THE GEOLOGY OF THE MOUNT JACKSON QUADRANGLE VIRGINIA

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ABSTRACT

The Mount Jackson quadrangle is located in the northern part of the Valley of Virginia, a part of the Ridge-and-Valley province. The quadrangle contains four physiographic units, from southeast to northwest the Shenandoah salient of the Blue Ridge, Page Valley, the Massanutten Range, and Shenandoah Valley.

Strata present in the area range from basal Cambrian to Middle Devonian. The Cambrian and Ordovician formations are found in Page and Shenandoah Valleys; the Silurian and Devonian, in the Massanutten Range. The stratigraphic column begins with rather pure dolomites (Tomstown dolomite) followed by a sequence of argillaceous dolomites (Waynesboro and Elbrook formations); these are overlain by a series of interbedded limestones, dolomites, and sandstones (Conococheague limestone). All four of these formations are Cambrian in age. The Ordovician begins with a thick formation of limestones and dolomites (Beekmantown formation) which contains a prominent chert member. The top of this formation is marked by an unconformity; it is followed by more limestones (New Market, Lincolnshire, Edinburg). In the east the Lincolnshire limestone is followed by the black shale facies of the Edinburg formation, which passes up into a sequence of coarser detrital rocks (Martinsburg formation, Cub sandstone) that record an uplift to the east. In the west the black shale facies occurs at the base of the Martinsburg formation, but the same upward change into coarser material is noted. A disconformity, marked by the absence of the Oswego and Juniata formations, separates the dark Cub sandstones from the white quartzite (Massanutten sandstone) which overlies it. This basal Silurian quartzite is followed in turn by a sequence of red beds, the Bloomsburg formation, which is followed by two limestones (Tonoloway, Catherine). A third disconformity at the top of these limestones is marked by the absence of the Oriskany sandstone; the limestones are overlain directly by the shales and siltstones of the Romney group.

The principal structures in the quadrangle are the typical Appalachian-type folds and thrust faults.

The northern and southern parts of Page Valley are structurally different. In the south the main structure is the Grove Hill-Newport fault, a rather low-angle thrust fault lying west of the Blue Ridge. The thrust fault itself is cut by a later east-west high-angle fault along which vertical movement was dominant. In northern Page Valley the main structure is an overturned syncline, poorly defined stratigraphically, near the eastern edge of the quadrangle. To the west, near the South Fork of the Shenandoah, is a peculiar fault that is interpreted as a backthrust with a steep, possibly overturned dip. North of this fault lies an outlier of Ordovician strata, apparently a landslide block from the east.

The Massanutten synclinorium is included in the Massanutten Range. The eastern syncline in this structure is isoclinal and overturned to the northwest. To the west is an open anticline with an axial plane dipping to the northwest, in contrast to most Appalachian folds. The western syncline is also anomalous, since it is overturned locally to the southeast. The folds in the synclinorium reach a culmination at New Market Gap. Two faults are also included in the structure.

In Shenandoah Valley the folds are again of the typical Appalachian type. The two on the east have been included by some in the Massanutten synclinorium. To the west of this anticline and syncline is a broad composite anticline; along the western limb of this fold there is local overturning of the strata and it appears that at least three folds are actually present in this group. In the southern part of the quadrangle are two thrust faults: the "Staunton" fault on the east and the Lincoln Hill fault on the west. The "Staunton" fault is a high-angle thrust fault; the dip of the Lincoln Hill fault is not so steep. In the northwest part of the valley is a third thrust fault, the Saumsville fault, a branch of the North Mountain fault.

Cenozoic deposits consist of stream gravels, stream terraces, and valley floor features. The high-level stream gravels are best developed in Page Valley, where they reach thicknesses of 100 feet or more and are composed of quartzite cobbles. In Shenandoah the gravel deposits are in the form of scattered patches, wich include one small deposit of limestone gravel. The stream terraces are better developed along the North Fork of the Shenandoah, in Shenandoah Valley, than along the South Fork in Page Valley; in both valleys, however, the terraces are strath terraces. The valley floor along both forks of the Shenandoah is dominantly of erosional origin; the valley floor, like the terraces, is better developed along the North Fork. Tufa deposits are found in several areas. Tufa dams are built across two of the tributaries to the North Fork at points downstream from faults. Concretionary tufa pellets are found along one stream in the Massanutten Range. No good evidence for peneplanes could be found in the area.

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INTRODUCTION

The field work on this dissertation was done during the summers of 1951 and 1952, occupying about five months in all. The work was done under the auspices of the Virginia Geological Survey and forms a part of a larger-scale project of this survey. The area lies in the northern part of the Valley of Virginia; a number of quadrangles to the north and northeast have been mapped previously by Charles Butts and R. S. Edmundson. Work is now in progress on the geology of two other adjacent quadrangles.

The area is of interest from various geological points of view; it was studied primarily, however, from the point of stratigraphy and structural geology.

The quadrangle includes a development of Silurian and Devonian strata in the Massanutten synclinorium, which has preserved these formations at a point considerably farther east than they are found elsewhere in this region. A good development of Middle Ordovician strata is present to the east and west of the synclinorium; these strata have been the subject of a good deal of discussion in recent years.

The geologic structures in the area include those of typical "Appalachian type"; in addition, there are several anomalous structures in the Massanutten synclinorium. In Page Valley the structures near the western front of the Blue Ridge were studied.

The geomorphology of the area is also of interest. High-level gravels are spread over large areas in Page Valley and over smaller scattered areas in Shenandoah Valley. Terraces along the major streams present some interesting features, as do the tufa deposits along some of the tributaries.

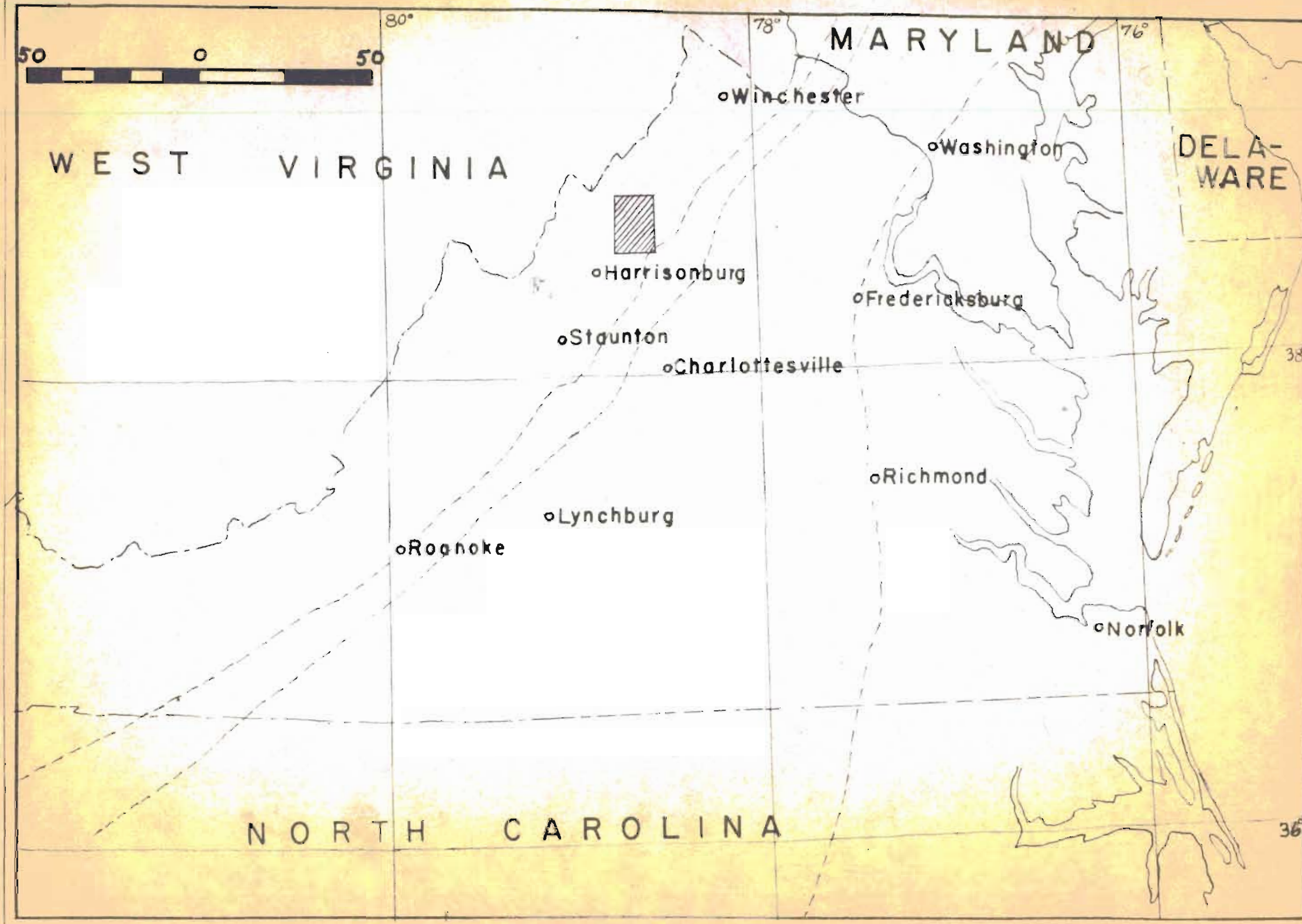


PLATE I. INDEX MAP SHOWING LOCATION OF QUADRANGLE

LOCATION

The Mount Jackson quadrangle lies between 38°30' and 38°45' north latitude and 78°30' and 78°45' west longitude, in the northwestern part of the State of Virginia. It is located about 90 miles WSW of Washington, D. C., and 150 miles NW of Richmond, Virginia. It includes parts of Page, Shenandoah, and Rockingham Counties.

The area is crossed by a number of good roads. U. S. Highway 11 runs northeastward through the Shenandoah Valley to the west of the Massanutan Range and State Highway 12 parallels it in Page Valley on the east side of the range. From the east U. S. Highway 211 crosses the area, crossing Route 12 at Luray and Route 11 at New Market. Route 11 is the main north-south road through the eastern part of the Appalachians, reaching from the northern end of Lake Champlain on the north to Birmingham, Alabama, at the south end of the Appalachian Ridge-and-Valley province. Two railroads cross the quadrangle from northeast to southwest. The Southern Railroad parallels Route 11 and the Norfolk and Western parallels Route 12.

The largest town included in the quadrangle is Shenandoah, on the southern edge of the map in Page County. It has a population of about 1800 and is situated on the Norfolk and Western Railroad; which is responsible for most of the employment of the inhabitants. Other small towns lie on U. S. Highway 11 on the west of the mountains. The chief ones are New Market and Mount Jackson, both of which have populations of less than 1000. These two towns and Tenth Legion to the southwest began as toll stations on the Valley Pike, which the modern highway now follows.

PREVIOUS WORK

The earliest geologic study of the area here discussed was that of William Barton Rogers, the state geologist of Virginia from 1835 to 1842. Rogers' work is often quite astonishing in its accuracy; despite the more than 100 years that have passed since his work was done, the refinement of the stratigraphic units, and the development of better base maps, many of his observations on the area have proven to be more reliable than those of more recent workers. Rogers' work covered the states of Virginia and West Virginia and is published as a series of Reports of the State Geologist which were later collected and published in one volume as The Geology of the Virginias (Rogers, 1884).

The next reference which was made to the area was made indirectly in 1891, when the Massanutten sandstone was named by Geiger and Keith (1891).

In 1896 A. C. Spencer published a reconnaissance survey of the entire Massanutten Range which included much of the Mount Jackson quadrangle as well as other areas to the northeast and southwest. Although the entire range was included in this study, the work was apparently centered in Fort Valley to the northeast of this quadrangle.

R. S. Bassler mentions several sections within the Mount Jackson quadrangle in his study of the cement resources of the state (1909).

In 1919 and 1922 two bulletins were published by the Virginia Geological Survey on manganese resources of the state and both of these include areas related to this quadrangle. The first of these (Stose, 1919) covers the deposits located along the west foot of the Blue Ridge and includes the southeastern corner of the Mount Jackson quadrangle. The second (Stose and Miser, 1922) deals with the deposits west of the Blue

Ridge and includes a description of the mines in the Massanutten Range to the northeast of the Mount Jackson quadrangle.

In 1933 a geologic map of the entire Appalachian region in Virginia was published by the survey (Butts, 1933). The map is accompanied by a short text describing the various formations mapped. In 1940-41 a more complete study of the Paleozoic formations was completed by Butts. This bulletin includes detailed descriptions of the formations and a shorter description of the structural geology and geologic history of this part of the Appalachian region.

The manganese deposits in the southeastern part of the quadrangle were studied by P. B. King in 1943 as part of the deposits of the Elkton region (King, 1943). This work includes the first really detailed study of the stream gravels along Page Valley. A larger and more comprehensive work by King is said to be in press at the present time.

Two years later a study of the commercial limestones and dolomites in the northern part of the Valley of Virginia was completed by R. S. Edmundson (1945); this deals only with the Cambrian and Ordovician strata. The following year a revision of the Middle Ordovician stratigraphy was published by B. N. Cooper and G. A. Cooper; this includes several sections within the Mount Jackson quadrangle. The two Coopers were assisted in this work by Edmundson, though the latter's name does not appear on the manuscript because of his disagreement with the authors' conclusions.

In 1949 a more complete study of the stream gravels in Page Valley was written by P. B. King (1949).

ACKNOWLEDGEMENTS

The field work upon which this dissertation is based was done under the auspices of the Virginia Geological Survey; the writer wishes to express his appreciation to the various officers of this survey, especially to Mr. W. M. McGill, chief geologist, for making this work possible. In addition the auther wishes to thank Drs. C. R. Longwell, John Rodgers, C. O. Dunbar, and R. F. Flint, all of Yale University, for their invaluable aid and, perhaps, even more invaluable encouragement during the time when the work was being done. Both Dr. Longwell and Dr. Rodgers visited the author in the field and made many suggestions which have been incorporated into the dissertation. Mr. Robert Young and Mr. William Brent, graduate students at Cornell University who were working in adjacent quadrangles, were also helpful in the regional relationships and interpretations. Finally a rather large debt of gratitude is owed to Dr. R. S. Edmundson of the University of Virginia for suggesting the quadrangle as a dissertation problem and for the training received from him during the summer of 1950 in the Strasburg quadrangle.

Two workers, now deceased, should be mentioned here for their indirect aid. These are W. B. Rogers and Charles Butts, both of whose works on the regional geology of the Appalachians were frequently drawn upon.

PHYSIOGRAPHY

The Mount Jackson lies, for the most part, in the Ridge-and-Valley province. Only the southeastern corner of the area lies in the Blue Ridge province. Physiographically the area can be divided into four parts: the Shenandoah salient of the Blue Ridge, Page Valley, the Massanutten Range, and Shenandoah Valley.

The drainage within the area flows into the drainage systems of the North Fork and the South Fork of the Shenandoah River. These two master streams flow to the northeast, the North Fork through Shenandoah Valley, and the South Fork through Page Valley. The two streams join near the town of Riverton to form the Shenandoah River, which enters the Potomac River at Harpers Ferry.

Shenandoah salient. The westward bulge of the main part of the Blue Ridge which lies to the east of the town of Shenandoah has been called the Shenandoah salient of the Blue Ridge (King, 1943). The area is quite mountainous and is covered by a thick forest growth that adds greatly to its inaccessibility. The topography is dominated by four ridges that extend northward from an unnamed high knife-like ridge near the southern edge of the quadrangle. The salient is drained by three streams — Honey, Lime, and Stony Runs — that flow northward into the South Fork of the Shenandoah and by Fultz Run which flows westward into the South Fork just south of the unnamed ridge mentioned above. All four of these streams are small, however, and during the hotter parts of the summer they may become completely dry.

Page Valley. Page Valley lies to the west and northwest of the front of the Shenandoah salient; it is a broad, relatively flat lowland underlain by weak carbonate rocks. The valley is narrowest in the south, where the Shenandoah salient extends westward from the Blue Ridge; it becomes wider towards the north, reaching a maximum width of about eight miles in the vicinity of New Market Gap and Hamburg. The lowland is drained by the South Fork of the Shenandoah; most of the tributaries to the river reach it from the east. The South Fork itself flows in a rather steep-walled valley cut in the lowland and is bordered by relatively narrow valley floor.

a. The Shenandoah salient of the Blue Ridge. Looking south from Luray, Page County.

b. Page Valley and the Blue Ridge . Looking southeast from New Market Gap in the Massanutten Range.

a. Short Mountain, a synclinal mountain in the Massanutten Range north of New Market, Shenandoah County.

b. New Market Gap in the Massanutten Range, showing Strickler Knob in the northern part of the range to the right.

Massanutten Range. The Massanutten Range borders Page Valley on the northwest. The name is used here to designate a group of relatively straight ridges which have a northeast trend; the entire group has been called simply Massanutten Mountain, but since this latter name is applied on the map to two of the ridges in the group the term "range" will be used when referring to the group as a whole. Distinct ranges of mountains cannot be recognized in most parts of the Ridge-and-Valley province and the term "range" is thus not generally used in this region; for such an isolated group of ridges, however, the term seems proper. The range is divided into a northern and a southern part by New Market Gap, which lies in about the center of the quadrangle. The ridges of which the range is composed are of the type called monoclinal ridges by Fenneman (1938) and by Lobeck (1939, p. 591). Since these ridges are not the result of a monocline, however, the application of this term seems unfortunate, and the term hogback will be substituted for it here. In addition to hogbacks, both synclinal and anticlinal ridges are present within the range; Short Mountain east of Mount Jackson is an example of the former, Catback Mountain of the latter.

The southern part of the range is drained by Cub Run and its main tributary, Pitt Spring Run; Cub Run leaves the range through a gap in First Mountain to flow into the South Fork of the Shenandoah. The northern part of the range is drained by Passage Creek and its tributaries. This drainage leaves the range through a gap in the northern end of the range; it flows into the South Fork.

The ridges and valleys of the range are largely covered by second-growth forests; the range is almost completely uninhabited, with the exception of a few farms in Fort Valley near the northern border of the quadrangle. Farther to the northeast, as this valley widens, a number of farms are found. The soil, which is derived from black shales and gray sandstones, is poor.

Shenandoah Valley. The Massanutten Range forms a rather narrow longitudinal strip of highlands along the middle of the Valley of Virginia, splitting this valley into two parts. The southeastern part was described above as Page Valley. The lowland to the northwest of the range will be called the Shenandoah Valley, although only the North Fork of the Shenandoah flows through this lowland. The Shenandoah Valley is bordered on the northwest by the first ridges of the Appalachian Mountains, which lie just a few miles northwest of the edge of the map. The topography of the Shenandoah Valley is much more irregular than that of Page Valley. The general surface of the lowland is broken by several lines and groups of hills, like those northeast and southwest of New Market and those between Quicksburg and Forestville. The area is drained by the North Fork of the Shenandoah River and by its chief tributary, Smith Creek. The valley floor along the North Fork is considerably more extensive than that along the South Fork.

