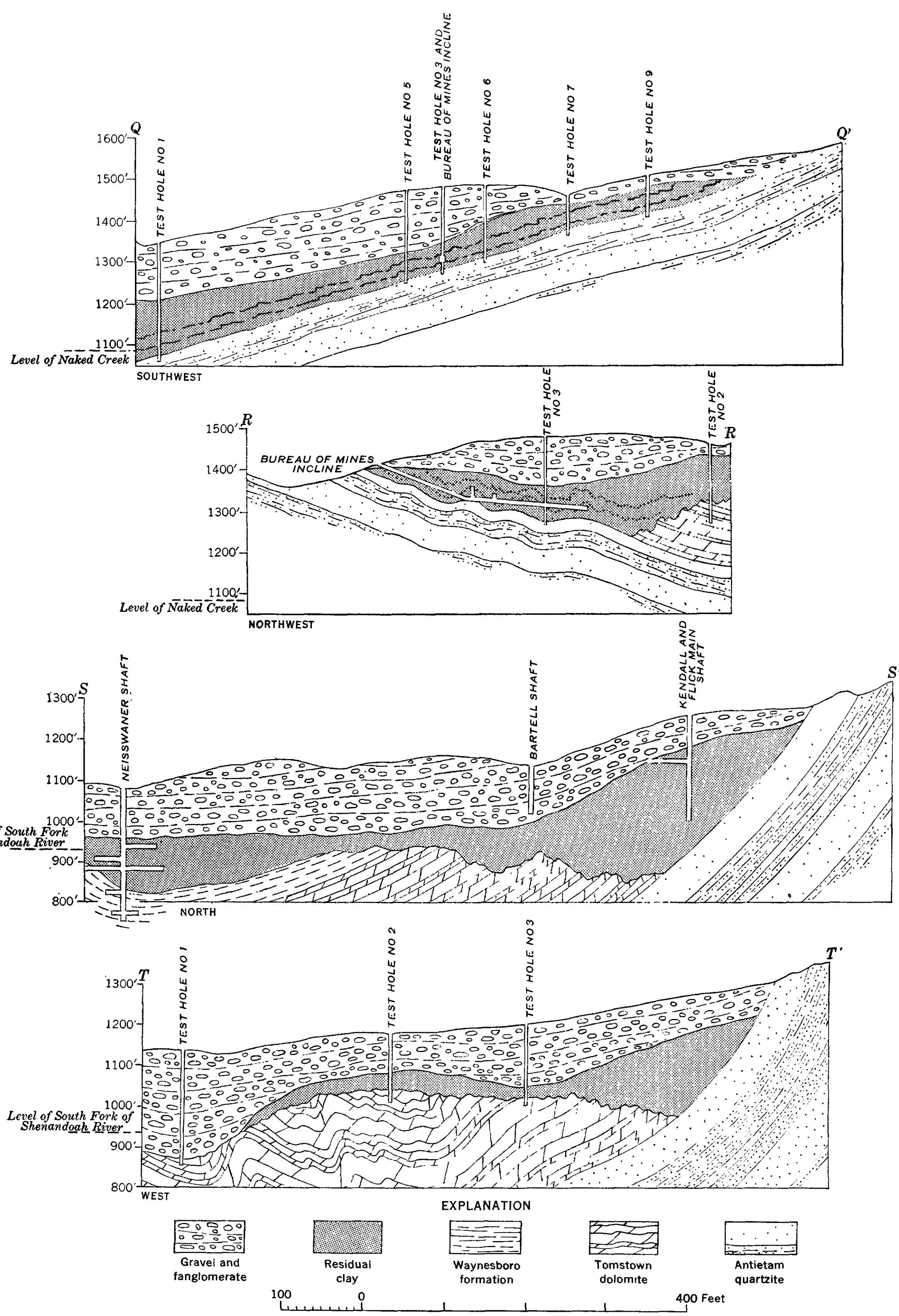


FIGURE 16.—Four sections, showing inferred relations of gravel and residual clay to bedrock along northwest foot of Blue Ridge. For location, see plate 6. Sections Q–Q′ and R–R′ are on Watson tract, 5 miles northeast of Elkton. For details of section R–R′, see plate 3. Section S–S′ is in the vicinity of the Elkton mines on northwest slope of Hanse Mountain, a mile south of Elkton. Section T–T′ is south of Giants Grave, 3 miles south of Elkton. Sections Q–Q′, R–R′, and T–T′ based on Bureau of Mines drill holes and underground workings put down in 1941. Section S–S′ based on records published by Hewett in 1916.

uum as it formed. At this time, the topography had reached a state of peneplanation, which no doubt corresponds to the closing stages of the development of the Valley Floor or Harrisburg peneplain.

Hewett (1916, pp. 45–47), in referring to the accumulation of manganese and iron-oxide deposits in the residuum suggests that they formed in a warm and moist climate, and that they "represent rapid accumulation during a period geologically brief." Similar climatic conditions no doubt existed during the accumulation of the residuum in which the deposits occur, but the time required for the accumulation of the residuum was probably longer than that required for the manganese and iron deposits.

DEPOSITS BETWEEN RESIDUUM AND OLDER GRAVEL UNIT

Lying stratigraphically between the residuum and the older gravel unit are small remnants of other deposits. Because of their position they are rarely revealed in natural exposures, but they have been uncovered in mine workings and other artificial openings. Only one remnant of such deposits was observed in the Elkton area, here termed the ancient gravel unit, but they are widespread in the southern Appalachians, as indicated below.

ANCIENT GRAVEL UNIT AT STANLEY MINE

The single observed occurrence of the ancient gravels lies in the north part of the Elkton area, in the open cut of the Stanley mine, which is a mile southwest of Stanley at an altitude of 1,350 feet. The deposit fills a steep-sided, eroded basin in clay residual from the Tomstown dolomite, and is overlain unconformably by coarse deposits of the older gravel unit (fig. 5). The ancient deposit consists of cross-bedded red sand, in which deeply weathered, rounded pebbles of sandstone and quartzite are embedded. Like the underlying clay, the deposit contains nodules and masses of manganese oxides that have impregnated or replaced the original sandy sediment. The overlying older gravel unit at this locality contains pieces of manganese oxides reworked from the residuum and from the ancient gravels, indicating that at least a part of the manganese mineralization of these units took place between the time of deposition of the ancient and older gravel units.

RELATED DEPOSITS IN OTHER AREAS

Mineralized, ancient gravels are present at the same stratigraphic position elsewhere in Virginia. Manganese-bearing pebbly sand and clay have been encountered and mined at the Kennedy mine, Augusta County, and at the Midvale mine, Rockbridge County, southwest of the Elkton area (Stose and others, 1919, pp. 103–107, 113–118; Hewett, 1916, p. 60).

North of the Elkton area, near Pond Bank, Pa., and Brandon, Vt. (Barghoon and Spackman, 1949), small basins of lignite of Tertiary age have been reported, which are said to lie on the valley-floor surface, and to be below the level of the surrounding mountains.

At many localities in the southern Appalachians deposits at the same stratigraphic position as the ancient gravel unit have been worked for bauxite. One of these is southwest of Greenville, Augusta County, Va., and others are in Tennessee, Georgia, and Alabama. These were intensively studied by Geological Survey field parties under the direction of Josiah Bridge during World War II, and a summary of the results has been prepared (Bridge, 1950). One of the deposits, near Elizabethton, Tenn., was studied by the writer and his colleagues (1944, pp. 210–213) and, according to Bridge, resembles those elsewhere. It lies on the valley-floor upland and consists of a mass of

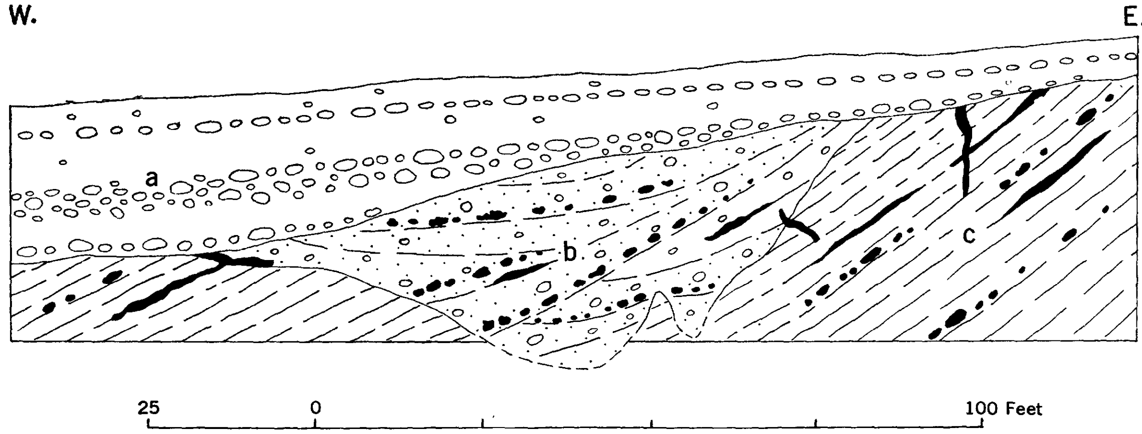


FIGURE 17.—Schematic section, based on outcrops in southern open-cut of Stanley mine, showing relation of ancient gravel unit (*b*) to residual clay derived from Tomstown dolomite (*c*), and to older gravel unit (*a*). Units *b* and *c* contain manganese minerals (shown in black) and are older than the mineralization. Unit *a* contains reworked fragments of manganese minerals, and is younger than the mineralization.

kaolinitic clay with a central core of bauxite. The deposit forms a steep-sided pocket in residuum derived from the underlying carbonate bedrock. In the kaolin are contorted lenses of lignite. The lignite at Elizabethton and at most other deposits has failed to yield identifiable plant remains, but, according to Bridge (1950), plant remains collected in clay and bauxite deposits in sinkholes on the valley-floor surface near Anniston, Ala., and Cedartown, Ga., have been identified by Roland W. Brown as of Midway (Paleocene) age.

AGE OF RESIDUUM AND OF DEPOSITS BETWEEN RESIDUUM AND OLDER GRAVEL UNIT

The residuum evidently accumulated during the closing stages of the development of the valley floor or Harrisburg peneplain. However, as indicated in the table on p. 53, no general agreement exists as to the age of this or other peneplains in the Appalachians.

According to widely accepted theories of Appalachian evolution, as shown in the table on p. 53, the shaping of the present land forms was accomplished in later Tertiary time. Johnson (1931, pp. 14–21) considers that the Schooley peneplain was not completed until middle Tertiary and the Harrisburg peneplain not until late Tertiary. Stose (1940, pp. 461–476), who believes that the Schooley was formed much earlier, suggests that it was not greatly dissected until the Miocene, which would result in assigning about the same date to the completion of the Harrisburg surface.

However, the valley floor evidently had a long geologic history before the deposition of the older gravel unit, even though the land surface itself was not much lowered by erosion. First, residuum accumulated slowly as a result of rock weathering, probably in a warm and moist climate, under conditions of peneplanation. Afterwards, deposits such as the ancient gravel unit were laid down locally on the surface. There are at least two types of these deposits between the residuum and the older gravel unit—mineralized sand and gravel, and kaolinitic bauxitic lignite-bearing clay. The origins of the deposits were diverse, and perhaps also their ages. In Georgia and Alabama, fossil plants in deposits on the valley floor surface indicate that these deposits are of early Teritary age. The deposits in Virginia may be as ancient, but their age has not been proved. After the deposition of the ancient deposits, both their surface and that of the residuum was eroded before the older gravels were deposited. If the older gravels are Pleistocene, the events which preceded their deposition would seem to require a considerable portion of Tertiary time.

GRAVEL DEPOSITS

The most extensive formations on the surface of the valley floor are a series of gravel deposits, laid down on several surfaces that stand above the level of the present drainage. In many parts of the area, three sets of deposits are apparent, herein referred to as the older, intermediate, and younger gravel units (pl. 1).

The three sets of deposits were laid down on surfaces at different altitudes, each separated from the next by a low scarp, and rising as steps or terraces away from the South Fork of the Shenandoah River, and toward the Blue Ridge and Massanutten Mountain. These relations are typically displayed on the divide southwest of Elk Run between Elkton and Hanse Mountain (sec. Y–Y′, pl. 6). In some other parts of the area the differentiation is less evident. The units may merge without a distinct intervening scarp, or isolated gravel patches can only doubtfully be assigned to one unit or another. In such areas, the tripartite subdivision may have been more or less arbitrarily applied. However, despite possible errors in detail, it is believed that the general relations shown on the map (pl. 1) are correct.

OLDER GRAVEL UNIT

The older gravel unit, which is highest in altitude, is less extensively preserved than the intermediate gravel unit which succeeds it (pl. 1). It forms a series of remnant benches that fringe the northwest base of the foothills of the Blue Ridge along the whole length of the Elkton area. Similar benches occur along the southeast foot of Massanutten Mountain, but only their outer edges were mapped during the present investigation. In addition to the benches, there are remnants identified as older gravel well out in the Shenandoah Valley in the vicinity of Fox Mountain (sec. X–X′, pl. 6). Here, two gravel-capped knobs project above the plain of the intermediate gravel unit on the divide between Naked Creek and Dry Run.

The older gravel unit on the Blue Ridge side lies generally on the eroded surface of residuum of the Tomstown dolomite and Waynesboro formation; on the Massanutten Mountain side it lies on the Martinsburg shale (pl. 6). The upper surface of the gravels is probably depositional. At the outer edges of the remnants the surface stands at altiudes of 1,100 to 1,200 feet, and slopes gently toward the axis of the valley. On the mountainward sides of the remnants the surface rises abruptly to heights as great as 1,500 feet and assumes the form of a piedmont alluvial slope (fig. 6). On the Massanutten Mountain side, where Cub Run enters the Shenandoah Valley at Catherine Furnace, there is a fine alluvial fan in the older gravels (pl. 1; sec. V–V′, pl. 6). Less distinct fans are also present on the Blue

Ridge side, as where Fultz and Stony Run leave the foothills northeast of the town of Shenandoah.

The deposits of the older gravel unit are probably thickest beneath the piedmont alluvial slope at the edge of the mountains. On the Watson tract, close to the mountains, 140 feet of gravel occur in test hole No. 5 (sec. Q–Q′, fig. 16). Similar thicknesses of gravel are present in the shafts of the Elkton mines along the northwest foot of Hanse Mountain (sec. S–S′, fig. 16), and in test hole Nos. 2 and 3 south of Giants Grave (sec. T–T′, fig. 16). In the latter area, an exceptional thickness of 260 feet of gravel was encountered in test hole No. 1. Here, gravel lies directly on unweathered Tomstown dolomite, and its base is 100 feet below the altitude of the nearby South Fork of the Shenandoah River; it may represent the filling of an old sinkhole. In the vicinity of Stanley in the northeast part of the Elkton area thicknesses of the gravel range from 50 to 175 feet according to Cady (1936, pp. 80–81).

The older gravel unit consists of pebbles, cobbles, and boulders in rude strata in a sandy clay matrix. Most of the fragments are quartzite, derived from the sedimentary rocks of the adjacent foothills and mountains. The fragments on the Blue Ridge side are largely white siliceous quartzite derived from the Antietam; many of the pieces contain *Scolithus* tubes. Also present are some fragments of ferruginous or feldspathic quartzite from the older units of the Chilhowee group, and massive greenstone from the Catoctin. On the Massanutten Mountain side, the fragments consist of sandstones of Silurian age. In the open-cut of the Stanley mine and at some other localities, the gravels contain pebbles of manganese oxides reworked from ore bodies in the residuum beneath (fig. 17). Most of the quartzite fragments are rounded, indicating a certain degree of transportation, but on the ridge west of Fultz Run, probably near the axis of a former alluvial fan, are angular blocks as large as 3 or 4 feet in diameter. The older gravels do not show any evidence of mineralization, cementation, deep weathering, or other marks of extreme antiquity. Most of the component quartzite boulders are fresh and strong, although in a few places they have disintegrated to such an extent that they can be crumbled into sand.

INTERMEDIATE GRAVEL UNIT

The intermediate gravel unit covers a somewhat larger area than either the older or younger gravel units (pl. 1). It lies on a bench at an intermediate height between the older and younger gravels, and also at an intermediate distance between the axis of the Shenandoah Valley and its margins. The most extensive area of the intermediate gravel unit is in the Elkton Embayment, where it forms the surface of broad plains between Naked Creek and Elk Run. As with the older gravels, the surface of the intermediate gravels rises toward the margins of the Shenandoah Valley and away from its axis, but alluvial fans and piedmont alluvial slopes are absent. The surface also descends northeastward in harmony with the gradient of the South Fork of the Shenandoah River. It stands at an altitude above 1,000 feet in the south part of the Elkton area, and at an alitude of less than 900 feet in the north part.

Like the older gravel unit, the intermediate gravel unit is composed largely of rounded quartzite fragments of various sizes. Some of these fragments were probably derived directly from the parent ledges, but other fragments were doubtless obtained by reworking of material from the older gravels. The constituents of the intermediate gravels are well displayed on the cultivated plain between Naked Creek and Elk Run, where numerous cobbles and boulders have been removed from the fields and piled along their edges.

Sinks or shallow undrained depressions on the surface of the deposits (shown by circles on pl. 1), are notable features of the intermediate gravel unit. Sinks are also present on the surfaces of the older and younger gravel units, but in smaller numbers. The sinks have been formed by underground drainage through solution openings in the underlying limestone and dolomite, and by collapse of the gravels into the openings. The sinks probably came into existence after the gravel was deposited, at a time when streams had cut below the gravel plain, thereby permitting renewed underground drainage.

A significant area of intermediate gravel unit lies north of Grove Hill and northwest of the South Fork of the Shenandoah River (pl. 1). Along the county road immediately north of the river the intermediate gravels contain large numbers of fragments readily identifiable as having been derived from the Antietam and Weverton formations of the foothills of the Blue Ridge. As this area lies on the opposite side of the river from the Blue Ridge, it suggests that the river had a course at the time of deposition of the intermediate gravels which was different from its present course.

Between the town of Shenandoah and the north edge of the Elkton area the South Fork of the Shenandoah River flows in a series of tightly looped, entrenched meanders, a part of an extensive system that extends for many miles north of the Elkton area. The deposit north of Grove Hill lies on the inside of one of the meander loops. The presence here of fragments derived from the Blue Ridge suggests that the meanders did not come into existence until after the deposition of the intermediate gravels. The meanders may

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have formed on the surface of the intermediate gravels immediately before streams were entrenched by renewed down cutting.

YOUNGER GRAVEL UNIT

The younger gravel unit lies on benches between the surface of the intermediate gravel unit and the present flood plain of the South Fork of the Shenandoah River (pl. 6). The tops of the benches stand 50 to 75 feet above river level. Most of the benches are small, the largest occupying areas of about a square mile each, and many of them lie within the loops of the entrenched meanders of the river (pl. 1). The thickness of the gravels may be observed at many places along the edges of the benches, and in most places is less than 25 feet. The younger gravels apparently have nearly the same composition as the intermediate and older gravels.

REGIONAL RELATIONS OF GRAVEL DEPOSITS

The gravel deposits of the Elkton area would be better understood if more were known of the extent of such deposits in surrounding regions. However, only casual references can be found in most reports, and mainly to the fact that the gravels obscure the bedrock formations. The higher gravels are generally assumed to have been associated with the formation of the Valley Floor peneplain, and the lower gravels are assumed to be river-terrace deposits (Wright, 1934, pp. 39–40).

The gravels seem to be associated mainly with mountain areas of sandstone or quartzite, such as the Blue Ridge and Massanutten Mountain in Virginia and South Mountain and Catoctin Mountain in Maryland. Butts (1933) indicates in a general way a belt of such gravels along the northwest foot of the Blue Ridge rom the headwaters of the Shenandoah northeastward through the Elkton area to a point north of Luray. Farther northwest in the Appalachian Valley gravel appears to be generally lacking, and bedrock outcrops are extensive.

The most detailed observations have been made in Frederick and Washington Counties, Md., by Stose and Stose (1946a, pp. 9, 88; also Jonas and Stose, 1938a). Here, "alluvial cones of mountain wash" occur on the flanks of Catoctin Mountain and South Mountain at altitudes of about 500 feet, and terrace gravels occur near the streams at altitudes of 420 to 440 feet and of 300 feet. The highest deposits are considered to be of early Pleistocene or possibly latest Tertiary age, and the lower deposits are considered to be of Pleistocene age. The sequence of deposits reported in this area closely resembles that in the Elkton area.

ORIGIN AND AGE OF GRAVEL DEPOSITS

The successive gravel deposits are so closely related in origin that they are probably not far apart in age. None of the deposits exhibits marks of great antiquity, such as cementation, mineralization, or deep weathering. There thus appears to be little justification for classing the older gravel unit as of Tertiary or Quaternary age, and the intermediate and younger gravel units as of Quaternary age, as was done in a previous report on the area (King, 1943, pp. 18 and 27). More probably all the gravel deposits are of Quaternary age.

The older, intermediate, and younger gravel deposits were laid down during successive, similar cycles. A cycle began with dissection of the bedrock or residuum of the valley floor and eventual reduction of part of the floor to a graded surface. During this part of the cycle, streams were capable of transporting out of the region all the material supplied to them, because erosion was not active on the adjacent mountains, and because of adequate volume. During later stages of the cycle, deposits accumulated on the surfaces previously cut. Streams were then incapable of removing all the material supplied to them, because of vigorous erosion on the adjoining mountains, and because of inadequate volume. Each cycle closed with renewed cutting by streams to newer and lower levels (fig. 18).

The causes of these cycles were probably fluctuations in climate, which in turn suggests that the gravel deposits were laid down during the Plebistocene, a time of climatic fluctuation. Butts (1940, p. 509) has interpreted the times of gravel deposition as related to the glacial epochs of the Pleistocene, on the assumption that such periods were times of greatly increased rainfall. The basis for this view is not tenable, for in the absence of other factors an increase in rainfall would cause an increase in the cover of vegetation on the mountains, and erosion would actually be retarded. For this reason the author (1949a) interpreted the gravels as having been laid down in interglacial epochs, or times of less rainfall.

However, C. S. Denny (personal communication, May, 1949) has pointed out that this interpretation fails to consider another climatic factor, that of temperature. The Elkton area is less than 200 miles south of the southernmost advance of the continental glaciers, and during glacial periods timber line was probably well down on the flanks of the mountains adjacent to the valley. The areas above timber line were subject to weathering and rock breakage by the action of snow and frost, so that large quantities of fragmental material were carried down and deposited on the valley surfaces below. Denny reports that in Pennsylvania he has traced gravel terraces of the nonglaciated area into terminal moraines at the edge of the glaciated area, thus demonstrating that the gravel deposits of that

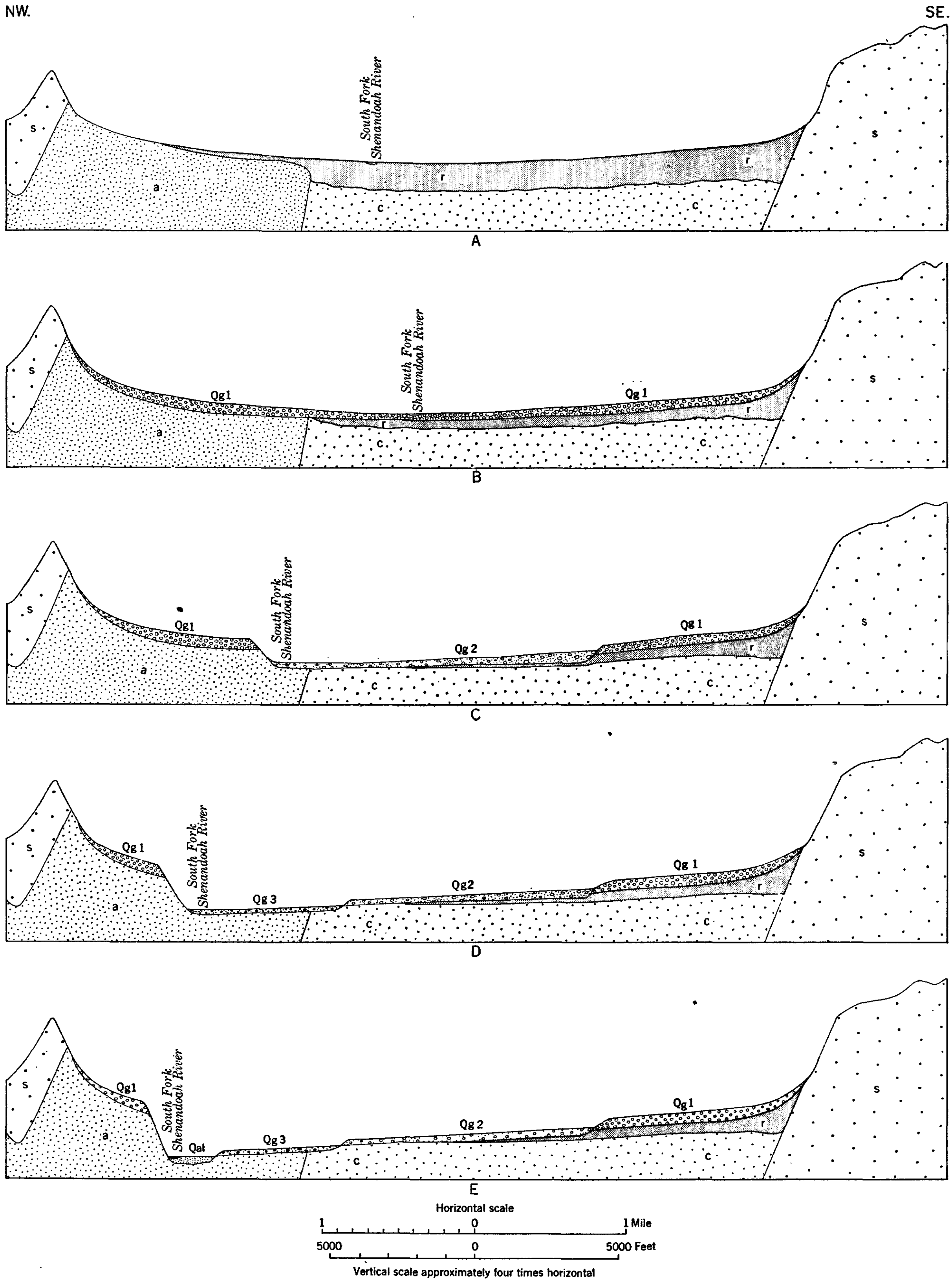

FIGURE 18.—Sections of Shenandoah Valley in Elkton area, showing its history as inferred in present report. Based on section W–W′ of plate 6. A. Time of formation of valley floor peneplain and main time of accumulation of residuum (r), probably during early Tertiary. B. After erosion of preceding surface and deposition of older gravels (Qg1), probably during early Pleistocene. C. and D. After subsequent periods of erosion, followed by deposition of intermediate gravels (Qg2), and younger gravels (Gg3), probably during later Pleistocene. E. After erosion of younger gravels and deposition of alluvium, (Qal), during Recent. Bedrock indicated by following letter symbols: (s) siliceous or arenaceous rocks; (c) carbonate rocks; (a) argillaceous rocks.

region were laid down during the glacial rather than the interglacial epochs.