STRATIGRAPHY

INTRODUCTION

Although the principal study undertaken in the quadrangle was its structural geology, it has been quite impossible to divorce the stratigraphy of the rocks from their structure. The study of the Paleozoic stratigraphy in the quadrangle could quite easily have been made a complete study in itself.

Rock units. The fundamental stratigraphic unit is the formation. In spite of this — or perhaps, because of this — there appears to be some disagreement as to just what a formation is, and it would seem profitable to go into this briefly before proceeding further, if only to anticipate certain objections that may arise from the writer's use of the term.

As used here, a formation is primarily a lithologic unit of very great lateral extent and limited thickness; its boundaries are drawn at horizons where the lithology undergoes an apparently significant change. A formation may be composed entirely of one rock type, as is the case with the New Market limestone of this report, or it may consist of several interbedded rock types, as in the Beekmantown formation. In any case, the rock types included in a formation comprise a unit: a sequence of interbedded shales and limestones between two thick sandstones is as much a unit as the sandstones. In some cases the lithology of a formation may change along or across its strike; the several geographically restricted rock types of which a formation may be composed are called facies of the formation. A change in facies may be caused by a change in one or more of the properties of the sedimentary rock included in the formation: color, grainsize, mineral composition, etc. The formation is basically a genetic unit, since it represents a response to a given environment; if the environment changes, then the lithology should also change. If the change in environment is geographic in distribution, then it is represented by a change in facies; if the change occurs with the passage of time, it is represented by a number of formations or of subdivisions of formations. The upward change in lithology may be sudden or gradual; thus, formation boundaries may be "natural" or artificial.

A formation may be subdivided into two or more units which are called members; the boundaries of these members are essentially parallel to the formation boundaries; they are thus distinguished from facies. It cannot be doubted, however, that a member may be a tongue of one of the facies of the formation.

Formations may be collected into groups, which are generally composed of related lithologies. Thus, the major units into which the stratigraphic column in the Mount Jackson quadrangle has been divided might be considered as groups, although they have not been named such.

Relation to time and time-rock units. Schenck and Muller (1941) have put forth a three-fold classification of stratigraphic units which has been widely accepted. In this classification three types of units are recognized: time-rock units, which are groups of strata deposited during the various time units; time units, which are segments of continuous geologic time; and rock units, which are mappable assemblages of strata.

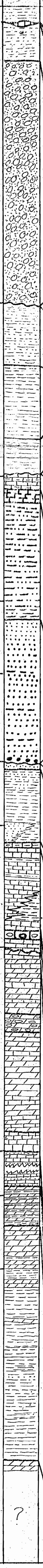
Some authors have preferred to think of formations as time-rock units rather than as rock units; such an interpretation will not be followed here, however. In the case of one of the formations described below, the included strata range in age from Late Silurian to Early Devonian (Catherine limestone). It may be possible by detailed work to separate the Silurian from the Devonian part of this formation; nevertheless, this formation, as defined, is a mappable lithologic unit and conforms quite well to the definition of a formation.

Paleontology. Since the time of William Smith paleontology has been an almost indispensible tool of the stratigrapher. The use of fossils in the correlation of strata has led to the advancement of stratigraphy to the place which it holds today in spite of recognized difficulties. However, the writer has attempted as far as possible to map the formations recognized in this area on the basis of lithology rather than of paleontology. Fossils are present in many of the formations and are even abundant in a few; they have been used only where necessary, however, and in most cases their use has been confined to correlating the formations in this quadrangle with those elsewhere in the Appalachians.

Earlier stratigraphic classifications. The earliest subdivision of the Paleozoic rocks of the region into formations was done by W. B. Rogers (1835). The strata mapped in the Mount Jackson quadrangle correspond to his formations II to VIII. Later, N. H. Darton (1892) gave names to these formations and these names were then used by Spencer in his work in the Massanutten Range (1896). In 1905 H. D. Campbell subdivided the lowest of Darton's formations into a number of smaller units. The next major change in stratigraphic nomenclature in this region occurred in the last half of the 1920's, when Charles Butts began applying names brought in from Pennsylvania and Tennessee, breaking the stratigraphic column into a number of smaller units in the process. Finally, in 1946, B. N. Cooper and G. A. Cooper revised much of the stratigraphy of the Middle Ordovician.

The classification used here is a combination of those of Spencer, Butts, and the two Coopers. Plate 5 gives a comparison of some of these classifications.

STRATIGRAPHIC COLUMN OF THE MOUNT JACKSON QUADRANGLE, VIRGINIA



System	Series	Formation	Thickness	Description
Cenozoic		Floodplain deposits	0-10 ft.	Light orange-brown clayey sand and sandy clay, with occasional gravel layers
		Tufa deposits		Porous buff-colored limestone (tufa) along Holman and Smith Creeks
		Stream terraces	0-25	Thin gravels at various levels between 10 and 80 feet above river level along the North and South Forks of the Shenandoah
		High-level gravels (Page Valley, Plains Mill, and Rudes Hill gravels)	0-150	Cobble and boulder gravels composed mainly of quartzite fragments in clayey matrix in Page Valley and on Rudes Hill in Shenandoah Valley; limestone gravel near Plains Mill in Shenandoah Valley
		Angular unconformity		
Devonian	Middle	Mahantango formation	?	Dark-colored, thin-bedded shales, siltstones, and fine-grained sandstones
		"Marcellus" shale	500?	Black fissile shale, usually much affected by cleavage
		Needmore shale	100?	Interbedded olive-gray clay shale and claystone and black fissile sha
	Lower	Disconformity		
Silurian	Upper	Catherine limestone	30-80	Fine- to medium-grained gray or pinkish clastic limestones, usually somewhat argillaceous, with local layers of siltstone
		Tonoloway limestone	50	Thin-bedded, usually mud-cracked argillaceous limestone
	Middle	Bloomsburg formation	200-600	Red shales, siltstones, and sandstones, with intercalated green siltstones and shales and white sandstones
	Lower	Massanutten sandstone	400-600	White orthoquartzite and quartzitic conglomerate, with a few thin siltstone layers
		Disconformity		
Ordovician	Upper	Cub sandstone	40	Brown fine-grained sandstone with minor amounts of siltstone and shale
	Middle	Martinsburg formation	1000+	Interbedded gray-brown hard sandstones, siltstones, and shales
		Oranda formation	50	Calcareous shale and nodular argillaceous limestone
		Edinburg formation Upper member Limestone facies	500-1500	Black fine-grained thin-bedded argillaceous limestone in Shenandoah Valley
	Lower	Black shale facies		Black fissile shale, locally silty, in Page Valley
		Basal member	30-120	Gray medium-grained nodular fragmental limestone
		Lincolnshire limestone	50-125	Dark-gray fine- to medium-grained cherty limestone
		New Market limestone Upper member	0-200	Massive dove-gray aphanitic limestone
		Lower member		Thin-bedded argillaceous dove-gray limestone with argillaceous partings
		Disconformity		
Cambrian	Upper	Beekmantown formation Upper member	500-900	Interbedded gray fine-grained limestones and dolomites
	Middle	Chert member	300	Gray dolomite extensively replaced by chert
		Lower member	1500	Gray thick-bedded dolomite and limestone
	Lower	Chepultepec member	300	Gray aphanitic limestone, somewhat clayey
		Conococheague limestone	?	Gray, generally clastic limestone and dolomite with interbedded sandstones
		Elbrook formation	?	Light-gray fine-grained shaly dolomite
		Waynesboro formation	3500?	Upper impure limestones and dolomites, lower shales
		Tomstown dolomite	1700	Coarse dolomite, usually deeply weathered to clay

Plate 5

Rogers 1837	Spencer, 1896 (after Darton)	Butts, 1940	Thornton, 1953
VIII	Jennings shale	Hamilton formation	Mahantango formation
	Romney shale	Marcellus shale	"Marcellus" shale
		Onondaga shale	Needmore shale
VI	Lewistown limestone	Helderberg limestone	Catherine limestone
			Tonoloway (?) limestone
V	Rockwood formation	Wills Creek shale	Bloomsburg formation
		Bloomsburg formation	
IV	Massanutten sandstone	Massanutten sandstone	Massanutten sandstone
		Martinsburg shale	Cub sandstone
III	Martinsburg shale		Martinsburg formation
II	Shenandoah limestone	Chambersburg limestone	Oranda formation *
		Athens formation	Edinburg formation *
		Whitesburg limestone	
		Lenoir limestone	Lincolnshire limestone**
		Mosheim limestone	New Market limestone *
		Beekmantown formation	Beekmantown formation
		Chepultepec limestone	
		Conococheague limestone	Conococheague limestone
		Elbrook dolomite	Elbrook formation
		Waynesboro formation	Waynesboro formation
		Tomstown dolomite	Tomstown dolomite

* Names proposed by Cooper and Cooper (1946)
** Name proposed by Cooper and Prouty (1942)

CAMBRIAN FORMATIONS

Chilhowee group

The various formations within the Chilhowee group have not been separated for the present report; a more detailed study of this group was made in 1943 by P. B. King, and remapping of the units for the present report was not undertaken. The group consists of three formations, an upper and lower sandstone separated by shales. Exposures of the group are limited to the Shenandoah salient, where the resistant sandstones in the group are responsible for the ruggedness of the topography.

Tomstown dolomite

Name. The Tomstown dolomite was named by G. W. Stose (1906, p. 208) from a town of that name in Franklin County, Pennsylvania. The name Tomstown dolomite has since been used by Stose (Stose and Miser, 1922) and others for the dolomite unit overlying the Chilhowee group in northwestern Virginia.

Limits. The Tomstown dolomite is distinguished from the underlying Chilhowee group by an abrupt difference in lithology: the Tomstown is a dolomite, whereas the upper formation in the Chilhowee group is a quartzite. The boundary between the two formations is thus drawn at the base of the lowest dolomite bed in the formation or, where the dolomite is deeply weathered, at the base of the residual clay derived from the dolomite. The upper boundary of the formation is nearly as distinct as the lower boundary; it is drawn at the top of the highest dolomite bed of appreciable thickness, since the lower part of the overlying Waynesboro formation is composed of shale.

Character. Within the area mapped the Tomstown dolomite is deeply weathered and in most places it is represented by residual clays. These clays are generally buff to brown in color, with a tough waxy character. Occasional layers of silty or fine sandy material are found and in some cases the original bedding in the formation has been preserved.

One outcrop of relatively fresh rock was found along Fultz Run. The rock here is a coarse "worm-eaten" dolomite with chert nodules.

Distribution and thickness. The Tomstown dolomite is restricted to the zone bordering the Shenandoah salient on the north and west; it lies entirely within the fault block bounded by the Grove Hill-Newport and the Stanley faults.

The formation underlies a part of the gently sloping surface that extends valley-ward from the Shenandoah salient. Details of the topographic expression of the formation are hidden by the Page Valley gravels.

The thickness of the formation is not too well determined. The upper boundary of the formation has been located only along Fultz Run; the base of the formation is exposed farther up the stream. The thickness of the formation along this stream is about 1700 feet.

Age and correlation. No fossils have been found in the Tomstown formation within the Mount Jackson quadrangle. Elsewhere in Virginia, however, the formation includes Archeocyathus, Olenellus, and Olenoides; the formation is thus of Early Cambrian age.

Farther south in Virginia and in Tennessee the formation is called the Shady dolomite.

Waynesboro formation

Name. The Waynesboro formation was named by G. W. Stose (1906, p. 209) from the town of Waynesboro in Franklin County, Pennsylvania. Use of the name has been extended into the northern part of the Valley of Virginia by Butts (1940) and others.

Limits. The upper boundary of the formation is somewhat easier to establish than the lower one, since it is better exposed. The formation is overlain by shaly dolomites belonging to the Elbrook formation; the upper member of the Waynesboro formation is composed of more massive dolomites, however, and the upper boundary can be drawn at the change from shaly to massive dolomite. Shaly dolomite also occurs in the upper Waynesboro formation, but this generally does not confuse the situation since the shale here forms only a small part of the strata. In most cases the lower boundary of the formation is concealed under several tens of feet of talus and alluvium, so that in mapping the Waynesboro formation has not been separated from the underlying Tomstown dolomite. Where the contact between these two formations is exposed along Fultz Run the boundary can be fixed: the lower Waynesboro formation is dominantly shaly, whereas the Tomstown dolomite is composed of dolomite. The change is thus similar to that at the top of the formation.

Character. Only the upper part of the Waynesboro formation is generally well exposed in the Mount Jackson quadrangle. The lower beds in the formation are generally covered by talus and alluvium away from the streams. The upper part of the formation is composed of dolomite and dolomitic limestone with only minor amounts of shale. Fresh surfaces of these rock types are light to dark gray; on weathering the dolomite becomes buff-colored, while the limestone is gray. Grain size ranges from coarse to aphanitic. In some cases the limestone and dolomite are interlaminated; such interlamination is apparent, however, only on weathered surfaces.

The lower part of the formation is composed largely of shale, which ranges from yellow to red in color; the red shale is distinctive. Some silty or even sandy beds also occur in the lower member.

Distribution and thickness. The Waynesboro formation is limited in its occurrence to the area bordering the Shenandoah salient on the west and north. It is confined to the fault block bounded by the Grove Hill-Newport fault on the west and the Stanley fault on the north.

Topographically, the formation forms a part of the surface sloping gently away from the mountains in the Shenandoah salient. At many places elsewhere in the state the Waynesboro forms low conical hills; such a topography may be concealed beneath the talus and alluvium that cover much of the formation.

The thickness of the formation in this quadrangle could be measured only along Fultz Run, along which both the top and bottom the formation can be established. The thickness here is about 3500 feet, about twice the thickness generally assigned to the formation; the strata may be folded several times within the Fultz Run section, but exposures are poor and the complications could not be found.

Age and correlation. The Waynesboro formation, like the Tomstown dolomite, is unfossiliferous within the Mount Jackson quadrangle. Between Harrisonburg and Roanoke, Virginia, however, a trilobite fauna has been found in the formation. This fauna includes both Early and Middle Cambrian forms, the Middle Cambrian ones being restricted to the upper parts of the formation.

a. Waynesboro formation: shaly dolomite in the middle part of the formation. On Crooked Run southeast of Grove Hill, Page County. Strata overturned, dipping east.

b. Elbrook formation: shaly dolomite with interbedded massive dolomite. On Norfolk and Western Railroad east of Crooked Run, Page County.

Farther south in Virginia and Tennessee the Waynesboro formation is called the Rome formation. It is essentially the same as the Russell and Buena Vista shales that were formerly used in the central part of the Valley of Virginia. In Pennsylvania the Waynesboro formation has been split locally into the Ledger dolomite above and the Kinzers shale below; these may be equivalent to the upper and lower members of the formation described above.

Elbrook formation

Name. The Elbrook formation was named by G. W. Stose (1906, p. 14) from the town of Elbrook in Franklin County, Pennsylvania. Use of the name has since been extended far into the Valley of Virginia both by Stose and by Butts.

Limits. The Elbrook formation is distinguished from the Waynesboro formation which underlies it by the shaly character of the dolomite in the Elbrook formation, the Waynesboro dolomite being more massive. The overlying Conococheague limestone is also massive in character; in addition, it consists largely of limestone rather than of dolomite. Thus the base of the formation is drawn at the base of the lowest shaly dolomite, while the top of the formation is placed at the top of the highest shaly dolomite.

Character. The lithology of the Elbrook formation is peculiar and differs quite radically from that of any of the post-Cambrian formations. It consists in large part of an aphanitic light-gray dolomite which on weathering becomes light gray or yellowish. The dolomite is platy in character, with very regularly spaced laminae of shaly material. Interbedded with this shaly platy dolomite are occasional beds of massive fine-grained light-gray dolomite; these layers are from one to three feet thick and are much more resistant to weathering than the shaly portions of the formation. Thus in weathered outcrops the formation appears to consist of thick massive beds of dolomite interbedded with soft yellowish shale.

Chert in the Elbrook formation forms irregular nodules or regular stringers of light-gray color; on weathering the chert becomes light brown. The chert masses are confined almost entirely to the massive dolomite beds. They are considerably less abundant in this formation than in the formations above.

Near the Grove Hill-Newport fault the Elbrook formation has been subjected to considerable deformation, and in some cases it becomes difficult to distinguish between the original lamination of the beds and the secondary cleavage formed as a result of this deformation. These surfaces that can be distinguished in this deformed zone are greatly contorted, giving the probably correct impression that a great deal of movement has occurred along the fault. Within the deformed zone the massive dolomite layers noted above have been squeezed out into a series of short lenses resembling the "boudinage" structure found in metamorphic rocks in the Piedmont.

Distribution and thickness. Exposures of the Elbrook formation are limited to a single belt in Page Valley. The belt of outcrop lies to the west of the front of the Shenandoah salient, which it parallels rather closely. In the southern part of Page Valley, as along Steam Hollow, the strike of the formation is to the north; along Honey Run, on the other hand, the formation strikes to the northeast. The belt of outcrop is not continuous. It is in part covered by the Page Valley gravels and, in addition, it is broken by the Stanley fault.

Good exposures of the formation occur locally along this belt. The best outcrops are along Crooked Run, a tributary to the South Fork of the Shenandoah east of Grove Hill. Other good exposures are found along the Norfolk and Western Railroad just east of Crooked Run and along an unnamed west-flowing tributary to the South Fork about two miles north of Ingham. The sheared zone is exposed along the Norfolk and Western Railroad east of Crooked Run.

The thickness of the formation could not be determined, since no continuous section showing both top and bottom of the formation exists in the quadrangle. South of the Stanley fault the top of the formation is cut out by faulting; north of the Stanley fault the bottom of the formation is cut out.

Age and correlation. Fossils are apparently absent from the Elbrook formation in the Mount Jackson quadrangle — or at least, well hidden. Apparently only one useful fossil has been found in the formation elsewhere in the state: Butts (1940, p. 78) reports a single specimen of Glossopleura probably from near the base of the formation. Thus the formation is probably in part Middle Cambrian.

In southwestern Virginia the shaly dolomites of the Elbrook formation undergo some change: the upper part of the formation becomes more shaly, passing into the fossiliferous Nolichucky shale, the dolomites below the Nolichucky then being called the Honaker dolomite. The fossils in the Nolichucky shale are of Late Cambrian age, so that the Elbrook farther northeast is probably also in part Late Cambrian.