It is therefore concluded that the gravel deposits were laid down during the Pleistocene, a time of climatic fluctuation, each deposit corresponding to a glacial epoch, and each time of erosion to an interglacial epoch.

RELATIONS BETWEEN FEATURES OF VALLEY FLOOR

The descriptions just given indicate that the valley floor includes a number of incompatible topographic features, formed under contrasting conditions, and probably widely separated in time. In view of these facts, the earlier and simpler conception of the floor of the Shenandoah Valley as part of the Valley Floor or Harrisburg peneplain tends to disappear. Actually, the widest tracts of valley floor in the Elkton area are the depositional surface of the intermediate gravel unit, formed at a time by no means as remote as that assumed for the Valley Floor peneplain (stage C, fig. 18). The entrenched meanders of the South Fork of the Shenandoha River, commonly assumed to date from the development of the Valley Floor peneplain, likewise seem to have been formed during the closing stages of the period in which the intermediate gravels were deposited. As the residuum that accumulated on the Valley Floor peneplain is now everywhere eroded and overlain unconformably by gravel deposits, it is unlikely that any remnants of the former peneplain surface are still present in the Elkton area (compare stages A and E, fig. 18). The surface features of the valley are entirely those that were established during the periods of gravel deposition and later.

Both Keith (1894, pp. 374–376) and Fenneman (1938, pp. 247–248) have noted a marked increase in the gradient of the Shenandoah Valley above Front Royal, as compared with its lower or northern section. This gradient is stated to be incompatible with the slope assumed for the Valley Floor peneplain at the time of its completion, and hence to be suggestive of subsequent warping or uplift. On the other hand, Wright (1934, p. 19) states than an

> important characteristic of the Harrisburg [Valley Floor] peneplane is its definite and sometimes steep upstream ascent. * * * In view of the fact that this downstream slope is practically universal in the southern Appalachians, regardless of the direction of flow, we must conclude that it is essentially original and not due primarily to warping.

Insofar as the Shenandoah Valley in the vicinity of the Elkton area is concerned, the gradients discussed by Keith, Fenneman, and Wright are those of the gravel deposits and not of the Valley Floor peneplain. These gradients are in harmony with the regimen of the existing streams. They appear, however, to be out of harmony with conditions as they are assumed to have existed at the time of accumulation of the residuum and the time of formation of the Valley Floor peneplain. It is therefore possible that the Valley Floor peneplain was uplifted or tilted after its formation and prior to the deposition of the gravel deposits.

TALUS

CHARACTER

The most extensive unconsolidated formation in the foothills of the Blue Ridge is talus, consisting of great fields of angular quartzite blocks that spread over the mountainsides, obscuring the bedrock beneath. Most of the talus fields are in areas of outcrop of the Antietam quartzite, or on slopes adjacent to it, but some are on outcrops of the Weverton formation, and a few are on outcrops of the pre-Cambrian rocks (pl. 1).

Most of the talus is on relatively steep slopes (25° or more) and is nearly bare of vegetation. It consists of angular fragments of all sizes, some 10 feet or more across, more or less firmly wedged together, yet with no evident matrix, and with many voids and openings between the blocks. In places there are broad surfaces made up of relatively small pieces (6 inches to 2 feet in diameter) interspersed with trains of much larger blocks. Most of the blocks are lichen covered. Some have been shattered into parallel plates, probably along incipient joints. Some of the aggregates of plates retain nearly the form of the original block, but others are completely broken and are strewn loosely over the surface. In some talus fields there is much dead and fallen timber, ranging from saplings to medium-sized trees.

Many of the talus fields are surmounted at the top of the slope by ledges of quartzite, and the blocks may have been derived from these ledges. However, in some places the ledges at the top are unimpressive, and in others, as in the Weverton areas, ledges are lacking entirely. This suggests wholesale disintegration of rock outcrops into talus, some of the blocks remaining nearly in place.

Parts of the block-covered areas are of much lower declivity than the rest, and form slopes of 10° or less. Some of the areas lie in valley bottoms and are fed by blocks from the talus fields on contiguous slopes. Other areas spread along the bases of the steeper slopes. The fragments in areas of low declivity are generally small (6 inches to 2 feet in diameter), but their surfaces are irregular in the extreme, with many ridges and hollows. Most of the block-covered areas of low declivity are densely overgrown by small trees and saplings. Similar but more extensive block-covered areas of low declivity have been described by Smith and Smith (1945, p. 1198) at nearby localities in Pennsylvania, Maryland, and Virginia.

ORIGIN

The talus fields do not appear to be in process of active formation or movement at the present time. The fragments are more or less firmly anchored and many of them are shattered by weathering. It is true that the dead and fallen timber noted in places suggests some degree of movement, but this may be relatively slight. No movement seems to be taking place in the block-covered areas of low declivity. These are covered by vegetation and the constituent blocks lie in such positions that they can hardly have been moved into their present positions by modern processes of erosion.

Probably the talus fields and block-covered areas of low declivity are a relic of conditions no longer existing in the region, and perhaps they were formed under the more rigorous climates of Pleistocene time. Such an interpretation has been made by Smith and Smith (1945 p. 1198) who suggest that movement of the blocks was "a product of solifluction under periglacial conditions in Pleistocene time." These authors assume, however, that during movement the blocks possessed a fine-grained matrix that was subsequently removed by running water. The existence of such a former matrix seems unlikely, as there is no evident source of fine material in the quartzite areas in which the talus fields occur, and it is difficult to imagine such a former matrix having been so completely removed as to leave no trace of its former presence.

ALLUVIUM

Alluvium occupies relatively small areas on the floor of the Shenandoah Valley, where it underlies the flood plains of the modern streams (pl. 1). From the town of Shenandoah northward, the alluvium along the South Fork of the Shenandoah River is narrow (sec. W–W′, pl. 6). In places the river is enclosed by rock walls on either side, and the alluvium at its widest extent forms scrolls on the insides of intrenched meander loops. South of Shenandoah, as in the vicinity of Elkton, the alluvial areas along the river are more extensive, and in places exceed a mile in width (sec. X–X′, pl. 6). Here, many of the tributary streams are also fringed by alluvial bottoms.

The alluvium consists of gravel, sand, and silt. Most of the fragments are finer in texture than those in the gravel deposits of the adjacent benches, suggesting that erosion at present is less active than it was during the epoch of gravel deposition. The coarsest alluvium apparently is deposited where modern streams are undercutting and reworking the earlier gravel deposits, for example, along Stony Run east of Shenandoah, where the flood plain and channel of the present stream is loaded with exceptionally coarse and abundant quartzite boulders. Most of the alluvium is only a few feet above the channels of the present streams, but in places terraces of alluvial material lie 10 to 20 feet higher.

The thickness of the alluvium is varied. North of Shenandoah, where the South Fork of the Shenandoah River is enclosed for long distances by bedrock, riffles here and there in the river itself suggest that bedrock lies not far beneath the channel. In the broad alluvial areas from Elkton southwestward bedrock is exposed at places in the channel. According to the records of the Virginia Geological Survey, at the Stonewall plant of Merck & Co. built on the alluvial flat 2 miles southwest of Elkton, water wells have encountered thicknesses of 31, 38, 57, and 124 feet of unconsolidated deposits above the bedrock (W. M. McGill, personal communication, September 1947). Therefore, the broad alluvial areas in the vicinity of Elkton are underlain by various thicknesses of unconsolidated deposits. Some of the thicker masses may represent buried, abandoned channels, others may be the filling of sink holes.

ECONOMIC GEOLOGY

The Elkton area contains deposits of iron, manganese, ocher, building stone, and limestone. Copper and magnetite occur in the Blue Ridge not far southeast of the area mapped. At the time of field work in 1940 and 1941, mineral resources were exploited only on a small scale. Building stone and limestone were being quarried, and some work was being done on the manganese deposits. Very little manganese ore was produced, however, and most of the operations did not pass beyond the prospecting stage.

IRON AND MANGANESE

GENERAL CHARACTER OF DEPOSITS

SUMMARY OF PRODUCTION

The principal mineral deposits that have been exploited in the Elkton area are those of iron and manganese oxides. Iron ore was mined in the area almost continuously between 1836 and 1905, during which period it is estimated that about 350,000 tons of concentrates were produced. Manganese ore and manganiferous iron ore were mined intermittently between 1884 and 1941, during which period it is estimated that about 23,000 tons of concentrates were produced. However, available records of production are so scanty that the estimates are based in part on the size of the workings, known rate of production, and other indirect data. Therefore there may be a large error in the estimates.

Possible production in yearly periods is indicated in the table below.

Estimated production of iron and manganese concentrates in the Elkton area (in long tons)

Periods	Iron	Manganese and manganiferous iron
1836–75	40, 000	none
1876–90	215, 000	2, 500
1891–1905	95, 000	5, 000
1906–20	none	11, 200
1921–39	none	4, 100
1940–45	none	200
Total	350, 000	23, 000

The principal producers of iron were the mines that were operated in connection with the Shenandoah iron works, near what is now the town of Shenandoah (fig. 19). Of these, the largest producers were the Fox Mountain mine and the Smith bank.[3] The principal producers of manganese were the Stanley mine south of the town of Stanley, and the Kendall and Flick, Niesswaner, and U. S. Manganese Corp. mines south of the town of Elkton.

RESERVES

No systematic estimates of reserves of iron or manganese ore can be made in the area. Estimates cannot be based on surface indications, as the producing beds are for the most part thickly covered by gravel. No large-scale openings have been made recently, and recent prospecting has been confined to small areas. Most of the older workings are now caved or are otherwise inaccessible, so the amount of ore in them cannot be determined. Workings which were accessible during the present investigation showed only a small amount of ore.

The iron ore of the area was rather thoroughly exploited before 1905, and it is probable that all the rich deposits for which there were obvious indications, or which were indicated by prospecting of the period, have now been mined out. Iron ore in small quantities was observed here and there in the area, and larger deposits may be hidden elsewhere under the gravel overburden, but it is doubtful that any of these could be exploited under existing economic conditions, or in competition with established sources of iron ore.

The manganese deposits have been exploited on a smaller scale and a number of rich deposits that were discovered by surface indications or by prospecting have been mined out. Other deposits may exist that would provide a profitable source of operations in the future, but if so, they remain undiscovered and without surface indications of their presence.

OCCURRENCE

All the iron and manganese deposits in the Elkton area are in the form of iron and manganese oxides, and were formed by concentration and replacement as a result of superficial processes such as weathering. The principal deposits are in the residuum of the Tomstown and Waynesboro formations along the northwest foot of the Blue Ridge. Iron and manganese oxides were noted elsewhere as a surface film on the weathered siliceous rocks of the Chilhowee group, and in the fault breccias associated with the Elk Run fault and other transverse fractures near Elk Run (p. 44). However, only the deposits in the residuum of the Tomstown and Waynesboro formations have been mined in the past, and it is unlikely that any of the others are of economic interest.

The greatest number of iron and manganese deposits are in residuum overlying the lower part of the Tomstown dolomite. Deposits are less common in residuum overlying the upper part of the Tomstown dolomite, and in residuum overlying the Waynesboro formation. However, there are a few notably rich deposits in residuum overlying the Waynesboro, the Boyer mine, the Garrison bank, the Fox Mountain mine, and the Neisswaner shaft. The bedrock structure in the vicinity of the deposits is varied, but most of the deposits are in areas of homoclinal or synclinal structure. It has been suggested that manganese deposits in synclines may prove to be more productive than those on monoclines, with the analogy in mind of the synclinal structure at the prolific Crimora mine, Augusta County, south of the Elkton area (Stose and others, 1919, pp. 53–54). However, the deposits are so varied, and their formation was influenced by such a variety of local conditions, that there is no assurance that any one will contain manganese rather than iron ore; that all synclinal tracts will contain manganese; or that a given synclinal tract will prove more productive than the adjacent homoclinal tracts.

All the deposits of iron and manganese oxides in the residuum of the Tomstown and Waynesboro formations lie beneath the highest benches at the margins of the floor of the Shenandoah Valley, or those capped by the older gravel unit. However, they probably have only a fortuitous relation to the gravel deposits or to the time of erosion that immediately preceded the deposition of the gravel. As already noted (p. 59), the gravels contain reworked fragments of the iron

[3] The term "bank" or "ore bank" has long been used in the Appalachians for open-cut mines in residual clay, worked for iron or manganese ore. The term doubtless refers to the fact that the cuts are generally put in on banks or hillsides. In the Elkton area, some of the workings are referred to as banks, others as mines. In the present report, local usage and published references are followed.

and manganese oxides. The iron and manganese deposits are probably closely related to the time of formation of the Valley Floor peneplain, and it is only beneath the remnants of the older gravel unit that materials that were close to the surface of the peneplain at the time of its formation are still preserved.

CHARACTER

All the residual clays derived from the Tomstown dolomite and Waynesboro formation contain disseminated iron and manganese oxides, which impart to them their characteristic yellow, brown, red, and black colors. Here and there the residual clays also contain concentrated bodies of iron and manganese oxides which are of economic interest, and form ore bodies such as those discussed in the present report.

The ore bodies consist of hard iron and manganese oxides in the form of spherical, grapelike, or botryoidal nodules ½ inch to 8 inches in diameter, or in even larger, very irregular masses, all embedded in clay. The enclosing clay is in part impregnated by soft iron and manganese oxides, but is in part free of oxides. The nodules appear to be more common in silty than in waxy clay, and in some deposits they are distributed along fairly definite zones and layers, separated by barren clay. Larger masses of iron and manganese oxides have been observed or reported in the Stanley mine, on the Watson tract (pl. 3, timber sets 76 to 80), and in the Neisswaner shaft (Hewett, 1916, pp. 63–64). Many of these masses follow the stratification in the clay, but they pinch out or change in composition laterally, and in places they cut across the stratification. Part of the iron and manganese oxides in such masses appears to have grown into openings, where it has developed botryoidal and stalactitic surfaces.

In the ore bodies, iron oxides and manganese oxides occur in all proportions. In the Elkton area deposits composed dominantly of iron oxides are relatively common. Manganiferous iron ore is also common, and it is reported that in some iron deposits the proportion of manganese tends to increase with depth. Deposits with a large amount of manganese oxides are less abundant. The iron oxides consist largely of varieties of limonite. The manganese oxides consist of various minerals that have been identified in previous reports as psilomelane, pyrolusite, and manganite. Recent mineralogical work has shown that many of these earlier identifications are in error, and that the minerals can only be certainly determined after laboratory study. No specimens for such study were collected during the present investigation, and they will therefore be referred to in this report by such noncommittal terms as hard manganese oxides and soft manganese oxides.

ORIGIN

The origin of the iron and manganese deposits in residuum of formations along the northwest foot of the Blue Ridge has been discussed by geologists for many years. The deposits have been concentrated in the residuum of deeply weathered rocks, and the original character of these rocks has been so nearly obliterated that the source of the deposits is no longer evident. Some of the earlier interpretations are indicated in the following excerpts from Lesley (1859, pp. 512–518):

> In the second annual report of the Pennsylvania Geological Survey, Mr. Rogers expresses in a sufficiently open way his original views of these beds, as resultants of a general ferruginous mud deposit against the north base of the South Mountain, it acting as a breakwater to a deluge coming from the north. * * * Any ocean of Tertiary or other age, covering the Appalachian belt * * * must be conceived as doing so either at once or gradually, either forcibly or gently, and as either deep or shallow. If at once and forcibly, from the northward, then all the brown hematite beds should lie along the north bases of all the mountains. It is needless to say that they do not. * * * One of Roger's emigrating polar oceans would be much more likely to clean out the limestone valleys of their brown hematite deposits than to furnish them with these. There remains then only the hypothesis of local weathering, with freshets, pools, swamps, and what not, requisite to fill deep cavities left by the original violent denudation of the surface to its present level. In this hypothesis local ferruginous rocks supply materials close at hand for local deposits of brown hematite; and as these ferruginous rocks will occupy constant positions in the series of formations, the brown hematite deposits from their wear and tear will lie in outcrop lines upon the mass. As the ferruginous formations are principally slates containing sulphuret of iron and native sulphur, the brown hematites will lie along the borders of the slate formations * * *, against the lower compact sandstone or massive limestone formations as the case may be.
>
> In one sense * * * they are contemporaneous deposits. They are the weathered or perhaps they are the degraded outcrops of the Silurian limestone formations on which they lie. If weathered merely, they belong to that unknown epoch subsequent to the coal when this part of the continent emerged, its topography fashioned, and its outcrops offered to the atmospheric agencies. Subsequently, intenser action than mere atmospheric was perhaps repeatedly applied to these outcrops and how much of an accumulation of brown hematite ore and sand and clay was produced at one and how much at another time cannot be demonstrated or perhaps even estimated.

Many of the earlier authors assumed that the iron and manganese deposits represented an original bed or beds of relatively limited stratigraphic position, now much disturbed by weathering. On the other hand, Harder (1910, pp. 100–101) concluded that the deposits were concentrated by the action of ground water from great thicknesses of the overlying sediments, and localized in their present positions by the impervious nature of the underlying Antietam quartzite. In reports by Stose and others (Stose and others, 1919, pp. 54–55; Stose and Schrader, 1923, p. 25; and Stose, 1942, pp.

163–172), it was concluded that much of the original manganese was derived from the immediately underlying shale, siltstone, and sandstone which form transition beds between the Antietam and Tomstown. These interpretations all include the assumption that the iron and manganese existed in the original sedimentary deposit. However, Kesler (1941, pp. 276–293) has suggested, as a result of studies in the Cartersville district of Georgia, that the manganese there was derived from a hydrothermal mineral introduced with other hydrothermal minerals along lines of structural weakness.

Observations on and analyses of unweathered rocks in northeastern Tennessee equivalent to the Antietam quartzite and Tomstown dolomite confirm the interpretation that the manganese was an original but disseminated constituent of the sedimentary rocks, probably in carbonate form, and was not of hydrothermal origin (King and others, 1944, pp. 57–59; Rodgers, 1945, pp. 129–135). Analyses of specimens collected by R. A. Laurence, P. B. King, and John Rodgers indicate that the stratigraphic horizon of the greatest accumulation of primary manganese is in beds 100 to 200 feet above the quartzite-dolomite contact, in the lower part of the Shady dolomite or southern equivalent of the Tomstown; here manganese in carbonate form occurs in concentrations as high as 1.24 percent. The transition beds at the top of the quartzite, the quartzite itself, and the higher beds of the dolomite contain little or no primary manganese.

The source of the iron ores in the Elkton area may likewise be in iron carbonates disseminated as a primary constituent in the Tomstown dolomite. Locally it may have been derived from pyrite and other minerals of hydrothermal origin scattered through the Tomstown and underlying Chilhowee group. Pyrite is abundant in these formations in some areas, but it was rarely observed in the Elkton area.

The relative time of accumulation of the iron and manganese minerals in the deposits is not fully known. In general the harder manganese oxides appear to have been derived from wad. "It appears that psilomelane, which contains less water than wad, tends to form most readily in masses of wad" (Hewett, 1916, p. 40). The relations observed in some specimens also suggest that the manganese oxides may have formed somewhat later than the iron oxides.

The concentration of iron and manganese oxides in the deposits took place during the process of formation of the residual clay, or during the time of completion of the Valley Floor peneplain. Concentration in residuum above the basal part of the Tomstown dolomite was probably aided by unusually deep circulation of ground water close to the dolomite-quartzite contact, owing to the impervious nature of the quartzite, as suggested by Harder (1910, pp. 100–101).

> When the rocks weathered, the manganese was dissolved as bicarbonate by circulating underground water, was transported along favorable channels, and was deposited as oxides in the clays produced by the previous decay of impure limestone, dolomite, and sericitic shales. (Stose and others, 1919, pp. 54–55.)

The concentration was a relatively late event in the process, for it followed, at least in part, the deposition of the ancient gravel unit in eroded hollows in the clay or dolomite. Moreover,

> the similar distribution of coarse quartz sand in nodules and in adjacent clay and the ragged areas of clay in hard nodules * * * show conclusively that the nodules of manganese oxides have grown by replacing the clay substance in which they are embedded. There is, further, no evidence of the crowding back of the enclosing material such as would occur if the nodules had grown in the clay without replacing it. (Stose and others, p. 45).

Some of the nodules contain slickensides, inherited from the clay which they replaced.

MINES

In the pages which follow, descriptions are given of the mines which have produced iron or manganese ore. They are named and their positions are indicated on the geologic map (pl. 1), and they are further illustrated by a map showing the former mines, railroads, and furnaces related to the operations of the Shenandoah Iron Works (fig. 19). Maps showing details in the vicinity of the Stanley mine, the Watson tract, and the Elkton mines have been published (King, 1943, pls. 5, 6, and 9) and are not repeated here. The geologic map (pl. 1) shows, in addition to the mines, the location of numerous prospect pits. These are not described in the present report, but their character has been indicated briefly in the previous publication (table 2, pp. 48–55).

STANLEY MINE

The Stanley mine (Prime, 1880, p. 36; Watson, 1907, p. 245; Harder, 1910, pp. 55–56; Stose and others, 1919, pp. 65–67; King, 1943, pp. 35–36, pl. 6. Also Paul Tyler, personal communication, August 1941), formerly known as the Eureka mine, lies a mile south of Stanley on the northwest slope of Roundhead Mountain at an altitude of about 1,400 feet (pl. 1).

Manganese was first discovered on the tract before 1880, but first production was in the 1890's, when cuts known as the Eureka mine were opened near the head of the present workings; a considerable tonnage of concentrates is reported to have been shipped. Analyses of the early ores quoted by Prime and Watson show percentages of manganese of 49.613 and 51.46, with phosphorus below 0.050 percent. In 1918 and 1919, the mine was operated by the Shenandoah Valley Manganese Corp., and 13 carloads (approximately 600 tons) of concentrates were shipped, mostly of low grade. The mine lay idle until 1928, when it was reopened by Paul Tyler of Washington, D. C., who operated it through 1936. Tyler shipped 4,000 tons, or 100 carloads of concentrates, mostly of good grade. The good grade concentrates averaged 46 percent manganese, 3 to 5 percent iron, 6 to 12 percent silica, and 0.15 percent or less phosphorus. The mine has not been operated since 1936.

The Stanley mine is in residuum overlying the lower part of the Tomstown dolomite. Farther up the mountain slope to the southeast and south the clay is bordered by outcrops of the Antietam quartzite. The quartzite on Roundhead Mountain to the south has a synclinal structure and the mine is situated on the northward projection of the synclinal axis (sec. A–A′, pl. 5). South of the workings, however, the quartzite appears to be upfaulted against the clay.

The mine workings consist of two large open-cuts, with an area of about 4 acres, and a number of shafts and pits. Extensive dumps spread down the slope from the workings to the northwest. The open-cuts expose buff, brown, or red clay, in part sandy, with a varied but obscure dip to the northwest. The clay contains fragments of chalcedonic chert, a few masses of jasperoid, and nodules of hard manganese oxides. Some of the clays are impregnated by wad, and here and there they are cut by veins of limonite. Operations carried on between 1928 and 1937 near the west end of the northern open-cut are said to have revealed a lens-shaped body of solid manganese oxides 10 feet thick, which pinched out down the dip. This body has been entirely mined out and was not visible in 1941.

In the southern open-cut a steep-sided depression may be seen in the clay, 100 feet long and 25 feet deep, that is filled by deposits of the ancient gravel unit, which here consist of red sand enclosing deeply weathered sandstone pebbles and cobbles (*b*, fig. 17). This material contains many spherical and botryoidal nodules of hard manganese oxide, which, being highly siliceous, have been avoided in mining. Both the residual clays and the ancient gravels are unconformably overlain by fanglomerates contemporaneous with the older gravel unit (*a*, fig. 17), which slope steeply away from the mountain and attain a thickness of 15 feet. The base of the fanglomerate truncates veins of iron and manganese oxides in the clay, and the gravel contains reworked fragments of manganese oxides derived from the clay.