Still farther south, mainly in Tennessee, the Honaker itself changes facies, passing into the Maryville limestone, the Rogerville shale,

a. Elbrook formation: "boudinage" structure in massive dolomite (a). East of Crooked Run along Norfolk and Western Railroad. Strata overturned, dipping east.

b. Conococheague limestone: limestone beds with wavy siliceous partings. Along Holman Creek west of Quicksburg, Shenandoah County.

and the Rutledge limestone. Northward the Elbrook formation continues into the Cumberland Valley in Pennsylvania; in the Nittany arch area, however, the beds equivalent to the Elbrook formation have been divided into two formations, the Pleasant Hill formation below and the Warrior formation above.

Origin. The shaly character of the Elbrook formation is fair evidence that the formation was deposited under near-shore conditions or at least, that a source of detrital sediments was present at not too great a distance. The dolomitic character of the strata may indicate rather shallow waters; the association of dolomite with evaporites in other areas certainly makes this seem plausible. The dolomite may represent a primary dolomitic sediment or it may have been formed by penecontemporaneous replacement of limestone. In either case the original sediment was quite fine-grained. The rock is quite fine-grained at present and any dolomitization would tend to increase rather than decrease the grainsize.

Conococheague limestone

Name. The Conococheague limestone was named by G. W. Stose (1908, p. 701) from Conococheague Creek in Franklin County, Pennsylvania. Use of the term has since been extended into Virginia by Stose and Butts.

Limits. The lower boundary of the formation is rather well marked. The formation is underlain by the Elbrook formation and the lower boundary of the formation can be placed at the top of the highest shaly dolomite. The upper boundary of the formation is somewhat more difficult to fix. Where the Chepultepec member of the Beekmantown formation can be recognized, the Conococheague can be separated from the Beekmantown on the basis of fossils.

Elsewhere the separation must be lithologic. This can be on the basis of the sandstones in the Conococheague or on the basis of its commonly clastic character. Dolomite is found in both formations and has proven unsatisfactory as a criterion for separating the two. The present writer has in practice generally drawn the top of the formation at the top of the highest calcarenite.

Character. Butts has described the lithology of the formation in the following terms (Butts, 1940, p. 87):

> "The dominant characteristic....is thick-bedded blue limestone which forms about 75 per cent of the formation. Most of the remainder is dolomite. Its most diagnostic features are beds of coarse-grained sandstone and laminae of siliceous and clayey material in many of the limestones."

In the Mount Jackson quadrangle the siliceous and clayey partings are absent in a large number of the exposures of the formation, a fact that makes recognition of the formation somewhat difficult if Butts' description is followed too closely.

A large part of the limestones included in the formation are quite distinctly clastic in their appearance; they occur in beds usually two to three feet thick, though thinner-bedded limestones are not unknown. The rock is a typical lime sandstone or calcarenite. Stylolites are commonly developed in these lime sandstones, especially east of the Massanutten Range, although their recognition is made difficult by the coarseness of the limestone fragments.

Some of the limestone layers do contain the "characteristic" siliceous or argillaceous partings. These are usually gray in color and are conspicuously harder and finer-grained than the granular limestones. The siliceous or clayey material is usually brownish except on fresh surfaces; in some cases it is iron-stained and red in color. In places this siliceous or clayey material may form almost half of a given bed. In many places the partings are quite regular and limestone becomes platy. Irregular partings that give the limestone a rough or knobby appearance are at least equally common.

Dolomite is also present in the formation, though it is rather less common than limestone. It is generally dark-gray and fine-grained and weathers to a smooth yellowish surface. Near Grove Hill in the eastern part of the quadrangle the dolomite is platy and fine-grained with irregular siliceous partings like those described in the limestones.

Still another common and characteristic feature of the formation is the extensive development of intraformational breccias and conglomerates. These rudites occur in or between beds of all types. The fragments are generally composed of limestone or dolomite with a matrix of much finer carbonate material or, in some cases, of quartz sand.

Locally layers of light brownish-gray dolomitic limestone occur which commonly laminated, weathering to a buff surface; it is fine- to medium-grained.

Chert occurs locally in irregular black nodules that are generally bleached to a light color around the margins.

The sandstone layers in the Conococheague limestone are composed of clean well-rounded medium-grained quartz sand cemented by calcite; the rock is thus a calcareous quartzite. When fresh the sandstone is light-gray in color and in appearance is quite similar to the calcarenites. On weathering, however, the calcite cement is dissolved, and the sand remains as a friable but not quite unconsolidated blocky sandstone. The sandstone layers are not laterally persistant, but rather form lenses of various lengths. Thus a given layer may be traceable for only a few feet or for

a. Conococheague limestone: breccia with fragments of limestone and dolomite in a sandy matrix. Along Holman Creek west of Quicksburg, Shenandoah County.

b. Conococheague limestone: dolomite bed containing Cryptozoan structure (light). Along Bulldog Creek west of Tenth Legion, Rockingham County.

several miles. The sandstones do not appear to be restricted to any zone within the formation but are scattered throughout the entire thickness.

Heavy minerals in the Conococheague sandstones consist largely of zircon and tourmaline. In addition, however, both staurolite and hornblende occur in appreciable quantities and are somewhat more euhedral than the tourmaline and zircon. It seems likely that these minerals are derived from a local source.

Distribution and thickness. Exposures of the Conococheague limestone are not restricted to the area east of the Massanutten Range, but occur in the Shenandoah Valley as well. In Page Valley the formation occurs in a single belt of outcrop extending from south of Alma to a point east of Grove Hill. This belt, however, is cut by both the Grove Hill-Newport and the Stanley faults. In Shenandoah Valley the formation is exposed in three areas: in the hanging wall-block of the Staunton fault, in the core of the Mount Jackson anticline, and in the northwest corner of the quadrangle.

The best exposures of the formation occur along State Road 767 between Quicksburg and Forestville.

Topographically the Conococheague limestone is quite distinct. The sandstone layers within the formation form a series of hills in all three of the outcrop belts west of the Massanutten Range. The hills are usually elongate parallel to the strike of the formation and are separated by valleys underlain by the limestone portions of the formation. East of the range this topographic expression of the formation is absent, probably because of the much smaller development of sandstones in the formation here.

The thickness of the formation could not be determined in this quadrangle. No continuous section showing both the top and the bottom of the formation is available. According to Butts (1940, p. 89) the thickness is about 2000 feet.

Age and correlation. Although some fossils do occur in the Conococheague limestone within the area mapped, none of them were more than fragmentary and all proved to be impossible to separate from the rock. Cryptozoan colonies are not uncommon, but are probably of little value in dating the unit. Butts reports the occurrence of specimens of *Tellerina wardi* (Walcott) from the formation near Natural Bridge and of *Symphysurina* from Frederick County, Virginia. The formation appears to be of Late Cambrian age.

Southward and westward the Conococheague limestone becomes more dolomitic, passing eventually into the Copper Ridge dolomite in southwestern Virginia and Tennessee, although the Conococheague limestone continues on into Tennessee in the southeastern part of the Ridge-and-Valley province. Northward the Conococheague limestone extends into the Cumberland Valley in Pennsylvania. In the Nittany arch area, however, the beds roughly equivalent to the Conococheague limestone have been called the Gatesburg formation; this formation contains considerably more sandstone than the Conococheague limestone.

Origin. The Conococheague limestone was deposited in seas sufficiently turbulent to transport quartz and calcite grains of relatively large size (about 1 mm.). The exceptional development of intraformational breccias and conglomerates in the formation is further evidence of turbulent conditions and may indicate as well a rather shallow depth of the seas. Wilson (1952) goes so far as to estimate a depth of not more than 100 feet. The sand appears to have been derived from the west, from the region of the Cincinnati arch. This western source is indicated by an increase westward in both the grainsize of the sand grains and the thickness of individual sandstone layers. Wilson's work was confined largely to southern Pennsylvania where the sandstones are persistant units. In the Mount Jackson quadrangle a western source area for the sand is indicated by the relatively greater development of the sandstones in Shenandoah Valley than in Page Valley.

The source material for the sand layers is thought to have been an older sandstone (Wilson, 1952). Wilson points out that if the Conococheague sandstones were a first cycle sediment, the finer-grained fraction of the detritus must be accounted for. The well-rounded character of the zircon and tourmaline grains seems to accord better with the theory of a second-cycle sandstone than with that of a first-cycle one.

BEEKMANTOWN FORMATION

<u>Name</u>. The Beekmantown formation was named by J. M. Clarke and Charles Schuchert (1899, pp. 874-878) from Beekmantown township in Clinton County, New York. The unit is called the Beekmantown group by Butts (1940, p. 102), in accordance with the usage in Pennsylvania, where four formations have been distinguished. In Virginia the lithologic differences between these formations is lost, however, and the unit is here mapped and described as a formation rather than as a group.

The use of the name Beekmantown for this unit is open to some question; but because the formation in the Mount Jackson quadrangle has about the same chronologic range as the Beekmantown in New York, and because the lithology in the two areas appears to be rather similar, the name will be retained.

Limits. The lower boundary of the Beekmantown formation is not very distinct in many areas. Where the Chepultepec member of the Beekmantown is present, the boundary is drawn at the base of the lowest dark-gray aphanitic limestone. Elsewhere, the formation boundary is generally marked by the change from coarse clastic limestone to fine-grained limestone and dolomite in the Beekmantown formation. It has been suggested that the top of the highest sandstone layer be used as the top of the Conococheague formation and, hence, the base of the Beekmantown, but typical Conococheague limestones are found above this highest sandstone and the writer has thus chosen to place the base of the Beekmantown at the top of the highest important calcarenite layer.

In most cases the upper boundary of the Beekmantown formation is more clearly marked. The top of the formation is placed at the top of the highest dolomite bed of appreciable thickness; where the lower New Market formation is thick and the post-Canadian disconformity is apparently absent, some difficulty may be encountered.

Character. The Beekmantown formation can be divided into four members on the basis of lithology:

Upper member
Chert member
Lower member
Chepultepec member

These four members do not appear to be strictly equivalent to the four formations which comprise the Beekmantown group in Pennsylvania and a geographic name is given only to the lower one. The upper and lower members are lithologically quite similar and are described together.

1) Upper and Lower members - Both the upper and lower members of the formation are composed largely of dolomite and limestone; the limestone-

a. Beekmantown formation: dolomite bed showing characteristic weathered surface. Near Leaksville, Page County.

b. Beekmantown formation: wormy dolomite-limestone intergrowth with rough surface due to solution of limestone. South of Grove Hill, Page County.

dolomite ratio is higher in the upper member than in the lower one, however, and limestone becomes increasingly abundant toward the top of the formation.

Dolomite is the characteristic lithology of the formation. It is generally aphanitic to fine-grained, and at many places shows a well-developed lamination. It weathers to a characteristically smooth, buff- or yellow-colored surface that in most outcrops shows a rather characteristic pattern of short fractures. The fractures are short and straight, breaking the surface up into a mosaic of angular polygons; they are most prominently developed on weathered surfaces and are apparently restricted to the dolomite. The color of the dolomite on fresh surfaces is usually light- to dark-gray; the laminated dolomite is in most cases brownish-gray. Much of the material might be described as porphyritic, since it contains rather large dolomite crystals up to ten millimeters long in a matrix of fine-grained or aphanitic dolomite. Granular, "sugary" dolomite is also present, though in lesser amounts and generally in only thin layers; it commonly grades laterally into the fine-grained, darker dolomite that is the more normal lithology. Dolomite is generally more resistant to erosion than limestone, so that most exposures of the formation are composed of ledges of dolomite separated by depressions underlain by the limestone.

The limestone in the upper and lower members is commonly gray on fresh surfaces and of rather fine grain; in many cases it closely resembles the limestones of the New Market limestone above. It is aphanitic to very fine-grained in all localities. Edmundson (1945, p. 152) gives an analysis of one of the limestones in the upper Beekmantown formation that compares quite favorably with the high-calcium New Market limestone above. A smooth light-gray surface is developed on the limestone during weathering, although in some cases the color is distinctly bluish-gray instead. No fracture

a. Beekmantown formation: dolomite (light) grading upward into limestone (dark). Near Leaksville, Page County. Strata dipping to west.

b. Beekmantown formation: interlaminated limestone (dark) and dolomite (light). South of Grove Hill, Page County.

pattern such as was noted on the dolomite is developed on the limestones in the formation. However, in many cases furrows following the steepest slope of an outcropping limestone bed are seen. The furrows have a well-rounded cross-profile but are separated from one another by sharp ridges; such features have been called karren, lapies, or clints (Von Engeln, 1942). They are commonly developed on limestones other than those in the Beekmantown formation, but are largely absent from the dolomite ledges.

Intermediate between the limestones and dolomites is a third type of rock that appears to be restricted to this formation. It consists of apparently vermicular intergrowths of limestone and dolomite; the limestone is aphanitic, the dolomite fine-grained and lighter in color. On fresh surfaces the two components are almost indistinguishable; on weathering, however, the more soluble limestone forms irregular pits and hollows in the surface, while the dolomite forms rough twisted ridges between these pits and hollows. In some cases this vermicular limestone-dolomite rock forms rather thick beds in the sequence; in other cases it forms a transition zone between limestone and dolomite layers. The vermicular lithology is almost entirely restricted to the upper member of the formation.

Intraformational conglomerates and breccias, although less common in this formation than in the Conococheague limestone below, are coarser in grain size and not too uncommon. The fragments in most such rudites are on the order of an inch in largest dimension; in some cases, however, the fragments may be from six inches to a foot in diameter. The fragments for the most part are slab-like and are apparently elongate or flat parallel to the bedding of the material from which they were derived. Most of these slabs are dolomite, although some limestone slabs are found locally. At one place, near the intersection of State Roads 798 and 620 in

Rockingham County a breccia was found in the Beekmantown formation that was composed of angular chert fragments, more or less equant and about an inch in diameter; the matrix was dolomite in this case. In other breccias and conglomerates in the formation occasional chert fragments have also been found. The matrix of these rudites is usually much less in volume than the fragments, and in many the rock greatly resembles a stone wall of well-fitted slabs. The breccias and conglomerates do not appear to be restricted to any part of the Beekmantown formation.

One of the most commonly noted features of the Beekmantown formation is the abundance of chert; like the vermicular limestone-dolomite rock, however, chert is not too abundant when compared with the amount of limestone and dolomite in the formation. The greater part of the chert is segregated in the chert member of the formation, which is described below, and from the hills underlain by that member most of the chert in the fields of the area is derived. In addition, however, some chert occurs in the upper and lower members and it will be described here.

Nodular chert is probably the most common mode of occurrence. The nodules are generally lenticular and flattened parallel to the bedding; in one case observed the nodules are actually bun-shaped: flattened on the bottom and rounded on top. Nodular chert occurs in layers parallel to the stratification; laterally a row of nodules may coalesce to form a solid though thin chert layer parallel to the bedding. The arrangement of these chert layers is in many instances quite regular; they usually are found in a more or less restricted thickness of strata within which the layers are separated by about a foot of dolomite. Nodular chert may be black or white in color, although the chert layers formed by coalescence of the nodules are generally of black chert.

Chert layers which have somewhat different relations are also present in the upper and lower members. When well developed these chert layers are quite indistinguishable from those of the first type, but certain aspects of their occurrence make it evident that the two types are of different origin. Where least abundant, the chert appears as small plates about half an inch long and an eighth of an inch in cross-section; they occur both above and below the bedding planes through a zone about three inches wide. Traced laterally the chert plates become more abundant and are finally fused into a solid layer of chert within which, the bedding plane can still be distinguished.

2) Chert member - The chert member of the Beekmantown formation is in many ways the most striking and interesting part of the formation and care must be taken not to overemphasize its importance. Much of the area which is underlain by the upper and lower members of the formation is covered by a thin veneer of chert nodules which have weathered out of the chert member and rolled down onto the upper and lower members. The chert member also forms a rather prominent ridge; there is a tendency to think of the entire width of this ridge as underlain by the chert member, whereas only a small part across the crest of the ridge is composed of the chert member. In outcrop the member is composed largely of large porous masses of light-colored chert which occur in a matrix of laminated dolomite. In relatively fresh exposures the chert in this member is seen in the form of irregular rather thick layers which parallel the bedding of the dolomite. On weathering, however, the dolomite is dissolved and the chert remains as large, more or less spherical masses of chert about the size, shape, and in many cases color of a head of cauliflower. Hence the common name "cauliflower chert" applied more or less informally to this material. Structures

a. Beekmantown formation: outcrop of chert member. East of Forestville, Shenandoah County. Strata overturned, dipping east.

b. Beekmantown formation: breccia of chert fragments in dolomite matrix. Near Mielers School, Rockingham County.

within the chert masses are in some cases quite spectacular. In many cases the chert has retained the laminated appearance of the dolomite which it has apparently replaced. In at least one case the dolomite slabs in a breccia have been replaced, then the matrix replaced by a second generation of chert. Fossils are not uncommon in the "cauliflower chert" and these chert masses constitute the best source of fossils within the entire formation.

3) Chepultepec member - The Chepultepec member at the base of the Beekmantown formation is the unit mapped by various previous workers as the Chepultepec limestone. According to John Rodgers, however, it is probable that the Chepultepec formation as the term is used in Tennessee reaches higher stratigraphic horizons than are included in the unit as mapped in northern Virginia. At several places within the Mount Jackson quadrangle the Chepultepec limestone appears to be absent or to be represented by a dolomitic facies which would be included in the Beekmantown formation as previously used. Because the dolomite facies of the Chepultepec member cannot be distinguished from the lower member of the Beekmantown which overlies it, the Chepultepec member partakes in large part of the character of a basal limestone facies of the formation. The term Chepultepec member is here used to include only the limestone facies of the unit.

The Chepultepec member is composed for the most part of aphanitic or very fine-grained dark-gray limestone of quite pure composition. In some localities the limestone contains siliceous partings similar to those found in the Conococheague limestone. Near the top of the member some thin dolomite layers may also be found.

Distribution and thickness. West of the Massanutten Range the Beekmantown formation underlies three elongate areas in the Shenandoah Valley. The first of these lies next to the range in the southern half of the area, that is, within the Endless Caverns-Hyden Spring anticline. The second exposure, which lies to the northwest and is somewhat more extensive than the first, lies within the Mount Jackson anticline. There are actually two belts of outcrop here which are separated by the Conococheague limestone. Finally, another area of Beekmantown formation occurs in the northwestern corner of the map.

East of the Massanutten Range the Beekmantown formation underlies a rather wide strip in Page Valley parallel to the eastern border of the range. This belt is narrowest in the south, but becomes wider northward as the amount of folding increases.

No good section of the entire formation, or even of any extensive part of it could be found west of the Massanutten Range. East of the mountains a good section is exposed along Cub Run and another good section of the upper part of the formation can be seen along the South Fork of the Shenandoah south of Grove Hill. See Geologic sections 10, 11, and 12.