During the time of operation by the Shenandoah Valley Manganese Corp., the mine and washer were connected by a branch railroad with the main line of the Norfolk & Western Railway, half a mile distant. The washer was located on the east slope of the valley of Stony Run. During operations by Tyler, the product was hauled from the mine by truck.

Except for the siliceous ore in the ancient gravel deposits, the amount of manganese ore at present in sight in the Stanley mine is small.

HONEY RUN MINE

The Honey Run mine is on the west side of Honey Run, a mile and a half south of Honeyville, and south of the Norfolk & Western Railway at an altitude of 1,150 feet (pl. 1). No published records are available regarding the mine, so its operators and its production are unknown. According to local residents, it was worked for iron ore between 1890 and 1900.

The Honey Run mine is in residuum overlying the lower part of the Tomstown dolomite, the top of the Antietam quartzite is a few hundred feet southeast of the workings and in Honey Run nearby it dips 40°–55° NW. The structure in the vicinity of the deposit is homoclinal (sec. B–B′, pl. 5). The probable relations between the Tomstown dolomite, the residuum, and the older gravel unit in the vicinity of the mine are indicated on section U–U′, pl. 6.

The workings consist of two open-cuts, each about an acre in extent, on opposite sides of the ridge west of Honey Run, associated with which are numerous prospect pits, and a few shafts, now caved. The open-cuts expose residual clay, which in many places contains iron oxides. Small amounts of manganese oxides were noted in the eastern open-cut and nearby prospects.

INGHAM MINE

The Ingham mine (Anonymous, 1883, p. 98; Stose and others, 1919, p. 67) is a mile east-southeast of Ingham station on the Norfolk & Western Railway, at the head of a valley at an altitude of about 1,300 feet (pl. 1). The mine may be the same as the Beverley Bank, shown on some old maps of the region. It is named for the Ingham family, who at one time owned the property; the property now lies within Shenandoah National Park. The Ingham mine was operated between 1880 and 1890 by Mills & Co., who in 1883 were shipping 10 carloads of iron-ore concentrates a week to Pennsylvania. During the period of operation the mine was connected with the railway by a tram road, the grade of which is still visible.

The Ingham mine is in residuum overlying the lower part of the Tomstown dolomite. The top beds of the Antietam quartzite are exposed a short distance up the slope east of the workings and dip 45° W. The structure in the vicinity of the workings is homoclinal. The divide south of the mine is a bench thickly covered by older gravels. The relations between the Tomstown dolomite, the residuum, and the older gravel unit is indicated on section V–V′, pl. 6.

The workings consist of numerous small open-cuts on each side of the valley, all less than an acre in extent. The workings are greatly slumped and overgrown, but show residual clay containing many pieces of iron oxides and a few pieces of manganese oxides.

Over the divide to the south, in the northern headwaters of the next branch at an altitude of 1,400 feet, is a single open-cut about half an acre in extent. This cut is reported by Stose and others to have been worked years ago for iron ore. According to local residents a carload of manganese concentrates was hand-picked and shipped from this cut about 1930. The cut exposes residual clay containing nodules of iron-bearing manganese oxides.

LITTLE ORE BANK

The Little ore bank (Stose and others, 1919, p. 68, listed as "Fultz Run prospect") is 1½ miles south-southeast of Ingham, on the east slope of the valley of Fultz Run or Steam Hollow, at an altitude of 1,380 feet (pl. 1). As the workings at the locality are small, it is doubtful that much ore was ever produced from it, but Stose and others report that two carloads of manganese concentrates were shipped from it about 1915 by Dent and Rogers.

The Little ore bank is in a saddle underlain by residuum of the Tomstown dolomite, lying between the mountains and an outlying knob capped by the older gravel unit. The top beds of the Antietam quartzite are exposed 200 feet up the mountain slope to the east and dip 30° W. The structure at the workings in homoclinal (sec. D–D′, pl. 5).

The workings consist of three or four pits, the largest 20 feet across, which expose buff residual clay containing pieces of chert and nodules of iron and manganese oxides. In some nodules the iron and manganese oxides are intergrown.

OPERATIONS OF SHENANDOAH IRON WORKS

Between 1836 and 1905, the present town of Shenandoah (formerly Shenandoah Iron Works Post Office, or Milnes station) was the center of a flourishing iron-mining and milling industry, known as the Shenandoah Iron Works (Hotchkiss, 1878; Anonymous, 1881, pp. 151–152; Anonymous, 1883, p. 6; McCreath, 1884, pp. 25, and 30–32; and Holden, 1907, pp. 431–433). The works were established in 1836 by Daniel and Henry Forrer, who operated them until 1866. The works were then sold to William Milnes, Jr., and associates of Pennsylvania, who in 1870 incorporated as the Shenandoah Iron, Lumber, Mining & Manufacturing Co. This company operated until after 1890, when the property was sold to the Allegheny Ore & Iron Co., now a subsidiary of Lukens Steel Co., of Coatesville, Pa. This company continued operations until about 1905, and still retains mineral rights on much of the property of the old iron works.

The property of the Shenandoah Iron Works consisted of 31,483 acres, of which 24,220 acres were forest lands in Massanutten Mountain and the Blue Ridge, and 7,263 acres were iron-bearing lands in the vicinity of the present town of Shenandoah. On the iron-bearing lands were located the Smith bank, the Boyer mine, the Kimball bank, the Garrison bank, the Baker bank, and the Fox Mountain mine, described below (fig. 19). The Fox Mountain mine and the Smith bank appear to be the workings first opened; ore samples from them were described by Rogers in 1838 and 1840 (Rogers, 1884, pp. 238, 529). The Kimball bank was opened before 1878, but apparently was not operated full scale until later. The Boyer mine and Garrison bank were not opened until after 1880.

Four furnaces were located on the property:

1. Furnace No. 1, near the river bank in the south part of present town of Shenandoah. Built in 1836 and destroyed by a great freshet in 1870. A cold-blast charcoal furnace, 9 feet across and 33 feet high. In 22 weeks in 1856 made 63½ tons of forge metal out of brown iron ore, probably from Fox Mountain mine.

2. Catherine furnace, 5 miles north of present town of Shenandoah, where valley of Cub Run leaves Massanutten Mountain. Built in 1846, but not in blast after 1860. A cold-blast charcoal furnace, 8 feet across and 32 feet high. In 22 weeks in 1856 made 526 tons of forge metal out of brown ore from nearby banks in Massanutten Mountain.

3. Furnace No. 2 (erroneously referred to as "Furnace No. 4" by Stose and others, 1919, pp. 69, 71) 4 miles southeast of present town of Shenandoah, on south bank of Naked Creek at settlement of Furnace. Built in 1857, and in blast until after 1890. A steam hot-blast charcoal furnace, 9 feet across and 36 feet high, with an annual capacity of 3,000 net tons. In 1881, made 60 tons of charcoal pig iron a week; in 1882, made a total of 2,400 tons; and in 1883, a total of 1,828 tons. In 1883, used 102 bushels of charcoal, 2.46 tons of ore, and 0.47 ton of limestone to make one ton of pig iron. After 1883, coke was mixed with the charcoal in about equal proportions. Used brown iron ore from the Fox Mountain mine.

4. Gem furnace, in south part of present town of Shenandoah, east of Norfolk & Western Railway and

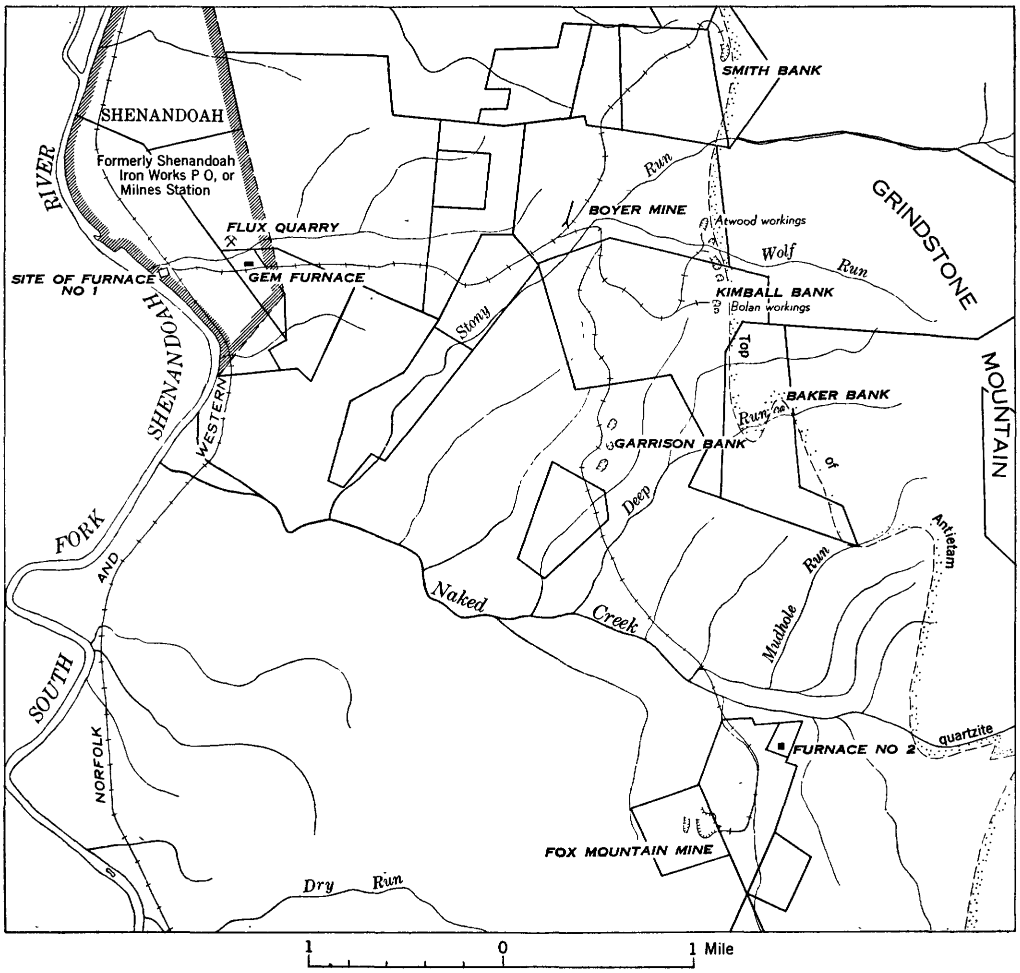

FIGURE 19.—Map of vicinity of town of Shenandoah, showing mines, furnaces, and railroads of Shenandoah Iron, Lumber, Mining & Manufacturing Co., as they existed in the 1880's. Land lines transferred from a map by Jedediah Hotchkiss, 1878.

about half a mile east of river. Built in 1883 and probably in blast until after 1900. A hot-blast coke furnace, 16 feet across and 75 feet high, with annual capacity of 30,000 net tons. In 1883, made 13,706 tons of pig iron, using 1.58 tons of coke, 2.41 tons of ore, and 1.25 tons of limestone to make 1 ton of pig iron. Used brown iron ore from various mines east of Shenandoah.

At the present town of Shenandoah there was also a forge or bloomery, built in 1871, equipped with 7 forge fires and a 20-ton steam hammer. In the 1880's the product of the iron works was shipped to Baltimore, Harrisburg, and Philadelphia for use in making wire, flange iron, and boiler plate. Before the Shenandoah Valley branch of the Norfolk & Western Railway was built in 1881, the product was shipped by barge 70 miles down the South Fork of the Shenandoah River to the line of the Virginia Midland Railway, thence by rail to Alexandria, and then by ship to its destination. The advent of the railroad not only improved shipping facilities for the product, but made possible the use of coke from West Virginia coal fields in the furnaces, to replace locally manufactured charcoal. In 1882, standard gage railway lines were extended from the main railroad to the mines (fig. 19).

SMITH BANK

The Smith bank ("Forrer's bank" in Rogers, 1884, p. 529; McCreath, 1884, p. 26; Stose and others, 1919, p. 68, erroneously termed "Kimball mine") is 2½ miles east-northeast of the town of Shenandoah, at the foot of the mountains on the north side of the divide between Fultz and Stony Runs, at an altitude of 1,450 feet (pl. 1). The Smith bank was opened as early as 1840, and was mined intermittently for iron ore as a part of the operations of the Shenandoah Iron Works, at least until 1890. The production of the mine is unknown, but judging from the extent of the operations, it must have been great, perhaps amounting to a quarter of all the iron-ore output of the iron works. After 1882, the mine was connected by railroad with the iron works at the town of Shenandoah (fig. 18). Between 1930 and 1940, the mine was worked for white, kaolinitic clay ("chalk") and hence is sometimes referred to locally as the Chalk mine. Only a small amount of clay was produced before these operations were abandoned. The following table gives partial analyses of ore from the Smith bank:

Analyses of ore from Smith bank

	(1)	(2)	(3)
Iron	55. 81	52. 19	49. 90
Silica	7. 67	5. 80	14. 67
Alumina	0. 75	4. 50	-------
Phosphorus	------	------	. 101
Water	11. 58	15. 00	-------

1. W. B. Rogers, 1840. Cellular, filled by reddish oxide.
2. W. B. Rogers, 1840. Stalactitic, bluish black, interstices filled by orange-red oxide.
3. A. S. McCreath, 1884. Sample of 109 pieces from prospect pits and old dumps.