Two of the members of the formation show characteristic topographic expression. The chert member, as mentioned above, forms a prominent, though not persistent ridge in Shenandoah Valley. The Chepultepec member, where present, generally underlies a valley, as in the eastern limb of the Endless Caverns-Hyden Spring anticline. The rest of the formation generally underlies a rolling topography of somewhat higher elevation than the surrounding country, probably due to the lesser solubility of the dolomite.

The thickness of the entire formation is on the order of 3000 feet. Of this, probably 300 feet belong to the Chepultepec member at the base of the formation and another 300 feet to the chert member about 500 to 900 feet below the top of the formation. The lower member is thus about 1500 feet thick and the upper member 500 to 900 feet thick.

Age and correlation. The Beekmantown formation is of Canadian or Early Ordovician age: it contains fossils generally thought to be restricted to this epoch (e.g., Lecanospira), it is overlain disconformably by Chazyan strata (early Middle Ordovician), and it is underlain by the Conococheague limestone which is thought to be Late Cambrian in age. The ages of the various members of the formation are somewhat more difficult to determine. The chert member, in which most of the fossils in the formation occur, contains fossils which are assigned by Butts to the Ceratopea zone of the Lower Ordovician; the fossils here are not too abundant, however, and this age for the chert member is based on the occurrence of Fusispira obesa (Whitfield), Orospira? sp., and Coelocaulus delicatus (Butts). If the chert member belongs to the Ceratopea zone of the Lower Ordovician, which is the upper zone in this series, then the upper member of the Beekmantown formation must also belong to the Ceratopea zone. The age of the lower member is somewhat more difficult to establish. The upper part may belong to the Ceratopea zone. At least a part of the lower member belongs to the Lecanospira zone, and it is quite possible that the entire lower member belongs in this zone; a few fragmental fossils of Lecanospira have been found in it. The Chepultepec member is apparently basal Ordovician. The principal fossil found in this unit is a small, slightly curved cepalopod with closely packed septa which has generally been called Dakeoceras. At other localities in Virginia these fossils are associated with Gasconadia, Ozarkispira, and Ophileta which are typical fossils of the Ozarkispira zone northward in the Appalachians and in the Ozark region.

In Pennsylvania the Beekmantown group is divided into four formations:

Bellefonte dolomite
Axemann limestone
Nittany dolomite
Stonehenge limestone

Southward the Axemann limestone changes facies and becomes a dolomite, so that in Virginia it is not possible to separate the two dolomites on a lithologic basis. Butts (1940, p. 118) calls the Lecanospira zone in Virginia the Nittany dolomite, while the beds in the Ceratopea zone are placed in the Bellefonte dolomite. In Pennsylvania, however, only the lower part of the Nittany dolomite contains Lecanospira, while Ceratopea occurs in the upper Nittany dolomite, the Axemann limestone, and the Bellefonte dolomite.

Just east of the town of Edinburg, which lies to the north of the Mount Jackson quadrangle, a sandstone occurs in the upper member of the Beekmantown formation. If this sandstone is equivalent to the sandstone in the Bellefonte dolomite of Pennsylvania, then it appears probable that the upper Beekmantown formation in the Mount Jackson quadrangle is equivalent to the Bellefonte dolomite.

The Chepultepec member of the Beekmantown formation appears to be equivalent to the Stonehenge limestone in Pennsylvania.

Origin. The rocks of the Beekmantown formation appear to be of rather shallow water origin: mud-cracks are found locally and breccias and conglomerates are found scattered through the formation. The entire formation, with the exception of local rudaceous and arenaceous phases, was apparently formed by the consolidation of lime muds deposited under quiet, shallow-

a. Beekmantown formation: cryptozoan reef, showing concentric structure in limestone (light) built around core of dolomite. Near Leaksville, Page County.

b. Beekmantown formation: mudcracks on upper surface of dolomite bed. Near Leaksville, Page County.

a. Beekmantown formation: typical exposure; outcropping beds are of dolomite. South of Grove Hill, Page County.

b. Beekmantown formation: conical hill developed on the chert member. North of Forestville, Shenandoah County.

water marine conditions, though later changes have somewhat altered this original aspect.

It is apparently under just such conditions that dolomitization takes place. In the Beekmantown formation this process is thought to have been penecontemporaneous with the deposition of the lime muds. Some of the dolomite may have been primary, however; the few aphanitic, brownish, very hard dolomite layers in the upper member are probably of such character. Most of the dolomite, however, was formed by the replacement of the limestone after the limestone was deposited. This is indicated in part by the relations between the limestone and dolomite. In some cases dolomite grades upward into limestone; there is no sharp boundary between the dolomite and limestone, although the lower boundary of the dolomite and the upper boundary of the limestone are quite sharp. In other cases just the opposite relations are found, the limestone grading up into dolomite. However, in no case is dolomite grading up into limestone underlain by dolomite grading down into limestone as would be expected if dolomitization were secondary. Perhaps the best evidence for replacement dolomite rather than primary dolomite is the vermicular intergrowth of dolomite and limestone which is apparently formed by partial replacement of limestone by dolomite.

The origin of the chert in the Beekmantown formation is somewhat more obscure. In some cases it is definitely secondary (i.e., post-depositional) since it occurs above and below a given bedding plane and along joints that cut across the bedding. In other cases it is undoubtedly penecontemporaneous. This is certainly the case with the occasional breccias composed of chert fragments in a dolomite matrix. The chert in the chert member of the formation also appears to be penecontemporaneous.

The "cauliflower" (porous) character of much of the chert in this member would seem to indicate its origin by replacement rather than by primary deposition. The silicified dolomite slabs in the breccias associated with the chert member are further evidence of a replacement origin. Penecontemporaneous rather than secondary or post-depositional origin is indicated by a number of items. The chert member has been traced from central Virginia as far as central Pennsylvania, where it is above the Axemann limestone, and this great areal extent of the member in itself is good evidence that replacement was penecontemporaneous: it is difficult to conceive of secondary silicification affecting such a restricted unit over such a large area. In some cases also breccias have been found composed of chert fragments in a dolomite matrix, a situation not easily explained by secondary silicification. Deposition of the chert member took place under conditions somewhat different from those during the deposition of the rest of the formation, resulting not only in extensive silicification but also in dolomitization and brecciation.

DISCONFORMITY

A break in the stratigraphic sequence between the end of the Canadian epoch and the beginning of the Champlainian epoch is best developed in the eastern part of the quadrangle, in Page Valley. The upper surface of the Beekmantown formation here is quite irregular, and this has resulted in the irregular development of the New Market limestone in this area. Along large parts of the Page Valley outcrop belts the New Market limestone is absent; where present, the formation is quite variable in thickness. In places the formation decreases in thickness from several tens of feet to zero within a distance of several hundred yards along the strike. Where it is present, this formation usually contains a conglomerate or breccia at its base. This rudite is composed of blocks of limestone and dolomite from the underlying Beekmantown formation; these blocks range up to six feet across.

Westward the disconformity decreases in importance. It is still recognizable as far west as the New Market exposures of the formation, where the basal New Market formation contains a bed of calcarenite. Still farther west no evidence of the disconformity was found and the upward change from the Beekmantown formation into the New Market limestone is transitional. Thus it would appear that the uplift that was the cause of this hiatus was greatest in the east.

MIDDLE AND UPPER ORDOVICIAN FORMATIONS

New Market limestone

Name. The New Market limestone was named by B. N. Cooper and G. A. Cooper (1946, p. 71) from the town of New Market in Shenandoah County, Virginia; the type section is thus included within the area discussed in this dissertation.

Limits. The base of the New Market limestone is marked by a disconformity in Page Valley and in the eastern part of Shenandoah Valley and is easily located; it is placed at the base of the basal conglomerate overlying the disconformity or at the top of the highest dolomite layer. In most of Shenandoah Valley the disconformity is not well marked and some difficulty may be encountered in finding the base of the formation, since aphanitic limestones like those in the New Market limestone are found in the upper Beekmantown formation. The base of the formation in such cases is placed at the top of the highest thick dolomite layer.

The top of the formation is more easily located. The upper boundary is placed at the abrupt change from the dove-gray aphanitic New Market limestone to the dark-gray clastic (fragmental) limestones of the overlying formation.

Character. Lithologically the New Market limestone is divisible into two members, The upper member is of more or less constant thickness, at least to the west of the Massanutten Range, and of quite constant lithology; the lower member, on the other hand, is quite variable in lithology and in thickness. Both members were noted previously by Edmundson (1945, p. 16) and by Cooper and Cooper (1946, p. 72).

1) Upper member - The upper member of the formation is the typical "Mosheim" limestone of quarrymen throughout the Valley, where it is quarried both as agricultural limestone and as a flux. It is a massive dove-gray aphanitic limestone that weathers white and breaks with a smooth conchoidal fracture. In most outcrops the formation contains numerous cavities which have been filled with crystalline calcite, giving this unit the local name "bird's-eye limestone". This lithology is constant and characteristic of the upper part of the formation everywhere west of the Massanutten Range. In the Madden quarry west of New Market, the type locality of the formation, however, a bed of coarser nodular limestone occurs near the top of the formation, separated locally from the overlying Lincolnshire limestone by a lens of the normal New Market-type lithology. Chert is wholly absent from this member of the formation.

2) Lower member - The lower member of the formation is of somewhat different lithology. It is characteristically thin- to platy-bedded

a. New Market limestone: the type section. Madden Quarry west of New Market, Shenandoah County.

b. New Market limestone: layer of granular limestone (a) just below the top of the formation. Madden Quarry west of New Market, Shenandoah County.

a. New Market limestone: basal breccia of limestone and dolomite fragments in limestone matrix. North of Hamburg, Page County.

b. New Market limestone: basal conglomerate of limestone and dolomite boulders in dolomite matrix. Between Hamburg and Leaksville, Page County.

and in most exposures was found to contain an appreciable amount of argillaceous material chiefly in the form of clayey partings between the thin limestone layers. Near the top these limestone layers are lithologically quite similar to that of the upper member of the formation; downward, however, the pure character of the limestone disappears and it becomes argillaceous or dolomitic, changing in color with this change in composition until it is a light brown. Locally thin laminae of pure dolomite may occur in this lower member.

East of the mountains the lower member is, in many localities, identical with that to the west. In other places, however, it may be missing or at least appreciably thinned and underlain by a conglomerate or breccia. This rudite is composed entirely of fragments of limestone and/or dolomite derived from the underlying Beekmantown formation; the fragments range in size from pebbles to boulders or blocks, with a maximum size of about six to eight feet. The matrix is composed of fine-grained limestone or dolomite. The grain-size of the rudite is always greatest at the base of the unit; upwards the phenoclasts decrease in diameter until the material finally merges with the platy argillaceous material overlying it.

West of the mountains the rudite is absent in most localities, although locally a chert or dolomite pebble conglomerate occurs at the base of the New Market limestone: locally also the basal layer of the limestone may be a lime sandstone rather than a conglomerate. In the belts of outcrop west of the Mount Jackson anticline no clastic material was seen at the base of the formation and the contact between the Beekmantown and the New Market appears to be gradational; in such cases the boundary between the two formations was drawn at the top of the highest bed of dolomite of any appreciable thickness.

Distribution and thickness. East of the Massanutten Range the New Market limestone occurs irregularly in a single belt of outcrop paralleling the eastern ridge of the range. This outcrop belt passes northeastward from the town of Shenandoah through Newport, lying west of Virginia Highway 12; northeast of Newport it crosses the North Fork of the Shenandoah River and makes a double swing around the crest and trough of a north-plunging anticline and syncline, crossing the river again near Alma. From Alma the belt extends northeastward again to a point about two miles north of Leaksville, where it is cut off by a fault. Because of this fault, however, the belt is repeated again to the west, beginning just west of Leaksville and extending from there northeastward through a point south of Hamburg. From this point the outcrop belt is again single, passing west of Hamburg and crossing the river again just west of the Luray power dam. The limestone does not occur continuously along this belt; within a few hundred feet it may change its thickness from almost 100 feet to zero. An excellent example of this sudden change in thickness can be seen in a field about 1-1/2 miles north of Hamburg:

	Distance along strike (in feet)				
	0	0	160	240	320
Thickness (feet)	75	65	35	30	0

The same sort of thing may be seen in a field southwest of Leaksville, and such relationships are probably not uncommon along this belt. The thickness of the formation as a whole varies from zero to 100 feet; that of the basal member, from zero to 98 feet; and that of the upper member, from zero to 50 feet. The basal conglomerate locally reaches a thickness of 70 feet in a field 1.3 miles north of Leaksville. In some places the formation is represented wholly by the lower member, and at others almost entirely by the basal conglomerate.

West of the Massanutten Range variation in thickness of the formation is noted, but it is never so extreme or so sudden as that east of the mountains. Exposures of the formation in the Shenandoah Valley occur in four belts. The southeastern belt, the Zenda-Rockingham belt of Edmundson (1945, p. 84), extends from Endless Caverns southwestward between Smith Creek and Phillips Hill; it lies in the west flank of the Endless Caverns anticline, the belt along the east flank being covered by sliderock within the quadrangle. South of the Mount Jackson quadrangle, however, the belt on the east flank of the anticline is exposed and the thickness here is about 80 feet (Edmundson, 1945, p. 86). In the Zenda-Rockingham belt the thickness ranges from 90 to 200 feet within the limits of the quadrangle; southward the average thickness is about 120 feet. The next belt of outcrop to the northwest is more or less parallel to U. S. Highway 11 southeast of Rudes Hill; this is the Strasburg-New Market belt of Edmundson (1945, p. 43). Within the Mount Jackson quadrangle the thickness is about 130 feet, although locally it may be as low as 90 feet; the thickness increases to the southeast beyond the boundary of the quadrangle. This belt lies on the southeast limb of the Mount Jackson anticline and is fairly simple in structure. The New Market limestone belt on the west limb of the anticline is considerably complicated by faulting and minor folding; this is the Lantz Mills-Forestville belt of Edmundson (1945, p. 55). North of the quadrangle the thickness averages about 110 feet; southwestward the thickness increases, however, reaching a thickness of around 150 feet in the area mapped. Exceptionally the thickness rises to 220 feet (Section 20). In the northwesternmost belt, the Saint Luke-Mount Clifton belt of Edmundson (1945, p. 57), the thickness is 120 to 180 feet in this area, and about the same northeast and southwest of the quadrangle. An exceptionally thick section of 207 feet was measured by the writer about 1.1 miles southwest of Forestville (Section 23); this same section was measured by Edmundson, who gives the thickness as 125 feet (Edmundson, 1945, section 36). It is quite possible that the writer included some beds belonging to the Beekmantown formation in the New Market limestone here, since the section was measured under somewhat difficult conditions (a large black Angus bull insisted on keeping a close watch on the author while the section was being measured).

The thickness of the basal member of the formation is quite variable within a given belt of outcrop as well as between these belts. It would thus appear more probable that the "lower member" of the New Market limestone partakes more of the character of a facies of the lower part of the formation rather than that of a member; the thickness of the "lower member" would thus depend largely on local conditions (amount of clayey and/or dolomitic material available).

Age and correlation. The New Market limestone was included in the Shenandoah limestone of Darton (1892, p. 13) and probably also in the Natural Bridge limestone of H. D. Campbell (1905, p. 446). It is essentially the same as the "Mosheim" limestone mapped by Butts (1940, p. 135) and by Edmundson (1945), although the basal member may be in part equivalent to Butts' Murfreesboro limestone (Butts, 1940, p. 120).

Neuman (1951) states that where the New Market limestone rests directly on the Beekmantown formation the two are separated by a disconformity. In Maryland the Row Park limestone occurs between these two formations and the unconformity is apparently absent. This would seem to indicate that the lower member of the New Market limestone northwest of Forestville may be equivalent to the Row Park limestone, since there is no indication in that area of any break between the New Market and Beekmantown.

The age of the formation is uncertain. It is definitely post-Canadian, since it rests disconformably on the Beekmantown formation in many places. According to Cooper and Cooper (1946, p. 74), "part, possibly all, of the New Market is Chazy". Neuman indicates (1951) that the New Market may be Black River in age. The latter author correlates the New Market limestone with the Pamelia limestone in New York. In Ontario the Pamelia limestone overlies upper Chazy beds with which it may be in part contemporaneous (Neuman, 1951, p. 306).

The Row Park limestone is called Chazy by Neuman. If the lower New Market limestone northwest of Forestville is equivalent to the Row Park limestone, then the New Market limestone as used in this dissertation is in part at least Chazyan in age.

<u>Origin</u>. The extremely fine grain size of the limestone in the formation appears to resemble quite closely that of the lime muds being formed at the present time in the extremely shallow waters over the Bahamas Banks (M. Black, 1933,; E. M. Thorp, 1939); it is to some such environment of deposition that the limestones of this formation can be ascribed. Conceivably similar deposits could be formed just as readily at great depths as a fine-grained facies of a coarser, near-shore clastic limestone; however, the presence in the limestone of corals and, in some zones, of mud cracks would seem to indicate a more or less shallow-water origin for the material. East of the Massanutten Range the basins of deposition of the lime muds were apparently isolated by ridges of dolomite, the basins mentioned being primarily depressions formed in the upper Beekmantown formation by post-Beekmantown erosion. Westward these basins were joined together to become a shallow sea. Eastward there appears to be no detrital facies of the limestones and the erosion at or near the end of Beekmantown

time may have been brought about by a rather gentle upwarping of a part of the floor of the Beekmantown sea rather than by any large-scale orogeny or epeirogeny in the hypothetical landmass of Appalachia in the east.

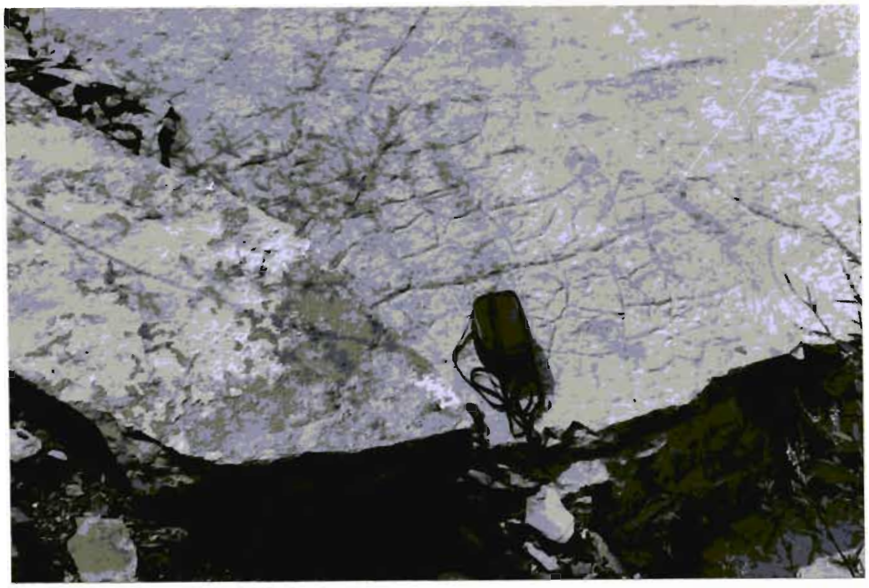
Lincolnshire limestone

Name. The Lincolnshire limestone was named by B. N. Cooper and C. E. Prouty (1943, p. 863) from a stream in Tazewell County, Virginia. Use of the term was extended into the present area by Cooper and Cooper three years later (Cooper and Cooper, 1946, p. 75).