The Smith bank lies in residuum overlying the basal part of the Tomstown dolomite. The top beds of the Antietam quartzite are exposed immediately east of the workings and dip 50° W. The structure at the workings is homoclinal (sec. E–E′, pl. 5). The residuum is overlain by older gravels that form the cap of the divide to the south. The relations between the Tomstown dolomite, the residuum, and the older gravel unit is shown on section W–W′, plate 6.

The main workings at the Smith bank are a very large open-cut, at least two acres in extent and more than 75 feet deep, elongated north and south parallel to the strike of the rocks (fig. 8). Two or three smaller cuts are closer to the quartzite contact. Near the head of the main cut are the timbers of underground workings, now caved. Several old pits and shafts are nearer the divide to the south, and were probably put in for prospecting purposes.

The main open-cut exposes brown and pink clay, with seams of white, sandy or silty clay, and white, kaolinitic clay. These dip about 30° NW. The clay contains pieces of gray, dull-lustered chert, and nodules, plates, and massive blocks of iron oxides. At one point near the head of the cut, a small amount of manganese oxides was noted, but these oxides are absent elsewhere. Along the rim of the cut on the west side and toward its head the clays are overlain unconformably by fanglomerates of the older gravel unit that attain a thickness of 25 or 30 feet.

BOYER MINE

The Boyer mine (McCreath, 1884, pp. 26–27; Holden, 1907, p. 433), sometimes called the Stony Run mine, is 2 miles east of the town of Shenandoah (pl. 1). It is much farther out in the Shenandoah Valley than most of the other mines of the Elkton area, being about half a mile from the mountain front. It lies in nearly level country north of Stony Run at an altitude of 1,225 feet.

The Boyer mine was opened in 1884 as a part of the operations of the Shenandoah Iron Works, and was worked for iron ore by the Shenandoah Iron Co., and its successor, the Alleghany Ore & Iron Co. until about 1905. The branch railroad from the iron works to the Smith mine ran by the entrance to the workings, providing adequate transportation of the product to the furnace. Late in 1884, the mine is reported to have been producing 50 tons of ore a day. The table shows partial analyses of ore from the Boyer mine:

Analyses of ore from Boyer mine

	(1)	(2)
Iron	50. 925	41. 35
Silica	13. 950	21. 95
Phosphorus	0. 297	0. 33
Manganese	------	0. 60

1. A. S. McCreath, 1884. Analysis of 11 pieces of lump ore from original opening.
2. R. J. Holden, 1907. Average analysis of later production, from records of Alleghany Ore & Iron Co.

The Boyer mine lies in the belt of outcrop of the Waynesboro formation, but all the surface near the mine consists of deposits of the older gravel unit. The dumps contain large quantities of hard, gray-brown and reddish silty shale, characteristic of the Waynesboro. The structure of the bedrock is unknown.

The Boyer mine was operated entirely from underground workings. These included a shaft 160 feet deep and a shallow tunnel nearly 1,000 feet long, trending N. 10° E. When the ore body near the tunnel was mined out, the pillars were robbed and the timbers removed, so the course of the workings can now be traced on the surface by a line of collapsed ground. The hard shale seen on the dump is said to have come from country rock between the veins, suggesting the presence of a series of narrow, elongate, superficial ore bodies, forming a part of the residuum but following the strike of the country rock.

KIMBALL BANK

The Kimball bank (McCreath, 1884, p. 27; Weeks, 1886, pp. 313–314; Harder, 1910, p. 56) lies 2½ miles east of the town of Shenandoah, at the foot of the mountains on the north and south sides of Wolf Run at an altitude of 1,500 feet (pl. 1). On maps prepared before 1880, ore banks termed the Comer and Fields are shown at about the same position as the Kimball bank. The north and south workings of the Kimball bank were referred to as the Atwood and the Bolan openings.

The Kimball bank was worked as a part of the operations of the Shenandoah Iron Works. It was probably mined on a small scale before 1880, but its main production seems to have been between 1880 and 1890. After 1882, the mine was connected with the iron works at the town of Shenandoah by a branch railroad line. The ore was concentrated by a washer on Wolf Run. Both iron ore and manganiferous iron ore were produced from the cuts, the manganiferous iron ore coming chiefly from the Atwood workings. The first table below shows available records of production, but the figures given for manganiferous iron ore may include some ore produced from the Garrison bank. The second table below shows analyses of ore.

Recorded production of Kimball bank

Year	Shipment of concentrates, tons	Kind of ore
1881	3,747	Lump iron ore.
1882	No record	No record.
1883	Operating	Not known.
Total up to 1884	2,000	Manganiferous iron ore.
	4,000	Iron ore.
1884	208	Manganiferous iron ore.
1885	2,155	Do.
1886	17	Do.

Analyses of ore from Kimball bank

1		2	
Fe	40.875	Fe_2O_3	70.00
Mn	7.349	MnO_2	13.31
SiO_2	15.440	SiO_2	4.73
P	0.084	P	trace
		Al_2O_3	0.86
		H_2O	11.02

1. A. S. McCreath, 1884. Analysis of 100 pieces, two-thirds from Atwood workings, one-third from Bolan.
2. J. D. Weeks, 1886. Analysis by W. M. Bowron.

During 1941, the Kimball bank was prospected for the Alleghany Ore & Iron Co., and small amounts of manganese oxides were discovered, but no mining was done and no concentrates were shipped.

The Kimball bank is in residuum overlying the lower part of the Tomstown dolomite. The top beds of the Antietam quartzite are exposed on Wolf Run 200 feet east of the workings and dip 20° SW. Farther north, they dip 40° W, indicating a small flexure which probably passes into the Tomstown dolomite in the south part of the workings.

The workings of the Kimball bank consist of a series of six or more open-cuts along the foot of the mountains, extending for nearly 2,500 feet. The largest northern cut is about an acre in extent; another just south of Wolf Run covers about 2 acres; and two closely contiguous cuts at the south cover about 3 acres. All the cuts are badly caved and contain trees of considerable size, but some fresh exposures were created during the prospecting operations of 1941.

The cuts all show brown, yellow, and gray, waxy residual clay, in places containing pieces of gray or white chalcedonic chert. Most of the cuts contain lumps, nodules, and large masses of iron oxides. In the central and northern cuts (probably the old Atwood workings) there is wad and some nodules of hard manganese oxides, but these are nearly absent in the southern cuts. According to Harder, considerable pyrolusite was once present in the Kimball bank.

BAKER BANK

The Baker bank (McCreath, 1884, pp. 27–28) referred to in some reports as the Merica bank, lies 3 miles east-southeast of Shenandoah, on the north side of Deep Run at an altitude of 1,450 feet (pl. 1, fig. 6). The Baker bank was worked for iron ore between 1880 and 1890 as a part of the operations of the Shenandoah Iron Works. Production was probably small; 1,500 tons of concentrates are reported to have been shipped before 1884. The table gives a partial analysis of the ore:

Analysis of ore from Baker bank

[From A. S. McCreath, 1884. Analysis of 170 pieces of lump and wash are from pile at mine]

Iron	44.450
Silica	16.690
Phosphorus	1.092

The Baker bank is in residuum overlying the lower part of the Tomstown dolomite. The bank lies in a shallow, south-plunging syncline and is flanked on the east, north, and northwest by the top beds of the Antietam quartzite (sec. F–F′, pl. 5). The synclinal axis is traceable northward into the mountains in the Antietam quartzite. Southward, it disappears beneath the older gravel unit.

The workings consist of two open-cuts, each half an acre or less in area, and some caved pits and shafts. Local residents report that there were some underground workings. The cuts show brown waxy clay, containing chert and many nodules of hard iron oxides. Manganese oxides occur only as a stain on the iron oxides.

GARRISON BANK

The Garrison bank (McCreath, 1884, p. 28; Weeks, 1886, pp. 313–314; Harder, 1910, p. 56) is 2¾ miles southeast of the town of Shenandoah (pl. 1). Like the Boyer mine, it is much farther out from the mountains than the other workings of the Elkton area. It lies on a low hill projecting from the gravel plain west of Grindstone Mountain at an altitude of 1,200 feet.

The Garrison bank was opened in 1884 as a part of the operations of the Shenandoah Iron Works, and was worked intermittently for manganiferous iron ore and iron ore for some years thereafter. It lay near the branch railroad from the iron works at Shenandoah to the Fox Mountain mine, so transportation of the mine product was facilitated. No information is available as to the amounts of concentrates produced, but some of the production may be included in figures given for the Kimball bank (table, p. 71). The following table gives partial analyses of the ore, by A. S. McCreath:

Analyses of ore from Garrison bank

	Fine ore	*Lump ore*
Manganese	52.691	53.656
Iron	2.325	1.537
Silica	2.795	1.995
Phosphorus	.324	.327

In 1941, the Alleghany Ore & Iron Co. did considerable prospecting on the tract. Numerous trenches were dug, some large openings were made in the northwestern open-cut, and two shafts 100 feet deep were sunk. A few tons of manganese oxides were handpicked during prospecting and were taken to Lynchburg, Va., and sold. However, no full-scale mining operations were undertaken.

The Garrison bank is in the belt of outcrop of the Waynesboro formation, and the workings expose brown, red, gray, and white, evenly bedded, decomposed silty shale which is residual from the Waynesboro. Some pillars of hard, unweathered shale project into the decomposed shale in the southwestern open-cut. The shales in general dip eastward and may be overturned (sec. F–F′, pl. 5). In the surrounding plains, the bedrock and residuum are concealed by the older and intermediate gravel units.

The workings consist of five open-cuts, the southwesternmost two of which are each about 2 acres in area and the others an acre or less. It is reported that the larger open-cuts to the southwest contained mainly iron ore, and some fragments of iron oxides are still visible in these. Most of the manganese ore of the early operations is said to have come from a small open-cut to the northeast and from underground workings nearby, but recent prospecting in this vicinity shows only thin seams of wad and pyrolusite parallel to the bedding planes of the decomposed shale. Small amounts of manganese oxides were found near the bottom of a 100-foot shaft near the center of the tract and in the cut of the old railroad line southwest of the workings.

The best showings of manganese oxides revealed by recent prospecting were in one of the northwestern open-cuts where wad, pyrolusite, and harder manganese oxides occur in considerable quantities, as seams parallel to the bedding of the decomposed shale, as cross-cutting veinlets, and in the matrix of breccia zones in the shale. It is also reported that a solid mass of manganese oxides weighing about 100 pounds was uncovered and mined during prospecting. However, the concentration of manganese oxides in the cut is small in relation to the mass of decomposed shale, and as a large part of the oxides consists of soft minerals, they cannot be separated by washing, but must be hand-sorted.

No extensive body of ore has been exposed by the recent prospecting, and the reserves of ore in the tract appear to be small.

WATSON TRACT

The Watson tract (Harder, 1910, p. 56; Stose and others, 1919, pp. 69–70; King, 1943, pp. 38–39, pls. 6–8) lies in a recess on the southeast slope of Grindstone Mountain, three-quarters of a mile north of the settlement of Furnace, at an altitude of 1,400 feet (pl. 1). The Watson tract was owned in 1941 by R. F. Watson of Furnace and a Mr. Sebrell of Richmond, Va.

The Watson tract was first prospected in 1908, and some mining was done before 1915, but no record of the production is available. The ore was washed and concentrated at the mine, and the concentrates were hauled in wagons to the Norfolk & Western Railway, a distance of 4 miles. In 1941, the tract was explored by the U. S. Bureau of Mines.

The Watson tract lies in residuum overlying the basal part of the Tomstown dolomite. The tract lies on the northwest flank of a southwest-plunging syncline, bordered on the east by steeply dipping beds of the Antietam quartzite and on the north by a broad anticline of the quartzite, which forms a subsidiary spur of the mountain (fig. 6). Along Mudhole Run, the top of the quartzite dips 20°–40° S.; test holes indicate that this dip, with minor variations, continues southward beneath the tract. Within the tract, the quartzite is overlain by a southward-thickening wedge of residual clay, and unweathered Tomstown dolomite was penetrated beneath the clay in Bureau of Mines test hole No. 2. The clays are overlain by a sheet of fanglomerate belonging to the older gravel unit, which in test hole No. 5 is 140 feet thick. The relations of the quartzite, dolomite, residuum, and gravel on the tract are shown in sections Q–Q′ and R–R′ of figure 16, which are based on test holes and underground workings of the Bureau of Mines.

The older workings consisted of an open-cut, three inclines, the longest of which was at least 100 feet long, several shafts as much as 65 feet deep, and many prospect pits. The exploratory workings of the U. S. Bureau of Mines consisted of 15 test holes, an incline 540 feet long (pl. 3), and a shaft 70 feet deep.

As shown in the test holes and incline, the residual clays have varied colors and textures and a complex structure. Some of them contain embedded pieces of chalcedonic chert, and many are impregnated or minutely veined by wad. Test holes in the northern part of the tract, within 600 feet of the outcrop of the quartzite, generally encounter hard manganese oxides in the clay in two or more zones between 25 and 75 feet above the top of the quartzite; the lower zone is at some places 7 feet or more in thickness. The oxides consist mainly of nodules of psilomelane lying in clay, but a lens-shaped body of solid ore 5 feet thick was crossed in the incline between timber sets 76 and 80 (pl. 3). In this lens, however, the manganese oxides are interlayered and intergrown with a considerable amount of iron oxides, and the lens tapers out within a short distance, its place being taken by stringers of wad and thin beds of iron oxide. In the shaft, which lies nearer the axis of the syncline, a good deal of manganese oxide was found in or near the same zone. Here there are layers of wad and wad-impregnated clay as much as 6 feet thick, enclosing irregular nodules and masses of hard manganese oxides.

These explorations have failed to reveal any ore body of large size.

FOX MOUNTAIN MINE

The Fox Mountain mine (Hotchkiss, 1878, pp. 14–17, 25–26, 41; McCreath, 1884, pp. 28–30; Benton, 1886, p. 15; Stose and others, 1919, pp. 71, 82 [4]) is 4½ miles southeast of the town of Shenandoah and half a mile southwest of old Furnace No. 2 and the present settlement of Furnace. It lies on the north slope of the eastern of two gravel hills, known as Fox Mountain (pl. 1).

The Fox Mountain mine was the greatest producer of iron ore in the Elkton area. It was probably first opened in 1836, with the founding of the iron works at Shenandoah, and samples of its ores were described by Rogers in 1838 (1884, p. 238). From that time, it was operated almost continuously until after 1890. In 1878, it was variously estimated to have produced 30,000 or 100,000 tons of concentrates. However, the main period of production was between 1880 and 1890, during part of which time it was producing 100 tons of concentrates per day. The total production of the mine was undoubtedly very great and probably amounted to more than half of all the production of the mines operated for the Shenandoah Iron Works.

During the early stages of its operation, the concentrates from the mine were hauled by wagons 4½ miles to the iron works in Shenandoah, but, in 1857, Furnace No. 2 was erected near the mine, so as to convert the ore to pig iron on the spot. After 1882, the mine and furnace were connected by a branch railroad line with the iron works in Shenandoah.

Many descriptions are available of the mine during its period of operations, but descriptions of the workings, the character of the ore, and of mining and milling methods vary from year to year. The following description by Benton (1886, p. 287) indicates the appearance of the mine and the nature of the mining and milling methods about the year 1880:

> The workings consist of one large pit about 275 feet long, 150 feet wide, and 50 feet deep, running about north and south. At the bottom, a tunnel extends from the west side, in a westerly direction, 175 feet. This tunnel is 10 feet wide and 10 feet high, is driven all the way in ore-bearing material, and is still being driven farther in a westerly direction. Two shorter tunnels of the same height and width extend in the same direction, one on each side of the main tunnel. The whole of the material in which these workings have been made is ore-bearing. It is a stratified deposit, the beds lying nearly horizontal, though showing local crumplings. The deposit consists of a great number of thin beds (one-quarter inch to 3 or 4 inches) of ocher and soft ferruginous clay or shale, of colors varying from light yellow to brown or black, with very thin layers of limonite interlaminated. A few layers, several inches thick, of limonite and manganiferous limonite occur, but these form a very insignificant proportion of the whole.
>
> The whole deposit is mined, screened, and about one-half saved as good ore; of this the coarser part is roasted and the finer is washed and roasted before being used in the furnace. The prepared ore thus obtained is all used in Furnace No. 2 of the Shenandoah Iron Works, the pig being made into charcoal blooms for boiler plates at the forge of the iron works, near Shenandoah Iron Works Post Office.

In some of the other descriptions, mention is made of greater quantities of coarser ore, either in lump, cellular, or massive form, which in part followed the stratification in the clay. According to local residents, a shaft 156 feet deep was put down in the floor of the cut late in the period of operation, probably partly for drainage and partly for exploratory purposes. However, no record is available of the materials penetrated.

The ores of the Fox Mountain mine were used entirely for iron, but they also contained small but variable amounts of manganese, silica, and alumina. In one analysis (No. 5, of table below) a small quantity of cobalt is reported. The amount of phosphorus was variable, ranging from 0.06 percent to 0.50 percent in different parts of the workings. Analyses of ore from the Fox Mountain mine, as reported by various authors, follow:

[4] Described on page 71 as "Furnace mine," and on page 82 as "Fox Mountain mine," the latter wrongly located in the southeastern rather than the northeastern part of Rockingham County.

Analyses of ore from Fox Mountain mine

	Fe	Mn	SiO_2	Al_2O_3	CaO	Co_2O_3	S	P	H_2O
1. W. B. Rogers, 1838. Brick red or brown, earthy, conchoidal fracture. Original in parts of 30; recalculated into percentages	48. 18	--------	19. 00	1. 33	Trace	--------	--------	--------	10. 00
2. W. B. Rogers, 1838. Deep brown, compact, with shining or velvety surfaces. Original in parts of 30; recalculated into percentages	55. 82	--------	2. 30	3. 56	--------	--------	--------	--------	13. 10
3. Jedediah Hotchkiss, 1878. Analysis by Booth and Garrett of Philadelphia in 1868	55. 84	--------	6. 75	0. 80	None	--------	0. 07	0. 13 (P_2O_5)	12. 85
4. Jedediah Hotchkiss, 1878. Analysis by W. M. Bowron. West face of cut at north end	70. 00 (Fe_2O_3)	13. 21 (MnO_2)	4. 73	0. 86	None	--------	None	Trace	11. 02
5. A. S. McCreath, 1884. Analysis of 145 pieces of lump ore selected from a section across whole face of deposit. Part of analysis omitted	52. 725	1. 275	6. 910	2. 100	0. 550	0. 130	0. 010	0. 266	12. 398
6. A. S. McCreath, 1884. Analysis of sample of wash ore	49. 900	0. 850	11. 360	--------	--------	--------	0. 033	0. 221	--------
7. A. S. McCreath, 1884. Analysis of sample from west face of open cut, 60 feet below surface	52. 050	0. 677	6. 930	--------	--------	--------	--------	0. 566	--------
8. E. R. Benton, 1886. Lump ore from main tunnel; raw, screened. Part of analysis omitted	41. 17	Trace	20. 13	6. 71	0. 17	--------	--------	0. 215	12. 55
9. E. R. Benton, 1886. From large pile of fine ore at washer near ore bank; screened, washed	46. 29	--------	--------	--------	--------	--------	--------	0. 166	--------

Like the Boyer mine and Garrison bank, already described, the Fox Mountain mine lies much farther out in the Shenandoah Valley and away from the mountains than the other mines of the Elkton area. Like the other two mines, it lies in the belt of outcrop of the Waynesboro formation, whose residuum is exposed in the workings. Unlike the other two mines, however, no unweathered rock is known to have been encountered. The structure of the residuum in the workings is complex, but is is not known to what extent this reflects the original structure. An interpretation of the structure near the mine is suggested on section II′, plate 5. The mine is on the north slope of a hill capped by an outlier of the older gravel unit; the surrounding plains are covered by the intermediate gravel unit. The relations between bedrock, residuum, and gravel deposits near the mine are indicated on section X–X′, plate 6.

The old workings of the Fox Mountain mine cover an area of nearly 10 acres, and form a single large-open-cut 40 to 60 feet deep, with many arms and branches. Many trees of considerable size grow in the cut and the central part is filled by water. The cut exposes maroon-red, brown, yellow, and gray waxy clay, mostly thinly laminated, with the colors in part in alternating bands. The laminae possess exceedingly varied dips, with much sharp folding and contortion. These clays differ in texture and structure from those at the Garrison bank. They were probably derived from weathering of calcareous shale, limestone, and dolomite, whereas those at the Garrison bank were derived from shale and silty shale. A few silty and gritty seams are present between the laminae or beds of waxy clay, suggesting the original presence of interbedded shaly and sandy layers. On the east side of the open-cut are also some thicker masses of friable, weathered sandstone.

Only small quantities of iron oxides are now visible in the workings, these being mostly seams and plates along the laminae. A few loose blocks of massive iron oxide were also noted in the floor of the cut. No manganese oxides were observed. It is clear that the rich and extensive ore body which once existed at this mine has been completely removed.

ELKTON MINES

The Elkton mines (Weeks, 1889, p. 133, and 1895, pp. 430–431; Watson, 1907, pp. 250–251; Harder, 1910, p. 57; Hewett, 1916, pp. 61–67; Stose and others, 1919, pp. 71–77; King, 1943, pp. 40–43, pl. 9) include the Kendall and Flick mine, the Neisswaner shaft, and the U. S. Manganese Corp. mine. They are a mile south of Elkton on the northwest slope of Hanse Mountain at altitudes of 1,100 to 1,300 feet pl. 1).

Hanse Mountain is carved from an anticline of Antietam quartzite on the northwest flank of which the beds dip 45°–60° NW. (sec. M–M′, pl. 5). Another minor anticline about a quarter of a mile northwest of the outcrop of the top of the quartzite is indicated by exposures in Hawksbill Creek and along State Highway 12 to the southwest. This anticline apparently continues into the mining area, as suggested by southeast dips in the Waynesboro formation in the Neisswaner shaft. The shallow synclinal basin between the two anticlines is overlain by clays residual from the Tomstown and Waynesboro formations, which in turn are overlain by a varied thickness of deposits of the older gravel unit, now considerably dissected. The surface appearance of the mining area is indicated on figure 5, and the probable relations between bedrock, residuum, and gravel are shown in section S–S′, figure 16.

Manganese ore was discovered in the area of the Elkton mines before 1888, and the first mining was probably in that year, when the Rockingham Manganese Mining Co. produced 36 tons of concentrates. Operations shortly thereafter were taken over by Kendall and Flick, who operated intermittently until 1910. In 1894, these operators produced the largest amount of concentrates in the State, or 1,190 tons. This material contained 48.25 percent manganese, 2.70 percent iron, and 10.50 silica; the phosphorus content was below the prescribed limits. In 1908 they produced 5,200 tons. The total production of the Kendall and Flick mine was about 10,000 tons of concentrates.

The Kendall and Flick workings extended for about a quarter of a mile along the foot of Hanse Mountain, but the main workings were in No. 3 hollow at an altitude of about 1,200 feet, in residual clay that overlies the lower part of the Tomstown dolomite. The main workings were a shaft 256 feet deep, connected with a mule tunnel whose entrance was lower down on the slope, and a long-open cut. All the workings are now caved and overgrown. According to Harder (p. 57):

The deposit consists of a mixture of manganese and iron ores embedded in variegated clay, either in separate pockets or mixed in the same mass. The manganese ore is largely psilomelane in cellular and nodular masses, with locally small scattered kidneys. Layers or lenses of dark-colored clay and wad are interbedded with the lighter colored clays.

According to Hewett (p. 63):

Iron ore only was taken from the open cuts, but it is reported that some manganiferous iron ore was obtained from the deep workings and removed through the mule tunnel. The walls of the eastern open cut show decomposed sandy shale, here and there impregnated with limonite and containing thin films of manganese.

Other old shafts, probably belonging to the Kendall and Flick mine, are farther east on the ridge between No. 3 and No. 2 hollow, and in No. 2 hollow itself. The dumps of most of these contain clay, chalcedonic chert, and manganese oxides, indicating that the shafts penetrated clay residual from the Tomstown dolomite. One shaft on the ridge at an altitude of 1,290 feet is reported to have struck quartzite boulders at 110 feet, and the Bartell shaft, at 1,120 feet in No. 3 hollow, was put down to a depth of 135 feet in 1915, and encountered only valley wash containing subangular boulders of quartzite (sec. S–S′, fig. 16).

The Neisswaner shaft lies 1,500 feet north of the Kendall and Flick mine between No. 2 and No. 3 hollows. This was opened by the Pittsburgh Manganese Co. in 1910, and operated almost continuously until 1915. The total production of the Neisswaner workings was about 1,750 tons of concentrates, ranging in manganese content from 46 to 50.5 percent, and consisting largely of psilomelane.