Limits. The lower boundary of the Lincolnshire limestone is drawn at the abrupt change from the dove-gray calcilutites of the underlying formation to the dark-gray clastic limestones of the Lincolnshire formation. Where the New Market limestone is missing in Page Valley, the boundary is drawn at the top of the highest dolomite or calcilutite layer in the sequence.

The upper boundary of the formation is not so easily located. It is usually drawn at the top of the highest cherty limestone in the sequence. However, in some instances, especially in the northwest corner of the quadrangle, the uppermost cherty limestone is distinctly nodular and argillaceous, resembling in these respects the overlying basal member of the Edinburg formation. In such cases the cherty argillaceous limestone beds were generally placed in the Edinburg formation.

Character. The Lincolnshire limestone is composed characteristically of dark-gray, fine- to medium-grained, clastic (i.e., fragmental) limestones which contain lenticular masses of black chert in most exposures. In



a. New Market limestone: mud-cracked limestone in the lower member of the formation. Madden Quarry west of New Market, Shenandoah County.

b. Lincolnshire limestone: typical lithology, showing black chert nodules. Madden quarry west of New Market, Shenandoah County.

many cases the limestone appears to be porphyritic; that is, coarser grains of calcite are scattered through a finer-grained groundmass.

Intercalated within this "normal facies" of the Lincolnshire limestone are beds or lenses of lighter-gray, coarser-grained, somewhat reefy limestone, called the Murat facies of the Lincolnshire limestone by Cooper and Cooper (1946, p. 76). Southwestward this Murat facies increases greatly in importance, forming what was called the Holston limestone by Butts in the vicinity of Lexington (Butts, 1940, p. 151). That this coarse calcarenite is a facies of the Lincolnshire limestone rather than a distinct formation is indicated by the occurrence in many localities within and outside of the Mount Jackson quadrangle of the "normal facies" of the formation above and below the beds of the Murat facies.

The distinction between the Lincolnshire limestone and the adjacent formations presents some difficulties in some exposures of the formation. It is easily distinguished from the New Market and the Beekmantown formations on which it rests, since both of these are generally aphanitic and not too cherty. The problem of separating it from the overlying lower clastic member of the Edinburg formation is somewhat greater. The limestones in this basal Edinburg are clastic, like those of the Lincolnshire; in general, however, the Edinburg strata are not cherty and are more nodular in character. In exposures where the Lincolnshire limestone and the basal beds of the Edinburg formation are well exposed, the change from the Lincolnshire to the Edinburg can be seen to be gradational, making it difficult to draw any precise boundary between the two formations. In practice the boundary is drawn at the horizon where shaly material begins to form an appreciable part of the lithology; in some cases such a boundary will place cherty beds within the basal Edinburg.

Distribution and thickness. In Page Valley the Lincolnshire limestone occurs in a single belt of outcrop paralleling quite closely the eastern ridge of the Massanutten Range; this parallels the outcrop belt of the New Market limestone which lies to the east. The thickness of the forma- along this belt is 30 to 80 feet, and both the normal and the Murat facies of the formation are developed, although the normal facies is much more important. The best exposure of the Murat facies in Page Valley and, indeed, in the entire quadrangle is in a small ravine west of Virginia Highway 12 and about 0.7 miles southwest of Grove Hill (Section 10). In this exposure the Lincolnshire limestone is about 80 feet thick; nine feet above its base are some 15 feet of medium-grained, gray, clastic limestone, the Murat facies, which is followed by the cherty beds of the normal facies of the formation. The beds belonging to the Lincolnshire limestone and underlying the Murat facies are still more peculiar, however: these are black, fine-grained, nodular argillaceous limestones essentially like the limestone facies of the upper member of the overlying Edinburg formation.

West of the Massanutten Range the thickness of the formation ranges from about 40 feet in the northwest corner of the quadrangle to 100 or 120 feet east of U. S. Highway 11. The distribution of the formation west of the mountains is essentially the same as that of the underlying New Market limestone, which is exposed in four belts as described above. The lithologic character of the formation shows little or no change between these belts of outcrop; in contrast to the formation east of the mountains, there is almost no development of the Murat facies here. The variation in thickness of the formation between these belts of outcrop is not so gradual as in the underlying unit: in the Zenda-Rockingham belt the thick- ness is about 100; in the Strasburg-New Market belt, 100-125 feet; in the

Lantz Mills-Forestville belt, 45 feet; and in the Saint Luke-Mount Clifton belt, 55 feet.

Topographically the Lincolnshire limestone forms a rather even-crested rounded ridge of moderate height between the valley underlain by the New Market limestone and the generally broader lowland underlain by the Edinburg and Martinsburg formations. The resistance of the formation is presumably due to its cherty character. In some areas the Lincolnshire ridge may be even more prominent than that underlain by the chert member of the Beekmantown formation, and in almost every case it is more persistant than the Beekmantown ridge.

Age and correlation. The Lincolnshire limestone was included by Darton in his Shenandoah limestone (Darton, 1892, p. 13) and was included probably in part also in the Natural Bridge limestone of H. D. Campbell (1905, p. 446). The Murat facies of the Lincolnshire was certainly included in the Murat limestone of the latter author (p. 446), which may also have included beds of the normal facies as well. The Lincolnshire limestone is essentially the same as the "Lenoir" limestone of Butts (1940, p. 139). It is the same as the "Lenoir" limestone mapped by Edmundson (1945, p. 16). Some beds included in the Lincolnshire limestone by Cooper and Cooper are placed in the Chambersburg by Butts (Cooper and Cooper, 1946, Section 20; cf. Butts, 1940, Section 48). In addition, the Lincolnshire limestone includes the Holston limestone of Butts.

The most prominent faunal elements in the formation are Dinorthis atavoides Willard and Sowerbyites triseptatus (Willard). In their original work Cooper and Cooper suggest that the Lincolnshire is post-Chazyan; however, according to C. O. Dunbar (personal communication, 1951), D. atavoides is of Chazyan age. Neuman (1951, p. 302) calls the formation post Chazy, but refrains from putting it in the Black River stage.

Origin. With the close of New Market time, deposition of lime muds in this area appears to have come to an end; the resultant clearing of the water of the shallow sea brought with it a great increase in the amount of animal life possible on the sea bottom, animal life which had probably been impossible before because of the turbid condition of the water. Such a clearing of the seas may well have been due to a climatic change such as a lowering of the temperature which would reduce the relative saturation of the sea water in calcium carbonate and hence reduce the rate at which precipitation of lime muds would occur. The remains of the shells and tests of this now abundant animal life are the principal component of the limestones deposited at this time. In the shallower waters to the east reefs or bioherms were formed locally and are represented in the stratigraphic column by the Murat facies; limestone debris broken from these bioherms is a second source of material for the present clastic limestones. The underlying New Market limestone must have become lithified soon after its deposition, since a third source of material for the Lincolnshire limestones was apparently the aphanitic limestone underlying it, pebbles of such limestone being scattered throughout the formation.

Edinburg formation

Name. The Edinburg formation was named from the town of Edinburg in Shenandoah County, Virginia, by B. N. Cooper and G. A. Cooper (1946, p. 78); it has been identified within the limits of the Mount Jackson quadrangles by the above authors in their original work.

Limits. The lower boundary of the Edinburg formation is placed in general at the base of the lowest argillaceous calcarenite in the sequence; this corresponds to the top of the highest cherty limestone except in the northwest corner of the quadrangle.

Where the Oranda formation is present, the upper part of the formation is an even-bedded limestone and the upper boundary of the formation is drawn at the base of the cobbly limestone layer which forms the lower member of the Oranda formation. Where the Oranda formation is absent, in Page Valley, the upper Edinburg formation is a black shale and is overlain by the Martinsburg formation. Here the boundary is much less certain. In general the shales in the Martinsburg formation are brownish rather than black and the upper boundary of the Edinburg formation may be drawn at the top of the black shale sequence. In at least some cases the black shales are followed by a series of sandstone beds at the base of the Martinsburg.

Basal clastic member. In most localities the Edinburg formation can be divided into two members: a lower coarse-grained unit called the "basal clastic member" and an upper finer-grained, somewhat argillaceous unit called the "upper member". In some cases the basal member may be more argillaceous than the upper member.

The basal member is essentially a coarse clastic limestone, light- to dark-gray in color, and in every exposure decidedly nodular in character. The calcarenite ("lime sandstone") nodules are generally separated from one another by bands of shaly or silty material which are gray in fresh exposures but weather brown or reddish. Lithologically the clastic limestone of this unit is quite similar to the underlying

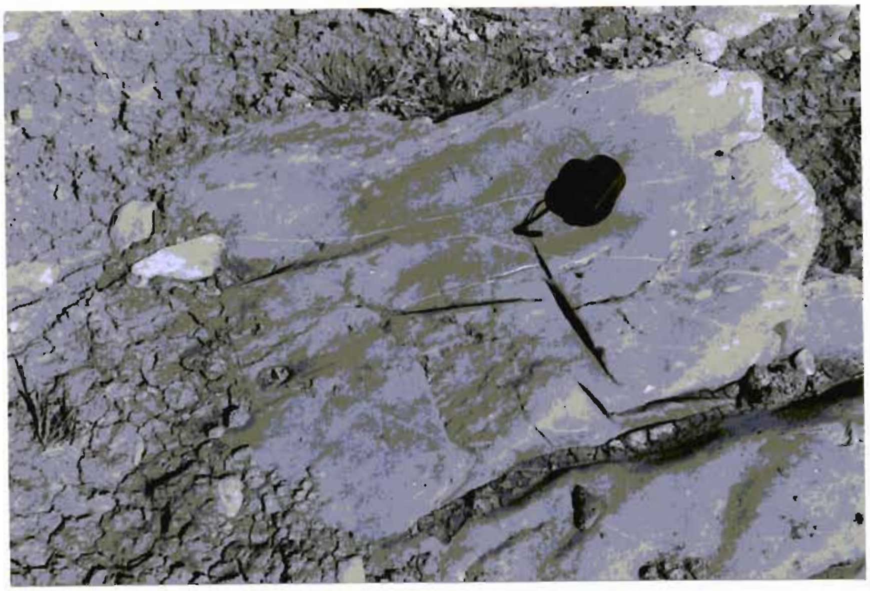
Lincolnshire limestone; it is distinguished from the Lincolnshire by being (1) coarser-grained, (2) lighter in color, (3) non-cherty, and (4) more argillaceous. The Lincolnshire is generally rather massive in character; where it is thin-bedded, it is generally not nodular. The basal clastic member is also somewhat more resistant to erosion than the Lincolnshire limestone, so that it generally occurs at the crest of the ridge underlain largely by the Lincolnshire. On weathering this basal member of the Edinburg formation generally breaks down first into a thin surficial layer of rubble composed of the calcarenite nodules which generally have a rusty color.

East of the Massanutten Range the top of this basal member is marked in many places by a pebble conglomerate, the pebbles composed of fine-grained limestone. West of the mountains a cobble conglomerate occurs about two miles west of the settlement of Athlone; the exact position of the conglomerate is uncertain, but the presence of a reddish shaly matrix makes it probable that the conglomerate belongs to the basal Edinburg rather than to the Lincolnshire.

The distinction between the Lincolnshire limestone and the basal clastic member of the Edinburg formation was discussed under the former formation and need not be repeated here. The upper boundary of the member, that is, the contact between the two members of the Edinburg formation, is actually easier to fix than the lower limit. The transition from the coarse calcarenite of the basal member to the fine-grained limestones of the upper member is generally abrupt and easily marked. In addition, in many exposures the calcarenites are separated from the argillaceous limestones above by a thin siltstone. This same siltstone has been recorded by both Edmundson and Cooper and Cooper within and beyond the quadrangle

a. Edinburg formation: typical outcrop of the basal member. Endless Caverns, Rockingham County.

b. Edinburg formation: weathered basal member, showing cobbly character. West of Forestville, Shenandoah County.



a. Edinburg formation: upper few feet of the basal member, showing its conglomeratic character. North of Hamburg, Page County.

b. Edinburg formation: shale facies at the base of the upper member. Endless Caverns, Rockingham County.

boundaries; in most such cases it was found to rest on a cobbly or nodular clastic limestone, the top bed of the "basal clastic member".

The above paragraph refers to areas in which the "basal clastic member" is overlain by limestones, as in most exposures west of the mountains. East of the Massanutten Range, however, and in the southern portion of the part of the Shenandoah Valley included in the quadrangle, the basal member is overlain by shales instead of limestones.

Upper member. The "upper member" of the Edinburg formation makes up the greater part of the formation in all areas studied. Most of the changes in facies which are characteristic of the formation occur within this upper member, whereas the lithology of the basal member appears to be notably unaffected by changes in the lithology of the overlying strata.

Cooper and Cooper have recognized two facies within this upper member (1946, p. 78):

> "One facies is composed mainly of black limestone and black shale, for which the name Liberty Hall facies of the Edinburg formation is proposed....The name Lantz Mills facies of the Edinburg formation is proposed for the contrastingly cobbly to nodular, buff-weathering limestone....."

Within the area of the Mount Jackson quadrangle, according to Cooper and Cooper, the formation is represented almost entirely by the Liberty Hall facies.

In practice it was found to be quite difficult to distinguish between the two facies. On the west side of the Massanutten Range the problem resolved itself into one of distinguishing between cobbly and non-cobbly black aphanitic limestones, since shale does not occur to any great extent anywhere except near the southern edge of the map. The limestones do not consist of two distinct types (cobbly and non-cobbly), but rather

a. Edinburg formation: limestone facies of the upper member. At Cedar Grove Church between Mount Jackson and New Market, Shenandoah County.

b. Edinburg formation: interbedded limestone and shale near the base of the upper member. East of Forestville, Shenandoah County. Strata dipping east.

appear to consist mostly of a wavy-bedded type that is intermediate between the two types mentioned above. For this reason the terms Lantz Mills and Liberty Hall facies will not be used in this paper.

This should not be interpreted to mean, however, that no change in facies exists within the upper Edinburg formation. Such changes are quite marked, although they are not strickly comparable to those outlined above. There are two distinct lithologic types included within this upper member of the formation: a black wavy-bedded limestone and a black shale. The limestone facies forms the bulk of the upper member within the Mount Jackson quadrangle; north of New Market and west of the North Fork of the Shenandoah River it could be said to compose almost the entire upper member.

The limestone facies is composed of black, mostly fine-grained, wavy-bedded argillaceous limestones that weather to a white or buff color; locally thin beds of argillaceous material are intercalated with the limestones, but this material is not shaly. The bedding ranges from even to cobbly, with the intermediate wavy type of bedding dominant. The grainsize of the limestones is also subject to some variation: local lenses of calcarenite may occur at almost any horizon; they are often quite fossiliferous, although the fossils are generally fragmental.

The shale is said to be black in fresh exposures of this facies; such exposures are the exception rather than the rule, however, and the shale is generally found to have a decidedly pinkish color, especially west of the Massanutten Range. Texturally it is not a pure shale, but rather appears to be intermediate between a shale and a siltstone. Within the Mount Jackson quadrangle west of the Massanutten Range the shale facies occurs near the base of the formation; its thickness is not great in comparison to that of the limestone facies above it.

The facies rather than formational character of this shale body is well shown by the great lateral extension of several thin tongues of the shale which reach far into the limestone facies; such tongues are usually only a few feet thick at the most and in all cases they occur just above the beds here assigned to the "basal member". Such thin beds have been observed at almost every exposure of the lower part of the upper member within the area mapped. That such tongues extend even beyond the boundaries of this quadrangle is shown by a brownish-buff shaly siltstone in the lower part of the Edinburg formation at Tumbling Run south of Strasburg, in Shenandoah County (Cooper and Cooper, 1946, section 20); the "argillaceous fine-grained sandstone" described from Frederick County by Edmundson may also represent this same siltstone tongue (Edmundson, 1939, p. 99).

East of the Massanutten Range the character of the upper argillaceous member is somewhat different. The shale facies is not restricted to the base of the member here as it is west of the range, but rather comprises the greater part of the member. The shale here is definitely black in color; on weathering it becomes yellowish rather than pinkish. Intercalated within this shale sequence are layers of black argillaceous limestone from one inch to several feet thick which increase in importance to the northeast. In most cases this limestone is the Liberty Hall-type limestone, i.e., it is evenly-bedded, but wavy-bedded or even cobbly limestones are not uncommon. Southwest of Newport the limestone facies fades into insignificance in Page Valley.

In all sections in Page Valley the upper limit of the Edinburg formation is almost impossible to mark. The Oranda formation is absent here and the black shales of the Edinburg formation merge upwards into the black and gray shales of the Martinsburg formation. In some and perhaps

a. Edinburg formation: limestone facies of the upper member, showing cleavage (vertical) and bedding. On Shenandoah-Rockingham County line south of Forestville.

b. Edinburg formation: limestone facies near the base of the upper member. North of Hamburg, Page County.

a. Edinburg formation: interbedded limestone (dark) and shale (light) in the upper member. West of Hamburg, Page County.

b. Edinburg formation: limestone facies (on right) passing upward into the shale facies. West of Alma, Page County.

all areas the presence of some sandy beds at the base of the Martinsburg makes it possible to draw some sort of boundary between the two. It has been suggested that such sandy beds are the equivalent of the Oranda formation west of the range (Cooper and Cooper, 1946, pp. 88-89).

Distribution and thickness. The Edinburg formation is present both east and west of the Massanutten Range, but, as indicated above, the lithology of the formation is quite different on opposite sides of the mountains.

In Page Valley the formation is limited to a single belt of outcrop which lies to the west of that of the Lincolnshire limestone. The "basal clastic member" is present in many but not in all exposures of the formation; the thickest development of this member in this area occurs about one mile north of Hamburg, where the member is 50 feet thick. Along Mill Creek the thickness is 28 feet and southwest of Grove Hill the thickness is 20 feet. The upper member of the formation is composed largely of black shale southwest of Newport; northeast of Newport limestone becomes more important, however, and good exposures of the interbedded limestones and black shales can be seen along Virginia Highway 12 and in the small quarry north of the highway west of Alma, and along U. S. Highway 211 just east of the South Fork of the Shenandoah. The total thickness of the formation in Page Valley is uncertain due to the lack of a definite contact between it and the Martinsburg formation; along Cub Run the estimated thickness of the Edinburg is about 1500 feet.

West of the Massanutten Range the formation is largely composed of the limestone facies, and its distribution closely parallels that of the New Market and Lincolnshire limestones. The basal member is well-exposed in most sections and ranges from 32 to 120 feet, with a definite increase in thickness to the northwest.*

No measurement of the thickness of the upper member was found possible in the area mapped; in every section where both top and bottom of the formation are exposed the formation is complicated by minor folding. One section was measured by Cooper and Cooper within the quadrangle near Cedar Church, just east of U. S. Highway 11 south of Mount Jackson (Cooper and Cooper, 1946, section 22). The lower 475 feet of this section is covered, however, and exposures down the strike of the formation show that there is considerable minor folding within this covered interval and above it as well. In addition, the Lincolnshire limestone which supposedly marked the base of the section could not be found even after intensive search and is not reported by Edmundson in a section measured by him at this same locality (Edmundson, 1945, section 41). The thickness of the formation here is probably closer to 400-500 feet and thus similar to that north of the quadrangle.

The shale facies west of the Massanutten Range occurs only in the Endless Caverns anticline and in the southern part of the New Market belt of outcrop; at its greatest development near Endless Caverns this facies has a thickness of about 150 feet.

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*It was recognized both by the writer and by John Rodgers that this increase in thickness of the basal Edinburg formation is complimentary to a decrease in thickness of the Lincolnshire limestone. There would appear to be a strong possibility that the Lincolnshire limestone and the basal Edinburg formation are facies of one another, which was one of the reasons for including the basal Edinburg with the New Market and Lincolnshire limestones on the geologic map. In the northwestern part of the quadrangle, furthermore, the separation of the Lincolnshire from the basal Edinburg formation is quite difficult. It is quite possible that such a facies change could account for the disappearance of the Lincolnshire limestone northward into Maryland and Pennsylvania (Neuman, 1951).

Correlation and age. The Edinburg formation includes the beds called the Liberty Hall limestone by H. D. Campbell (1905, p. 447) and probably also a part of the beds which the same author placed in the Murat limestone. In Darton's classification the Edinburg would probably fit in part into the Shenandoah limestone and in part into the Martinsburg shale; that is, the limestone facies would probably have been called part of the Shenandoah limestone and the shale facies part of the Martinsburg shale. The Edinburg formation includes both the emended Chambersburg limestone and the Athens shale as mapped by Butts (1940, pp. 159, 195), Butts and Edmundson (1939, p. 169), and Edmundson (1945, p. 17), the Athens shale being essentially the Liberty Hall facies and the Chambersburg limestone the Lantz Mills facies.

The basal member of the formation is probably equivalent to the Whitesburg limestone of Butts and Edmundson (Butts, 1940, p. 154; Edmundson, 1945, p. 17) and to the Botetourt member of the Edinburg formation as named by Cooper and Cooper (1946, p. 80). There is a persistant tendency on the part of these authors to recognize the Whitesburg or Botetourt unit only in areas where it is overlain by the shaly facies of the Edinburg formation (Liberty Hall facies, "Athens" shale) (Edmundson, 1945, p. 90). Beds of lithologically similar character are present, however, at the base of the limestone facies of the Edinburg formation as well as at the base of the shaly facies and have been reported in a number of measured sections by Butts, Edmundson, and Cooper and Cooper (e.g., Butts, 1940, section 48, bed 6; Edmundson, 1945, section 40, beds 2 and 3; Cooper and Cooper, 1946, section 20, beds 4 and 5). Because these beds are not called the Botetourt member by Cooper and Cooper, who named that unit, the name "lower clastic member" is used here.

Prominent fossils in the Edinburg formation include _Nidulites pyriformis_ Bassler and _Echinosphaerites aurantium_ (Gyllenhal) in the limestone facies and various species of _Climacograptus_ and _Diplograptus_ in the black shale facies. The lower clastic member is rich in trilobite fragments, probably the most abundant of which is _Arthrorhachis elspethi_ Raymond; calyces of _Echinosphaerites_ are also commonly abundant.

The age of the Edinburg formation is Black River for the most part (Cooper and Cooper, 1946, p. 86), although the uppermost part of the formation may be Trenton in age.

Origin. The sedimentary rocks of the Edinburg formation represent the initial deposits formed during the Taconian revolution which reached its maximum late in the Ordovician Period. This initial uplift was centered in a region to the southeast of the Mount Jackson quadrangle, since the shale facies which represents the uplift increases in importance in this direction. The shale facies is replaced to the northeast and northwest by limestones; southwestward the limestone facies is not encountered again until one reaches southwestern Virginia. Evidence of this uplift is not limited to the shale facies, however; argillaceous, presumably terrigenous material is found in the limestone facies as well and is characteristically present in the lower clastic member of the formation. The limestone facies of the formation represents deposits formed at the same time as the black shales, but at a greater distance from the source of this detrital material. The axis of the trough of deposition in Edinburg time probably lay to the west of the present area. The presence of a conglomerate at the top of the lower clastic member is interpreted as due to local erosion at a depth just above the base level of deposition; the lime sands west of the Massanutten Range for the most part lay below this base level and were not disturbed by later wave action. Uplift to the southeast was apparently sporadic, the siltstone layer at the top of the lower clastic member indicating one minor pulse that was followed by quiescence and attendant deposition of limy sediments.

Oranda formation

Name. The Oranda formation was named by B. N. Cooper and G. A. Cooper from the hamlet of Oranda in Shenandoah County, Virginia (Cooper and Cooper, 1946, p. 86). Use of the name was extended into the Mount Jackson quadrangle by the above-mentioned authors in the original paper.

Limits. The Oranda formation is distinguished from the underlying Edinburg formation by the cobbly character of its limestones and the base of the formation is thus drawn at the base of the cobbly limestone layer. The Oranda is distinguished from the overlying Martinsburg formation by the argillaceous character of its limestones and the calcareous nature of its shales; that is, the shales in the Martinsburg are usually black and non-calcareous where these overly the Oranda formation, while the local limestones in the Martinsburg formation are not shaly. The top of the Oranda formation is thus drawn at the top of the shaly limestone in the upper Oranda formation.

Character. In all of its outcrops within the quadrangle the Oranda formation is composed of two members. The lower member is a nodular, gray, finely crystalline impure limestone interbedded with which are lesser amounts of gray calcareous siltstone or shale. On weathering this lower member takes on a yellowish color and in general breaks down to a rubble of limestone cobbles, the shale layers being much weaker than the limestone

a. Oranda formation: lower cobbly member. South of Cedar Grove Church, Shenandoah County.

b. Oranda formation: upper shaly member. South of Cedar Grove Church, Shenandoah County.

nodules. This lower member in general is unfossiliferous or poorly fossiliferous. The limestone nodules are composed of fine limestone sand and often the grains include fragments of fossils, especially crinoid stem plates, but well-preserved identifiable forms are lacking.

The upper member of the Oranda formation, though generally thinner than the lower one, is the more conspicuous of the two in outcrop, since it is more resistant to weathering. It is essentially a very shaly gray limestone, the calcium carbonate content again being in the form of calcite sand. Although resistant to weathering, this upper member appears to be less resistant to tectonic forces than the lower member and in almost all exposures it has a well-developed cleavage superimposed on it, making determination of the attitude of the actual bedding surfaces difficult. On weathering the upper member takes on a rusty color and breaks down into slabs and chips that make it rather easy to trace the formation across the area. Fossils are quite common or even abundant in this upper unit.

Topographically the formation is generally expressed by a low ridge held up mainly by the upper member; the ridge generally stands only a few feet above the surrounding area, but its persistance makes it easily recognizable.

Distribution and thickness. The Oranda formation is limited entirely to the area west of the Massanutten Range within the Mount Jackson quadrangle. Exposures of the formation have been found east of the Massanutten synclinorium in Clarke County, northeast of the area here described.

Exposures of the Oranda formation have been noted locally along the western limb of the Endless Caverns anticline, but in most places the formation has been cut out by faulting.

The best exposures of the formation are along the eastern limb of the Mount Jackson anticline. At Cedar Grove Church southwest of Mount Jackson the formation is exposed in a cut along State Road 616. The formation has a thickness of 55 feet here:

Geologic section 1. Along State Road 616 east of Cedar Grove Church

Martinsburg shale (Thin fissile brown shale)
Oranda formation (55 feet)
2. Limestone, shaly, finely crystalline, dark gray to black, fossiliferous. . . . . 18 feet
1. Limestone, nodular, compact, finely crystalline, dark gray to black, with thin wavy intercalations of dark gray limy shale. . . . . 37 feet
Edinburg formation (Thin-bedded cobbly limestone)

About one-half mile southwest of Cedar Grove Church is another section of the formation, this one considerably thicker:

Geologic section 2. Along farm road east of U. S. Highway 11 and about one-half mile southwest of Cedar Grove Church

Martinsburg shale (thin-bedded brown fissile shale)
Martinsburg shale ? (12 feet)
4. limestone, black, fine-grained, thin-bedded, weathers light gray; interbedded with thin dark shales . . . . 12 feet
Oranda formation (74 feet)
3. Limestone, dark gray, finely crystalline, shaly, weathers yellowish; contains Sowerbyella, Christiania, Reuschella . . . . 40 feet
2. Shale, yellowish-gray, calcareous, interbedded with nodular black very fine-grained limestone. 22 feet
1. Limestone, dark gray, medium-grained, nodular, slightly crinoidal, interbedded with thin gray shale . . . . 12 feet
Edinburg formation (Thin- and wavy-bedded black limestone)

Other good exposures in this same belt occur just east of U. S. Highway 11 along the entrance road to Endless Caverns and along State Road 608 which leads from U. S. Highway 11 to Athlone. The thickness averages about 50 feet.

West of the Mount Jackson anticline the Oranda formation has been involved in a series of rather tight folds and the cleavage developed in the formation as a consequence of this deformation makes any determination of its thickness difficult.

Correlation and age. The Oranda formation is essentially the same as the Christiania bed at the top of the Chambersburg of Butts and Edmundson (Butts, 1940, p. 197); in addition, however, it may include some beds of slightly greater age below the Christiania bed.

The abundant fossils found in the formation have made correlation with the Shoreham limestone of New York possible; this latter formation and, consequently, the Oranda formation as well are lower Trenton in age.

Origin. The Oranda formation represents a rather abrupt transition from the limestones of the Edinburg formation to the shales, siltstones, and sandstones of the Martinsburg formation. The initial stages of the Taconian revolution which had taken place during the deposition of the Edinburg formation were relatively mild; with the close of Edinburg time, however, diastrophism seems to have become more violent and more widespread, with the resultant large-scale areal transition from limestone to detrital deposition.

Martinsburg formation

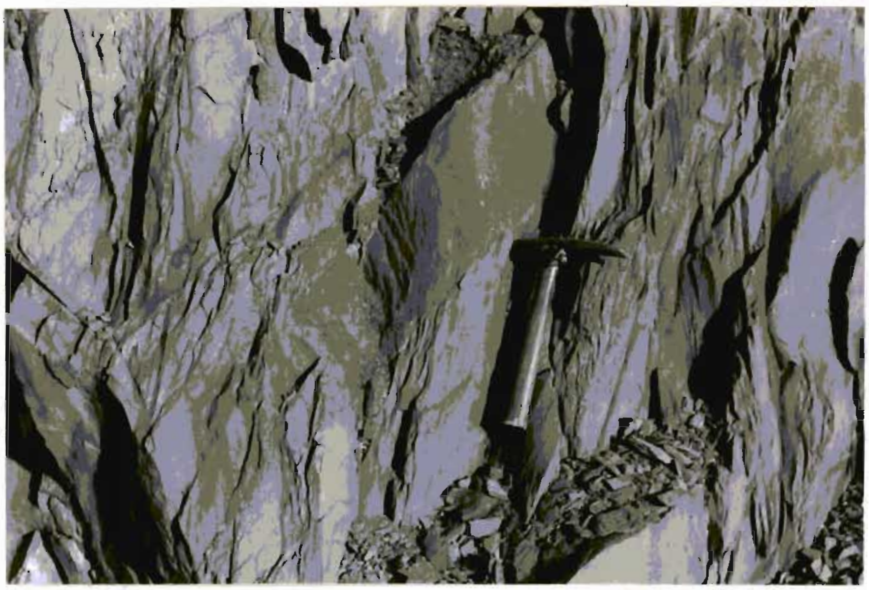
Name. The name "Martinsburg" was first applied to this formation by H. R. Geiger and Arthur Keith (1891, p. 161); the name is taken from the town of Martinsburg, West Virginia. The formation in the type area is a shale and the original name is thus "Martinsburg shale"; in the Mount Jackson quadrangle it is more heterogeneous and is called the "Martinsburg formation" instead.

Limits. The lower boundary of the Martinsburg shale is placed at the top of the black shale sequence in Page Valley and at the top of the shaly limestone in the Oranda formation in Shenandoah Valley. The top of the formation is marked by the gradation from brown shale and sandstone to the brown sandstones of the Cub sandstone.

Character. The lower part of the Martinsburg formation differs on opposite sides of the Massanutten Range; the lower part, however, is the only part showing this change in facies.

West of the mountains the lower several hundred feet of the formation consist of black shales interbedded with black limestones. The character of this western facies of the lower Martinsburg is extremely similar to that of the black shale facies of the Edinburg formation, which lies to the east of the mountain. The limestone is quite argillaceous, grading in many places into a calcareous shale. In the absence of the Oranda formation the separation of this lower Martinsburg lithology from the Edinburg formation would probably be quite difficult, and it is thus on the presence of the Oranda formation west of the mountains that the Edinburg and Martinsburg formations are separated. In sheared zones, as along the Lincoln Hill fault, the two formations become even more similar; in this case, since the Oranda formation has locally been removed by faulting, the recognition of the fault becomes more difficult.

East of the Massanutten Range the character of the lower part of the formation is greatly changed. Here, instead of black shales and limestone, the strata consist of black shales and argillites interbedded with rather thick beds of sandstone. The sandstone layers in this assemblage are generally dark gray to brown in color, depending upon the amount



a. Martinsburg formation: lower sandstones and siltstones. Note the almost vertical cleavage. Between New Market Gap and Hamburg, Page County.

b. Martinsburg formation: lower sandy beds. Cleavage dipping east, toward observer; bedding nearly vertical. Along Cub Run, Page County.

of weathering to which they have been subjected; they are notably more resistant rocks than the shales and argillites and form minor ridges. The sandstone appears to be a graywacke, composed largely of detritus from pre-existing sediments that lay to the east of the Massanutten synclinorium. The shales and argillites have been greatly cleaved, so that most of this finer-grained material has more the character of a black slate than of a shale or argillite.

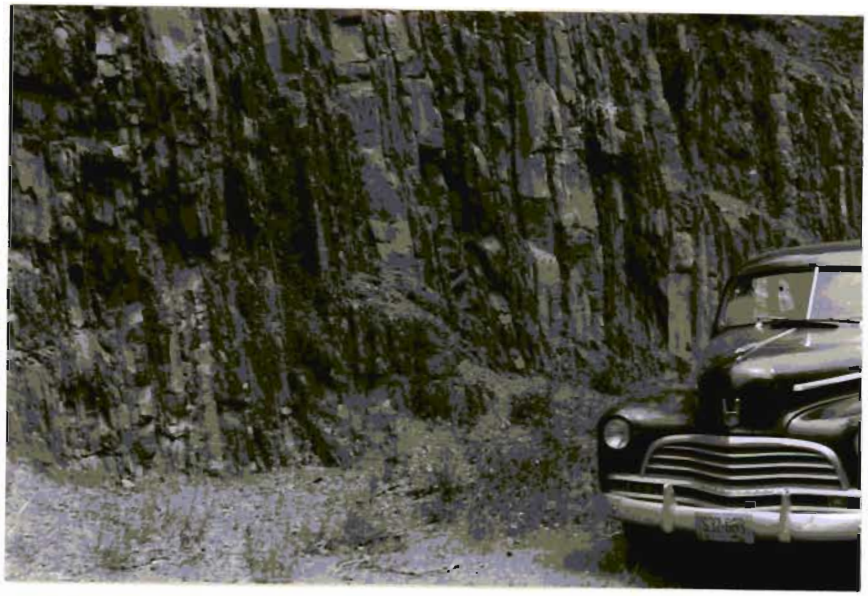
Above this lower part of the formation both east and west of the mountains lies an apparently thick sequence of interbedded sandstones and shales. Normally the sandstone is dark-gray on fresh exposures, weathering to a light brownish color. It is a coarse- to medium-grained low-rank graywacke. In some cases the sandstone is brown even on fresh surfaces; this brown sandstone is also a graywacke, but it is more silty, finer-grained, and softer than the gray sandstone. In fresh exposures the shale is pearl-gray in color. Before it is weathered, no primary fissility or lamination is observable, although the rock yields readily to deformation, resulting in the development of prominent slaty cleavage. On weathering the shale becomes brown and soft. This weathering begins along bedding and joint planes, and in relatively fresh roadcuts the shale appears to consist of two kinds of lithology: brown shale about one inch thick along the bedding planes and gray shale between the bedding planes. Where the rock is cut by joints these brown weathered zones follow the joint planes as well, leaving the unweathered gray shales as blocks surrounded on four sides by the weathered zone. The distinction between the fresh and the weathered material is so sharp that the rock will normally break along the boundary between fresh and weathered rock. A distinct lamination can generally be seen in the weathered shale.

Above the sandstone-shale sequence the formation is composed of a much thicker series of yellowish and brownish siltstones, claystones, and shales that extend to near the top of the formation. This material is rather weak in character, and is much cleaved; even in rather recent road cuts the material has been extensively weathered and is quite soft.

Near the top of the formation sandstones again appear, increasing in importance upward until the Cub Sandstone appears just above the Martinsburg formation.

Distribution and thickness. The Martinsburg formation is restricted largely to the parts of the quadrangle within and on the flanks of the Massanutten Range. Thus it appears in a broad belt along the eastern and western flanks of the Massanutten synclinorium, below the crests of Short, Kerns, First, and Massanutten Mountains. It is also exposed in the anticlinal valleys leading northeast and southwest from New Market Gap, in the gorge of Pitt Spring Run in the southern part of the range, and along the axis of the cross-fold at New Market Gap. West of the mountains the lowermost beds of the formation may be included in the minor synclines near Forestville and in the last syncline to the northwest of that town.