The Neisswaner shaft is 312 feet deep. Its lower part is in barren, hard, unaltered, red and green shale of the Waynesboro formation. Ore occurs at depths between 140 and 206 feet in residual clays derived from the shale. Hewett (1916, pp. 63–64) wrote:

The zone which yielded the ore * * * was roughly U-shaped in cross-section and about 30 feet in maximum thickness in the arms. * * * Within this zone hard, rounded and slaglike masses of manganese minerals were found, for the most part in dark brown to black wad, which formed highly irregular bodies in soft, variegated clay. Locally, however, the manganese minerals were embedded in pure ocher containing little manganese, but none were observed in white or pale yellow clay. Although some bodies of wad were small and apparently isolated, many of the larger bodies were connected by irregular pipes and seams of wad, and by following these it was possible to locate new bodies in the zone. As the explorations and stoping tended to follow the ore, the result in places was a veritable maze of drifts and raises. Although the round ore nodules are generally solid, many of the slaglike masses are cavernous, and stalactites of psilomelane hang vertically from their walls.

In 1916 the tract on which the Elkton mines are located was taken over by the U. S. Manganese Corp., which put down many test holes and produced manganese from two shafts that are close to the quartzite outcrops in No. 1 hollow at an altitude of 1,270 feet. This company is reported to have produced several thousand tons of concentrates containing 42 to 50 percent manganese, 2 to 5 percent iron, and 8 to 10 percent silica. The northeastern shaft is 210 feet deep. "At this depth * * * it is reported a bed of well-rounded quartzite boulders was struck. These boulders are clearly water-worn and must form a part of a stream channel. All the ore was found above the bed of boulders" (Stose and others, 1919, p. 76).

The dumps consist of brown sandy and silty clay, waxy clay, chalcedonic chert, and plates and nodules of manganese oxides. Similar material was also seen on the dumps of two shafts on the ridge to the west, at altitudes of 1,290 and 1,310 feet. This material is clearly residual from the Tomstown dolomite, so the boulders probably lie in a cavern or crevice filling.

During operation of the Elkton mines, tram roads, grades of which are still visible, were built at various times in No. 1, No. 2, and No. 3 hollows. These connected the workings with the washer and mill on the Norfolk & Western Railway, a mile to the north. The first mill burned in 1909, and in 1911 a more elaborate mill was erected on the same site, equipped with a double log washer and jigs. This has now been dismantled.

The Elkton mines have produced a large quantity of manganese concentrates in the past. The part of the tract between and around the mine openings appears to have been well prospected, but without revealing any further large bodies of unmined ore.

SELLER MINE

The Seller mine (Harder, 1910, p. 57; Stose and others, 1919, p. 81) is a mile and a half southeast of Island Ford station on the Norfolk & Western Railway, on the south side of the valley of Two-Mile Run, at an altitude of about 1,300 feet (pl. 1).

The workings were opened about 1900 by Kendall & Flick, who sank a shaft 60 feet deep not far south of the run, and made an open-cut farther up the slope to the south that was 200 feet across and 20 to 30 feet deep. A tunnel was extended beneath the open-cut from the north, partly for drainage and partly to mine the deeper part of the deposit. During operation, the mine was connected with the railroad by a tram road. No record is available as to the amount or quality of the ore shipped.

The mine was again worked for 6 months in 1941 by the McCarrick brothers, who enlarged the open-cut by drag line and treated the ore at a washer on Two-Mile Run. In October 1941, the mine was again shut down. Three carloads of ore are reported to have been shipped, that contained about 30 percent manganese and much iron and phosphorus.

The Seller mine is in residuum overlying the lower part of the Tomstown dolomite. The top of the Antietam quartzite lies a few hundred feet southeast up the mountain slope, and in Two-Mile Run dips 40° NW. The structure near the mine is homoclinal (sec. P–P′, pl. 5).

The open-cut reveals an overburden of the older gravel unit a few feet to 25 feet thick. The gravels are more deeply weathered here than elsewhere, but are not mineralized. The gravels are underlain by buff, brown, and red waxy clay, having a steep but obscure dip to the northwest. The clays contain much limonite in irregular masses and veins and are in part deeply impregnated by wad. Some large masses of soft wad and of hard manganese oxides that were exposed in mining showed slickensides probably inherited from the original clays. There are also nodular masses of the harder manganese oxides.

At the time of the last visit (October 1941), most of the larger masses of ore that had been exposed in mining had been taken out, leaving only relatively barren clay. The recent mining had, moreover, exposed the timbers of old underground workings, suggesting that much of the deeper part of the deposit had been removed in the earlier operations.

OCHER

MINES

The residuum of the Elkton area has been worked not only for iron and manganese ore but for ocher, but these operations are now likewise abandoned. Between 1876 and 1907, ocher was mined southwest of Stanley and east of Furnace along Naked Creek.

STANLEY DEPOSIT

This deposit (Prime, 1880, p. 36; Anonymous, 1880, p. 173; McCreath, 1884, p. 382; Watson, 1907, p. 228) lies about a mile southwest of Stanley on the east bank of Stony Run, just north of the tracks of the Norfolk & Western Railway, and half a mile north of the Stanley manganese mine (pl. 1).

The deposit was opened in 1876 by the Oxford Ocher Co. of Detroit, Mich., which purchased a tract of about 50 acres. Before construction of the Shenandoah Valley line of the Norfolk & Western Railway, the product was hauled by wagon 18 miles to New Market, Va., for shipment over the Baltimore & Ohio Railroad. Subsequently, shipments were made over the railroad line nearby. In 1876, 200 tons were shipped; in 1877, 350 tons; in 1880, 875 tons; and in 1882 and 1883, 1,064 tons. In other years, the mine apparently produced between 500 and 1,000 tons. Operations are reported to have continued until after 1907, but the workings have been long abandoned.

The old workings are along the east bank of the valley of Stony Run and are now much caved and overgrown. They lie in clay residual from the Waynesboro formation, and this clay is exposed at many places for half a mile along the bed and banks of the run, both north and south of the railroad. The clay is brown or yellow, silty, and of great uniformity throughout. It is thinly and evenly laminated, the laminae dipping 45° to 60° NW. The clay was probably derived from the decomposition of silty shale, but with little consequent reduction in volume. Away from the run, the clay is masked by a considerable overburden of the older gravel unit, and although extensions of the clay beneath the gravel are indicated by water wells, the overburden would impede further exploitation of the deposit.

NAKED CREEK DEPOSIT

This deposit (Anonymous, 1883, p. 14; Watson, 1907, p. 229) is about half a mile east of the settlement of Furnace along the southwest bank of South Naked Creek. It is on property formerly owned by William Merica, and was opened about 1880 by the Virginia Mining & Manufacturing Co. of Alexandria, Va. In 1880 it is reported that 112 tons were mined, but it is doubtful whether the deposit was ever extensively worked.

Along the southwest bank of South Naked Creek a short distance above its mouth are banks of yellow, orange, and red waxy and silty clay, probably residual from the Tomstown dolomite. According to local residents these are the clays that were worked, but no excavations of any size are now evident.

LIMESTONE AND DOLOMITE

QUARRIES

Limestone and dolomite have been quarried in many places in the Elkton area, and some of the quarry sites are indicated on the geologic map (pl. 1). However, only one quarry was in operation at the time of the present investigation in 1941. Notes on resources of limestone, magnesian limestone, and dolomite in the Elkton area have been given by Edmundson (1945, pp. 128–152).

ELKTON LIME & STONE CO. QUARRY

This quarry is 2½ miles southwest of the town of Shenandoah. It lies west of the South Fork of the Shenandoah River on the south bank of Humes Run, and a few hundred feet west of the county road from Shenandoah to McGaheysville. The quarry was opened in 1935 and is owned and operated by T. W. Mundy of Shenandoah, under the name of Elkton Lime & Stone Co.

The quarry is in the top of the Beekmantown dolomite, which at this locality dips 80° W. The overlying limestones of Middle Ordovician age succeed the Beekmantown at the west end of the quarry. In 1941, the quarry face was about 500 feet long and 50 feet high, and had been cut back about 100 feet from the original surface (fig. 11). No overburden was present, except a few feet of residual clay and wash. In 1944, according to Edmundson (1945, pp. 131–134), quarrying had been extended eastward along the south side of the run, and across the county road.

A detailed section of 1,196 feet of beds has been measured by Edmundson in the quarry and to the east. Of the exposed beds in the section, 247 feet are classed as limestone, 276 as magnesian limestone, and 576 feet as dolomite. Limestone and magnesian limestone predominate above, and dolomite beds become increasingly thicker and more numerous downward. The dolomite is light gray and finely crystalline; the limestone is darker and denser. The limestone is considerably fractured and contains gash veins of calcite. Some fossils occur, which are mostly small gastropods seen in cross-section. At the west end of the quarry a small limestone cavern has been exposed by quarrying operations.

An analysis of a composite sample of 78 feet of dolomite from the middle of the quarry, obtained by Edmundson, indicated a content of 57.28 percent calcium carbonate, 37.01 percent magnesian carbonate, and 3.52 percent silica.

The quarried product is crushed and screened, the coarser material being used for road metal and construction material, and the finer material as agricultural lime.

QUARRIES NEAR SHENANDOAH

In the town of Shenandoah are a number of old quarries, now abandoned, that have been opened in the Conococheague limestone and the Beekmantown dolomite. Limestone was probably first quarried here as a part of the operations of the Shenandoah Iron Works. As indicated by the records of the iron furnaces (mss. p. 262), much limestone was used as flux in making pig iron out of iron ore. Limestone and dolomite were probably also quarried for construction purposes by the Norfolk & Western Railway, for the characteristic rocks of this locality may be recognized in abutments and retaining walls for some miles north and south along the railroad line.

The largest quarry in this vicinity is in the south part of the town of Shenandoah east of State Highway 12, on the north slope of a valley a few hundred feet west of the site of the Gem furnace (fig. 19). This quarry covers an area of nearly 3 acres and has a face 50 feet high or more. The quarry is in Conococheague limestone, which dips steeply toward the east. The limestone forms beds a foot or two thick and contains argillaceous seams and a few sandy layers, as well as nodules of chert. The proximity of this quarry to the furnace suggests that the product was used mainly as a flux.

OTHER QUARRIES

Small quarries have been opened elsewhere in the Elkton area in the Elbrook dolomite, the Conococheague limestone, and the Beekmantown dolomite, but are not now in operation. They have been worked in the past mainly for road metal and local construction purposes.

BUILDING STONE

A few quarries have been opened in the quartzites and other siliceous rocks of the Chilhowee group as a source of building stone. In 1941 quartzite from the top of the Antietam was being worked on Gap Run at the point where it leaves the mountains 4 miles south of Elkton. Openings were made on both the east and west slopes of the valley, and as the rock was much jointed and broken into talus, it was easily removed. This rock was being used for retaining walls and other construction along the Skyline Drive in Shenandoah National Park.

Another quarry, not now in operation, has been opened on the east slope of the valley of Naked Creek a quarter of a mile southwest of Jollett. This quarry is in massive conglomeratic quartzite of the lower member of the Weverton formation. Shale of the middle member of the Weverton is exposed in the upper part of the opening.

COPPER AND MAGNETITE

Two other kinds of mineral deposits may be mentioned, although they are outside the area mapped, on the crest and northwest slopes of the Blue Ridge, in the Catoctin greenstone.

Copper has been prospected at many places in this area, and has been mined on a small scale at a few localities. The occurrences have been described by Phalen (1906, pp. 140–145) and Watson (1907, pp. 504–511). According to Watson:

> The ores consist chiefly of cuprite and native copper with small amounts of the sulphides bornite and chalcopyrite. * * * The ore occurs along crevices and joint planes, in small, irregular shaped lenses of quartz, and as disseminated grains through the more epidotized portions of the basalt. * * * The ores do not extend more than 50 feet below the surface at many of the localities and at some it is less. From their occurrence in shear zones in the rock; from the confinement of the ore mainly to the secondary epidote and quartz veinlets; and from the character of the ore itself, it is believed that the ores have been formed by a concentration of material leached out of the locally copper-rich portions of the igneous rocks. The shear zones have afforded a place for the gathering of these solutions and the deposition of material. The ores seldom occur in actually continuous masses, but can sometimes be traced for miles by the copper-bearing strata.

Mines have been opened in the copper deposits near Ida, Stony Man, and Fishers Gap in the Stony Man quadrangle, northeast of the Elkton area. Another mine has been opened at High Top near the crest of the Blue Ridge in the southeast part of the area shown on the geologic map (pl. 1).

Magnetite has also been reported on the northwest slope of the Blue Ridge, where it likewise occurs in the Catoctin greenstone. Two occurrences were reported by Prime (1880, p. 38) in the valley of Hawksbill Creek above Marksville, both lying in the Stony Man quadrangle.

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