The thickness of the formation is unknown. It has not been possible to measure the thickness of the formation anywhere within the synclinorium in this quadrangle or, thus far, in the adjacent quadrangles. Based on its narrowest belt of outcrop in the Mount Jackson quadrangle, south of Endless Caverns, the thickness is probably about 1000 feet. Because of structural complications in this region, however, this thickness may be too small and the formation may be as much as 3000 feet thick. It seems probable, moreover, that its thickness is greater east of the mountains than to the west.



a. Martinsburg formation: upper sandstones and shales. Along road east of Catherine Furnace, Page County. Strata overturned, dipping east.

b. Cub sandstone: typical lithology as exposed in the type section. Locality same as above.

Age and correlation. The age of the Martinsburg formation is given by Butts (1940, p. 209-213 as Trenton to Maysville. No diagnostic fossils were found in the formation in the Mount Jackson quadrangle with the exception of a fragment of a cryptolithid trilobite found by John Rodgers near the top of the formation along Cub Run.

The formation appears to be equivalent to the Trenton limestone and Reedsville shale of the southwestern part of the state.

Origin. The Martinsburg formation appears to represent a vast deltaic accumulation of detritus poured into the Appalachian trough from a rising landmass to the east. The sediments become coarser to the east, and westward more marine zones appear. These sediments represent detritus shed westward from the rising Taconian folds in the Piedmont to the east. This uplift began during Edinburg time, as is indicated by the appearance of black shales in the latter formation. Increased intensity of the deformation or westward migration of the axis of the deformed area is indicated by the more westward extent of the detrital sediments in the Martinsburg formation. Thus, the black shale facies of the Edinburg reappears in the Martinsburg formation, but farther to the west and to the north, while the black shale facies in the Edinburg is overlain by still coarser material.

Cub sandstone

Name. The name "Cub sandstone" is here proposed for the fine-grained sandstone unit that lies between the Martinsburg formation and the Massanutten sandstone in the Massanutten synclinorium. The sandstone is named after Cub Run, a tributary to the South Fork of the Shenandoah River, which flows westward out of the southern part of the Massanutten range. The type section of the formation is along National Forest Road 65, which parallels Cub Run, just east of Massanutten Mountain.

Limits. The upper boundary of the formation is quite distinct; it is placed at the base of the massive white orthoquartzites of the Massanutten sandstone. The lower boundary of the formation is less easily distinguished. The formation is underlain by the soft siltstones and interbedded siltstones and shales of the Martinsburg formation; the lower boundary is drawn at the top of the highest shale sequence of any appreciable thickness in the Martinsburg formation.

Character. The Cub sandstone is composed largely of brown or olive-colored fine-grained low-rank graywacke with minor amounts of siltstone and scattered intercalations of thin shale. In the type section the sandstone comprises about 87% of the formation, the siltstone 2%, and the shale 11%. The sandstones locally contain cross-bedding of the low-angle lenticular type. In most of the places where the formation is exposed it is deeply weathered and its true character is often difficult to distinguish.

The type section of the formation is given below:

Geologic section 3. Along National Forest Road 65 just east of Catherine Furnace

Massanutten sandstone		
20. White pebbly orthoquartzite		
Cub sandstone		
19. Sandstone, orange, friable; contains chips of olive-gray shale up to 1.5 inches in diameter. .	4 ft.	7 in.
18. Siltstone, olive, blocky; weathers light olive-brown	0	7
17. Sandstone, orange to red, fine-grained.	2	5
16. Sandstone, mottled orange and olive, hard; weathers to spheroidal boulders	1	3
15. Sandstone, brown, fine-grained; weathers to spheroidal boulders	1	8
14. Sandstone, green to brown, fine-grained; weathers blocky	2	4
13. Shale, sandy, olive-colored; weathers pinkish .	0	5
12. Mudstone, olive-colored, micaceous.	0	5

		ft.	in.
11.	Sandstone, brown, fine-grained, blocky.	6 ft.	8 in.
10.	Shale, olive-brown, sandy and micaceous	0	10
9.	Sandstone, olive-brown, spotted with orange . .	1	10
8.	Shale, orange-brown, micaceous.	1	11
7.	Sandstone, greenish, fine-grained	0	3
6.	Shale, olive-gray, fissile; weathers gray with orange spots	1	1
5.	Sandstone, greenish and brownish, slabby or blocky, locally cross-bedded.	11	4
4.	Sandstone, olive-brown, fine-grained; contains concretions of limonite	0	10
3.	Shale, olive.	0	2
2.	Sandstone, orange to olive, fine-grained. . . .	2	3
Martinsburg formation			
1.	Interbedded shale and sandstone		

Distribution and thickness. The Cub sandstone is limited to the ridges of the Massanutten Range; its best exposures are in the southern part of the range, however. Besides the type section, other sections are exposed along Pitt Spring Run west of Catherine Furnace.

The thickness of the formation appears to be rather constant; it is about 40 feet.

Age and correlation. The Cub sandstone underlies the Massanutten sandstone, which is Early Silurian (Medinan) in age and overlies the Martinsburg formation which appears to be at least in part of Late Ordovician (Cincinnatian) age. The age of the Cub sandstone appears to be Late Ordovician or Early Silurian.

Elsewhere in the Appalachians of western Virginia the strata between the Martinsburg shale and the Tuscarora (lower Massanutten) sandstone belong to two formations, the Oswego sandstone and the Juniata formation (Butts, 1940, pp. 219-229). It seems quite probable, then, that the Cub sandstone is equivalent at least in part to one or both of these formations. Lithologically it is quite similar to the Oswego sandstone, a greenish iron-speckled sandstone. The Juniata formation is composed of red sandstones and siltstones that appear to have been derived from the east; it seems to be quite improbable that such a red formation would become less red in color as its source area is approached. If the Cub sandstone were equivalent to the Juniata formation, not only would such a change have to take place, but a hiatus would exist between the Cub sandstone and the Martinsburg shale; actually the passage from Martinsburg to Cub is a gradational one.

The Cub sandstone may, on the other hand, be equivalent to the Orthorhynchula linneyi sandstone which has been noted at many places at the top of the Martinsburg shale. According to Butts (1940, p. 208), this Orthorhynchula bed can be traced continuously from central Pennsylvania southward into Tennessee. No specimens of Orthorhynchula linneyi (James) were found in the sandstone in the Massanutten Range, but fossils would become less common in the formation as it is traced eastward towards the rising landmass formed by the Taconian disturbance.

Origin. The tendencies towards increase in grainsize with decreasing age which were noted in the Edinburg and Martinsburg formations below the Cub sandstone are continued into the Cub sandstone, which represents the coarsest detrital sediment deposited in the area of the Massanutten synclinorium during the Ordovician Period. Thus, it represents still greater uplift of the landmass to the east or a nearer source area than does the Martinsburg shale. The absence of the Oswego and Juniata formations above it would seem to indicate that the axis of uplift was being shifted to the west as the Ordovician Period progressed, until finally the eastern part of the present Appalachian Valley was uplifted sufficiently for the overlying formations to be removed by erosion if, indeed, they were ever deposited.

DISCONFORMITY

The most pronounced stratigraphic hiatus within the Paleozoic section in the Mount Jackson quadrangle occurs at the top of the Ordovician System. The youngest Ordovician formation that can be accurately dated is the Martinsburg formation, apparently of Maysville age. It is overlain by the Cub sandstone, which is probably also Maysvillian, and this is followed by the Massanutten sandstone, which belongs to the Silurian System. Thus, the formations which represent the Richmondian age elsewhere in the Appalachians of Virginia, i.e., the Juniata and Sequatchie formations, are absent, and apparently most, if not all, of the Oswego sandstone is unrepresented.

Westward these formations which are missing in the Massanutten Range are present in Little North Mountain, indicating that here also uplift was centered to the east.

At Harrisburg, Pennsylvania, Stose (1930) has described a similar hiatus, in which the Martinsburg formation is overlain by the Tuscarora sandstone. In this case, however, the relation is that of an angular unconformity, the Martinsburg formation having been folded and eroded prior to deposition of the Tuscarora sandstone. No such angular unconformity could be determined in the Mount Jackson quadrangle.

MASSANUTTEN SANDSTONE

Name and previous usage. The name "Massanutten sandstone" was first proposed by Keith and Geiger (1891); the sandstone was named after the Massanutten Range where, according to these authors, it is typically developed. At the time that the name was proposed, however, no type section of the formation was designated and there is no evidence in the original paper of any extensive work done in the area of the Massanutten Range, since the formation was first used in Northern Virginia. As originally defined, the Massanutten sandstone was supposedly underlain by the Martinsburg shale and overlain by the Newark group. However, it was later discovered that the lithologic unit originally called Massanutten sandstone in northern Virginia was involved in somewhat complicated faulting and that this unit is actually the Antietam sandstone of the Lower Cambrian (Wilmarth, 1938).

The next person who used the term Massanutten sandstone was N. H. Darton (1892, p. 14):

> "The Massanutten sandstone receives its name from the prominent Massanutten mountains in which it is typically developed...... White and red quartzites prevail.....The basal beds are alternating beds of dark sandstone and shale; these are succeeded by white and gray quartzites which in turn give place to thinner-bedded red and brown sandstones and shales."

Later, in the Staunton folio, Darton stated that the formation consists of an upper white or gray massive quartzite and a lower sequence of thinner-bedded red or brown sandstone or quartzite (Darton, 1894). Finally, in the legend to the geologic map in the Monterey folio, he sub-divided the Massanutten sandstone into three formations (Darton, 1899):

Cacapon sandstone
Tuscarora sandstone
Juniata sandstone

In 1896 the results of what appears to be the first extensive field-work in the Massanutten Range since the time of W. B. Rogers were published by A. C. Spencer (1896). Apparently in an attempt to make the formation in the Massanutten Range analogous to that mapped by Darton to the southwest, Spencer divides the formation into three members:

> "The lower member consists at the bottom....of very fine clay, but there is a constant increase in the size of grain upward until shale is replaced by micaceous sandy layers and these by coarser sandstone.....
>
> The shale which separates the two members is fine-grained and argillaceous.....
>
> The upper division.....is an indurated sandstone, composed entirely of well-washed and sorted quartz, in which cross-bedding is characteristic throughout. It is generally a sandstone of rather coarse grain....."

The term Massanutten sandstone was next used in the report on the manganese deposits of the region (Stose and Miser, 1922, p. 29). The authors of this paper state that "the white sandstone of Medina age and the underlying yellowish sandstones are together called Massanutten sandstone". However, at another place in that publication the white sandstone is called the Tuscarora sandstone (p. 96).

The latest usage of the term was by Dr. Butts (1940, p. 234), who writes that the formation includes beds of Clinch and Clinton age. In two measured sections (pp. 254 and 255) the Massanutten sandstone is described as a gray thick-bedded quartzite.

The term Massanutten sandstone has thus been used in a number of different ways. Much of the confusion over this unit in the early literature was probably caused by a lack of study of the type region of the formation, the Massanutten Range, prior to Spencer's work; Spencer then tried to make the formation in the type region fit the definition given to the formation outside of the type region. The present author cannot help but feel that if work in the type region had preceded rather than followed the work in the Staunton and Monterey quadrangles, the Massanutten sandstone would have been used as a white quartzose sandstone rather than as a sequence of red, brown and green sandstones. In the Massanutten Range the white massive quartzite is a prominent and persistant unit that is easily distinguished from the units underlying and overlying it. In this work the name Massanutten sandstone will be restricted to the unit so defined. It is a unit that is a product of distinctive conditions of sedimentation which differed from the conditions represented in the underlying and overlying formations; in addition, it is a mappable unit and is thus in accordance with most generally accepted definitions of a formation.

Since no type section of the formation has been given previously, a type section for the formation has been chosen on the east slope of Massanutten Mountain at Burners Gap, in the northern part of the Massanutten Range.

Limits. The Massanutten sandstone is easily distinguished from both the overlying redbeds and the underlying brown siltstones and sandstones. Both the upper and lower boundaries of the formation are quite sharp.

Character. The Massanutten sandstone is an excellent example of an orthoquartzite, that is, a quartz sandstone in which the grains are held together by a silica cement. Because of this siliceous cement the rock is very hard and is generally also rather light in color; in grain size it ranges from a fine-grained sandstone to a granule or pebble conglomerate. Sandstone is much more abundant than conglomerate in the formation, however, the conglomerate occurring as scattered lenses at various levels in the sequence, but most notably at the base of the formation. The sands are poorly stratified or, rather, the principal stratification of the formation is greatly complicated by cross-lamination which generally dips at a low angle relative to the main bedding surfaces.

In addition to the white to gray sandstones and conglomerates that compose far more than 99 per cent of the formation, thin layers of sandy siltstone or silty shale occur at various levels. These shale and siltstone bodies are lenticular in character and often pinch out completely within a distance of a few feet.

Complete sections of the Massanutten sandstone are by no means abundant because of the relative weakness of the overlying and underlying units as well as because in many places much of the formation is covered by its own sliderock. One good section of the formation was examined just east of Burners Gap, a not-too-prominent gap in the eastern ridge of the Massanutten Range northeast of New Market Gap. The exposure here is along a long-abandoned road down the eastern slope of the mountain and, with the exception of a few feet of poorly exposed material at the top of the formation, is quite complete. This section has been chosen as the type section of the formation:

Geologic section 4. Along abandoned road at Burners Gap

Bloomsburg formation (Lower 12 feet)	
22. Covered, with local exposures of reddish-brown sandstone.	12 feet
Massanutten sandstone (700 feet)	
21. Covered, with local exposures of white quartzitic sandstone	140
20. Orthoquartzite, white to buff, coarse-grained, cross-bedded, beds 1/2 to 2 inches thick; occasional bands of conglomerate 1 to 4 inches thick. Contains rather uncommon Arthrophycus and Scolithus	156
19. Sandstone, gray, shaly; contains nodules of fine-grained orthoquartzite.	1/2
18. Orthoquartzite, gray, fine-grained	1/2
17. Shale, brown, micaceous, shoepeg weathering. .	1
16. Sandstone, brownish-red, fine-grained.	1/4
15. Sandstone, pink, fine-grained.	3
14. Orthoquartzite, white, coarse-grained, cross-bedded	13
13. Shale, gray, sandy; contains 1-inch layers of sandstone; weathers purplish.	1
12. Orthoquartzite, white to buff, coarse-grained, cross-bedded.	26
11. Shale, gray, sandy	1/4
10. Orthoquartzite, white to buff, coarse-grained, cross-bedded.	4-1/2
9. Orthoquartzite, gray, fine-grained	1
8. Orthoquartzite, white to buff, coarse-grained, cross-bedded.	3

a. Massanutten sandstone: cross-bedded quartzite with thin siltstone layers. North of New Market Gap, Page County.

b. Massanutten sandstone: typical exposure of the quartzite. In Cub Run Gap, Page County. Strata overturned, dipping east.

7.	Orthoquartzite, gray, fine-grained.	1/4
6.	Orthoquartzite, white to buff, coarse-grained, cross-bedded	149
5.	Sandstone, gray, shaly; contains thin layers of quartzite	1
4.	Orthoquartzite, white to buff, coarse-grained, cross-bedded	156
3.	Shale, reddish-gray, sandy; weathers red.	1/4
2.	Orthoquartzite, white to buff, coarse-grained, cross-bedded	41
1.	Pebble conglomerate, white, quartzose	3

Cub sandstone (Brown friable sandstone)

Heavy mineral separations were made from samples of beds 15, 16, and 20, but the heavy minerals present are rather few. Most of the separates consist of leucoxene, hematite, zircon, and tourmaline; these constitute more than 92 per cent of the heavy minerals in each of the samples examined. In addition a few grains of staurolite, rutile, and hornblende were found. The mineral grains are for the most part quite angular; the zircon is quite strikingly euhedral and even the tourmaline grains show only slight modification of the original crystal outlines except by fracturing. A short description of each of the more common of these heavy minerals is given below:

Hematite - bright orange-red, sometimes translucent grains; grain boundaries generally irregular.

Leucoxene - white opaque irregular to rounded grains that sometimes appear to be pseudomorphous after some crystalline mineral of unknown identity.

Tourmaline - broken euhedral crystals that are pleochroic in brown, blue, and green; some grains show a color zoning from dark green at one end of the grain to light green at the other end.

Zircon - generally euhedral grains, composed of prism terminated on both ends by dipyramid faces; colors are white, light brown, and pink; some grains contain acicular inclusions of undetermined character; some grains are zoned.

Hornblende - subhedral slightly rounded grains that are light yellowish green in color.

Staurolite - angular to subangular equant grains pleochroic in yellow.

Distribution and thickness. The outcrops of the Massanutten sandstone are confined to the ridges of the Massanutten Range, after which the formation was named.

The topographic expression of this formation is certainly more striking than that of any other formation mapped. The Massanutten sandstone is the resistant bed which "holds up" the ridges in the Massanutten Range.

The thickness of the formation probably varies from 500 to 700 feet in most parts of the range. At the gap of Cub Run west of Newport the thickness was measured as 540 feet and just to the west along Pitt Spring Run the thickness was found to be 570 feet.

Correlation and age. As was pointed out above, the Massanutten sandstone was thought by Darton to be equivalent to the Juniata, Tuscarora, and Cacapon formations. There seems to be no very strong evidence that this correlation is correct, however. In the Massanutten Range the sandstone rests on the Cub sandstone and is overlain by the Bloomsburg redbeds and its stratigraphic range could include all of the formations listed by Darton as its equivalents. It is unlikely that the Juniata formation is represented in the Massanutten sandstone. The Juniata formation has been shown to be of non-marine origin; west of the Mount Jackson quadrangle the thickness of the Juniata increases eastward, seemingly indicating that the source of the Juniata sediments was to the east. A red continental formation would be quite unlikely to grade source-ward into a white sandstone.

It does seem probable, however, that both the Clinch-Tuscarora sandstone and the beds of the Clinton group are represented in the Massanutten sandstone. The situation here is analogous to that in eastern Pennsylvania, where the Shawangunk conglomerate has been shown by F. M. and C. K. Swartz (1931) to pass westward into the Tuscarora and Keefer sandstones, which are separated by the Rose Hill shales. That is, the Keefer and Tuscarora sandstones in Pennsylvania are tongues of the Shawangunk conglomerate that reach westward into the finer detritus of the Rose Hill shales. In Virginia the Tuscarora and Keefer are both present west of the Mount Jackson quadrangle, with the same stratigraphic relations as in Pennsylvania. A similar change of facies in Virginia may be inferred.

Supposed fossils found in the Massanutten sandstone are Arthrophychus alleghaniensis (Harlan) and Scolithus verticalis Hall both of which also occur in the Clinch-Tuscarora sandstone and possibly in the Keefer sandstone.

The Massanutten sandstone is thus thought to be equivalent to the Clinch-Tuscarora sandstone (Medinan series) and the Clinton group (lower Niagaran series).

Origin. The sands which now compose the Massanutten sandstone were spread out over a low coastal plain or into a shallow sea from the highlands formed to the east during the Taconian revolution. The interpretation of these deposits as beach deposits formed by a slowly retreating shallow sea seems to be accepted by most authors (Butts, 1940, p. 487; Woodward, 1932, p. 96; Dunbar, 1949, p. 188) and is indicated by the abundant development of cross-bedding of the non-eolian type throughout the formation. The Scolithus tubes and the peculiar trails called Arthrophycus are also the types of organic structures that might well be preserved in sandstones derived from littoral sediments.

The source of the sands presents somewhat more of a problem. The entire Massanutten sandstone, with the exception of a very few thin shale layers, is typical orthoquartzite. Such rocks have been grouped by Krynine (1941) into three genetic classes: first-cycle quartzites, second-cycle quartzites, and cleaned graywackes (Krynine, 1941). The first type is formed by the intense chemical decay of the crystalline source rock, resulting in the destruction of everything except the most stable minerals (quartz, zircon, tourmaline, rutile); the second type is derived from the first-cycle orthoquartzites; the third type is formed by the winnowing of a graywacke, leaving behind only the quartz. The Massanutten sandstone, or rather its partial equivalent, the Clinch sandstone, has been called a second-cycle orthoquartzite by Krynine. However, the presence of euhedral heavy minerals like the zircon and tourmaline described above are not what one would expect to find in a second-cycle orthoquartzite; in addition, the gradation of the formation westward, at least in part, into the Rose Hill shale is not what would be expected if the Massanutten sandstone were derived entirely from a pre-existing first-cycle orthoquartzite. The well-preserved crystalline shapes of these heavy minerals from the Massanutten sandstone indicate that they were derived from crystalline (igneous or metamorphic) rocks rather than from a pre-existing orthoquartzite, in which case the heavy mineral grains would be rounded rather than euhedral.

It is believed that during the early (Ordovician) stages of the Taconian revolution the Cambro-Ordovician sedimentary rocks were stripped off the crystalline core of the landmass formed as a result of this uplift. These crystalline rocks then underwent a rather extensive period of weathering to produce a thick mantle consisting of clays and other weathering products along with a rather large amount of extremely stable minerals (quartz, zircon, tourmaline). At the beginning of the Silurian this mantle was eroded and the sediments deposited in the shallow sea that occupied the Appalachian trough to the west. Here the sediments were reworked by marine agencies and the finer silts and clays were carried westward into the deeper parts of the trough, leaving behind the clean quartz sands of the Massanutten sandstone.

BLOOMSBURG FORMATION

__Name.__ The Bloomsburg formation takes its name from the town of Bloomsburg in Columbia County, Pennsylvania (White, 1883, p. 252), where it is well developed. Use of the name Bloomsburg in this quadrangle is based on the correlation of the upper Massanutten sandstone with the Clinton group. In its type locality the Bloomsburg is composed of the redbeds lying between the Clinton group and the Upper Silurian limestones. The name Bloomsburg has been used in the Massanutten Range by earlier workers as well (Bevan et al. 1938; Butts, 1940).

__Limits.__ The Bloomsburg formation is composed essentially of redbeds and is thus easily distinguished from the underlying white quartzites and the overlying limestones. Both the upper and lower boundaries are quite sharp.

__Character.__ The Bloomsburg formation is composed largely of red siltstones and sandstones with lesser amounts of green siltstones and green and red shales. Near the base of the formation are one or more beds of greenish-white orthoquartzite; only one such layer has been found in the Mount Jackson quadrangle, but several such sandstone layers occur to the north and northeast. A massive sandstone layer, apparently of similar character, is mentioned by Butts and Edmundson (1939, p. 171) as occurring near the top of the formation west of Little North Mountain in Frederick County. Otherwise the strata are all relatively weak; this, combined with the large

a. Bloomsburg formation: red siltstone beds near the base of the formation. In Crisman Hollow, Page County. Strata dipping to east.

b. Bloomsburg formation: white sandstone layer interbedded with red siltstones somewhat higher in section shown above.

amount of sliderock originating in the subjacent Massanutten sandstone, makes exposures of the Bloomsburg formation poor and, indeed, quite uncommon. Most of the characteristics of the formation described above are taken from a single exposure of the formation along National Forest Road 274; except for small, widely scattered outcrops elsewhere in the quadrangle, this is the only exposure of the formation in the area mapped.

F. M. Swartz (Bevan et al, 1938, pp. 25, 27) describes a sequence of green sandstones from 60 to 220 feet thick which overlies the Massanutten sandstone in the northern part of the Massanutten Range; these beds are correlated by Swartz with the Clinton formation. The exact reason for this correlation is not clear; the invertebrate fossils characteristic of the Clinton beds elsewhere in the Appalachians are absent in the Massanutten syncline and the only criterion for the correlation seems to be the presence of brown "iron" sandstones in this green sandstone sequence. Admittedly the green color of the sandstones would be as valid a criterion for distinguishing these beds as a formation as the color difference between the Massanutten sandstone and the Bloomsburg formation; the strata included in the "Clinton" of Swartz are not all green, however. Some red beds are said to occur in the "Clinton"; in the words of Dr. Swartz, "these beds are transitional between the Clinton and the Bloomsburg and are probably best considered as Clinton" (Bevan et al, 1938, p. 27). In the opinion of the present author, the fact that the Clinton into which these beds are supposedly transitional is represented only by the transitional beds outweighs the other factors, and the green sandstones above the Massanutten sandstone are here assigned to the Bloomsburg formation.

Distribution and thickness. The Bloomsburg formation is confined to the synclines of the Massanutten synclinorium; that is, to Duncan and Crisman

Hollows north of New Market Gap and to Catherine and Pitt Hollows south of the gap.

The formation is rather weak and forms a part of the slopes of the ridges in the range. Even the more resistant white quartzite layers are not important topographically.

No estimate of the thickness of the formation could be made in the Mount Jackson quadrangle, although it is at least 200 feet thick and perhaps as much as 600 feet. At the northern end of the synclinorium the thickness of the formations equivalent to the Bloomsburg formation in the Mount Jackson quadrangle is given by Swartz (Bevan et al, 1938, p. 24) as 425 to 675 feet. In Woodstock Gap in the northern part of the Massanutten Range the thickness of the Wills Creek and Bloomsburg formations (Bloomsburg formation of this dissertation) is given as 430 feet (Butts, 1940, geologic section 65).

Correlation and age. The Bloomsburg formation as used here includes beds which, elsewhere in the Massanutten synclinorium, have been called the Clinton formation, Bloomsburg sandstone, Wills Creek formation, and Indian Springs member of the Tonoloway limestone (Bevan et al, 1938, p. 24; Butts, 1940).

In Pennsylvania, where the regional Silurian relationships have been more thoroughly studied than in Virginia, the Bloomsburg redbeds have been found to grade westward into a sequence of limestones and shales (see Plate 28). A similar change in facies is thought to have taken place in Virginia. East of the Massanutten Range, if exposures of these formations still existed, the strata between the Catherine limestone and the Massanutten sandstone would all be redbeds. Passing westward into the Massanutten Range the upper part of this redbed sequence grades into the impure limestones of the Tonoloway limestone. In places within the range, but not within the Mount Jackson quadrangle, the Tonoloway limestone is underlain by yellow shales containing ostracods that are probably Leperditia elongata willsensis Ulrich and Bassler; these shales are equivalent to the Wills Creek formation which in Pennsylvania is also a facies of the Bloomsburg formation. The occurrence of this shale facies within the Mount Jackson quadrangle appears to be local. Still farther west, in Little North Mountain (Butts and Edmundson, 1939) the redbeds that overlie the Clinton group are in turn overlain by the Wills Creek formation and the Tonoloway limestone. Finally, at the northeastern end of Great North Mountain the basal Bloomsburg formation has passed into the limestones and shales of the McKenzie formation (Butts and Edmundson, 1939).

The age of the Bloomsburg formation in the Mount Jackson quadrangle is probably late Niagaran to early Cayugan, based on the facies changes and correlations cited above.

Origin. The Bloomsburg formation appears to be of non-marine origin; this is based both on the red color of the formation and upon certain minor features of the formation. The red color of the formation is due to the presence of ferric oxide, probably hematite, which indicates that the sediments were deposited under oxidizing conditions. Such oxidising conditions would be encountered more likely in non-marine than in marine environments. Many of the red siltstones and sandstones contain somewhat irregular, more or less vertical (with respect to the bedding) zones of green sediment. These rather narrow green zones are more or less cylindrical in cross section and extend down from the tops of the beds; they do not differ in any visible way from the red portions of the beds except in their color, which is probably due to local reduction of the iron in the sediment.

The shape of these structures suggests that they are the remains of plant roots which reached down into the silts and sands from above. No identifiable plant remains were found in the formation, although some of the green siltstone beds do show black, apparently carbonaceous markings on the bedding planes.

The exact form of the deposit is not so clear. The gradation of the formation westward into truly marine deposits indicates that the sediment was deposited in the transitional zone, and the formation most probably represents a deltaic coastal plain built westward from a landmass to the east into the shallow sea that then occupied the Appalachian geosyncline. Plant life was apparently rather abundant, at least locally and at various times during the building of the deposit. With the overflow of sediment-bearing streams, however, the parts of the plants above ground were swept away, leaving behind only the lower part of their root systems which were then buried by more sand and mud.

The problem of the origin of the Bloomsburg formation raises the problem of the origin of redbeds in general. Suggestions as to the conditions necessary for redbed formation have ranged from arid to extremely humid and from tropical to frigid. Source rocks for redbeds are known to include igneous, sedimentary, and metamorphic rocks. The red color has been considered at various times to be due to original red minerals, to red minerals of secondary origin formed in the source area, and to red minerals of secondary origin formed in the basin of deposition.

In the Bloomsburg formation the red color is due to hematite, which occurs both as a coating on the detrital grains and as part of the matrix. It is probably of secondary origin and was derived from a deeply weathered mantle in the source area. According to Krynine (1949, p. 61) such red soils will develop on silicate rocks under moist tropical or sub-tropical conditions with an average temperature of over 60° F. and a rainfall of more than 40 inches per year. A silicate source rock for the Bloomsburg is indicated by the large amount of quartz in the formation. Conditions in the basin of deposition were at least locally reducing, as indicated by the presence of some green layers in the formation. In all probability, however, deposition of the red sediments was so rapid that, unless a large amount of organic matter was incorporated in the sediment, the oxidized character of the iron was not altered.

UPPER SILURIAN-LOWER DEVONIAN LIMESTONES

Tonoloway (?) limestone

Name and usage. The Tonoloway limestone was named by E. O. Ulrich (1911, Pl. 28) and by G. W. Stose and C. K. Swartz (1912, p. 7) from Tonoloway Ridge in Washington County, Maryland.

The term "Tonoloway(?) limestone" is used here to designate a distinct rock unit at or near the base of the Siluro-Devonian limestone sequence. The Tonoloway(?) limestone in the Mount Jackson quadrangle is correlated with that in the type locality only on the basis of lithology, and it may be that we are dealing here with a lithologic facies rather than with a lithologic unit that has some constant relation to time horizons. However, since the term formation is used here as a mappable lithologic unit, this limestone can certainly be treated as a formation.

Limits. The lower boundary of the Tonoloway(?) limestone is generally marked by an abrupt change from red shales or siltstones to the platy limestones of the Tonoloway(?). The upper boundary, however, is less clearly marked, since the lithologic change involved is less radical. The upper boundary of the formation is generally drawn at the top of the upper bed of platy limestone in the limestone sequence. Thin layers of platy limestone may appear higher in the sequence, but they are definitely subordinate to the non-platy limestones of the overlying Catherine limestone.

Character. The Tonoloway(?) limestone is essentially a gray shaly limestone that weathers light-gray to white. The limestone is fine-grained to aphanitic and is often mud-cracked (Plate 29). This type of lithology is found at the base of the Siluro-Devonian limestone sequence wherever it is exposed in the quadrangle.

Distribution and thickness. The Tonoloway(?) limestone is confined to the valleys of the Massanutten Range, that is, to the synclines of the Massanutten synclinorium.

Good exposures of the formation are found along many of the streams in these valleys. North of New Market Gap the limestone is rather poorly exposed along National Forest Road 274 about five miles northeast of the gap. Other exposures occur along Passage Creek farther to the northeast, one seven miles northeast of the gap (Geologic section 13) and another south of the bridge over the creek on State Road 616. In Duncan Hollow these limestones are exposed in the streambed near the abandoned farmhouse shown on the topographic map and elsewhere along and above the stream between the house and the road. Near Moreland Gap the formation is again exposed along Mountain Run south of the house and cemetary which lie east of the gap.

In the southern part of the range the limestone outcrops along Pitt Spring Run near Catherine Furnace (Geologic section 4) and also along Roaring Run north of the furnace.

a. Tonoloway(?) limestone: typical exposure of laminated limestone. Along Pitt Spring Run west of Catherine Furnace, Page County.

b. Tonoloway(?) limestone: mudcracks on laminated limestone. Along Passage Creek west of Camp Roosevelt, Shenandoah County.

The thickness of the Tonoloway(?) limestone is probably about 50 feet, its thickness on Passage Creek seven miles from the gap. Elsewhere only incomplete sections (less than 50 feet thick) could be found. At Seven Fountains, a number of miles to the northeast in the Strasburg quadrangle, Swartz has reported a thickness of at least 290 feet for what appears to be the same formation (Bevan et al, 1938, p. 26).

Correlation and age. No fossils were discovered in the Tonoloway(?) limestone in the Mount Jackson quadrangle. Swartz reports a number of Tonoloway fossils from the limestone at Seven Fountains, however. Limestones of similar lithology are recorded by Butts (1940, geologic section 65) from Harsberger Gap to the southwest, where they contain fossils of Wills Creek age; the thickness of these limestones at Harshberger Gap is similar to that of the Tonoloway(?) limestone in the Mount Jackson quadrangle.

The age of these limestones, like their correlation, must remain in doubt until fossils are found in them. The work of Butts and Swartz would seem to indicate a Late Silurian age.

Origin. The presence of much shaly material in these limestone would seem to indicate a near-shore origin for them; the presence of mud-cracks would further indicate a rather shallow-water if not tidal-flat environment. The formation would appear to be composed of limy and argillaceous muds deposited on the floor of a shallow sea near a landmass of rather low relief.

Catherine limestone

Name. The name Catherine limestone is here proposed for the dominantly limestone unit that underlies the dark shales of the Romney group and overlies the shaly Tonoloway(?) limestone. The name of the formation is taken from Catherine Furnace, an abandoned iron furnace near the confluence of Pitt Spring and Cub Runs in the southern part of the Massanutten Range.

Limits. The lower boundary of the Catherine limestone is drawn at the top of the highest bed of platy limestone in the Siluro-Devonian limestone sequence. The upper boundary is more clearly marked: it is drawn at the abrupt change from the limestones to the gray-green shales of the Needmore shale.

Character. The general character of the Catherine limestone is well illustrated in the type section:

Geologic section 5. Along Pitt Spring Run a few hundred yards west of its junction with Cub Run, Page County.

Needmore shale	
11. Shale and claystone, olive-brown	
Catherine limestone	
10. Limestone, dark-gray, medium-grained, massive; contains stringers of black chert; weathers white. .	4 feet
9. Limestone, dove-gray, shaly; contains lenses of black chert; weathers light gray.	9
8. Covered.	8
7. Calcarenite, light-gray, coarse-grained; contains fragments of brachiopods and crinoid stems	6
6. Calcarenite, reddish-gray, medium-grained, cobbly. .	1/2
5. Limestone, gray, fine-grained, shaly	3-1/2
4. Calcarenite, pinkish-gray, coarse-grained.	10
3. Calcarenite, dove-gray, coarse-grained, with shaly partings	39
Tonoloway(?) limestone	
2. Limestone, dove-gray, aphanitic, with shaly partings; weathers buff.	25
1. Limestone, dove-gray, aphanitic, with irregular shaly partings	10

The formation consists mainly of fine- to coarse-grained limestones with minor amounts of shale anc claystone, though none of the latter are exposed in the type section. The limestone is generally light- to dark-gray in color; occasional layers colored brown, brownish-gray, greenish-gray, and olive-gray are present in the northern part of the range, however. The calcarenites or lime sandstones are usually medium- to fine-grained, with a light-gray color that may be modified locally to a pinkish tinge. Crinoid columnals and brachiopod shell fragments are common constituents of these calcarenites, and at some places fragments of shales and fine-grained limestones are also included. The limestones are generally impure and grade from limestone into mudstone with an increase in the amount of argillaceous material. These impurities may be dispersed throughout the rock, as generally in the green and brown limestones mentioned above, or they may be segregated into irregular bands separating nodular layers of limestone.

The mudstone and claystone beds in the formation are best developed in the northern part of the Massanutten Range; an especially good section showing this type of lithology is given as Geologic section 12. These detrital layers are generally greenish to brown in color, of very fine grain, and often calcareous.

One of the more unusual lithologic types present in the formation is a red sandy mudstone containing nodular layers of limestone one to two inches thick. In outcrop the mudstone commonly has a pitted surface due to the solution of the limestone nodules and because most exposures of the formation are found in the stream beds. Such features are not confined to the red mudstones, however, since the occasional beds of grayish mudstone may also contain similar limestone nodules. In addition the mudstones may contain thin lenses or layers of medium-grained calcarenite.

Distribution and thickness. The distribution of the Catherine limestone is essentially the same as that of the Tonoloway(?) limestone described above, in that it is confined to the synclines of the Massanutten synclinorium. It seems quite doubtful that the name Catherine limestone should be used in areas outside of this synclinorium, since in most other localities the various units included in the Catherine limestone can be recognized and mapped as separate units.

Good exposures of the Catherine limestone are not as abundant as those of the Tonoloway(?) limestone below. The best exposures are represented by the three measured sections of the formation: the type section along Pitt Spring Run, geologic section 13 along Passage Creek some seven miles northeast of New Market Gap, and geologic section 12 south of the bridge by which State Road 616 crosses Passage Creek. Other exposures may be found north of the house about 3/4 mile east of Moreland Gap and along Mountain Run in that same area.

The thickness of the formation appears to be about 80 feet in the sections along Pitt Spring Run and south of the bridge on State Road 616. However, along Passage Creek in Crisman Hollow the thickness is only 33 feet.

Correlation and age. The beds here called the Catherine limestone have generally been called Keyser limestone by previous workers (Bevan et al, 1938, p. 24, 26; Woodward, 1943). A number of fossils of Keyser age have been found in these limestones, including Chonetes jerseyensis Weller, Camerotoechia litchfieldensis (Schuchert), and Stromatotrypa globularis Ulrich and Bassler (?). In the section in Crisman Hollow, however, some Becraft or New Scotland fossils were found, including Spirifer concinnus Hall. The Catherine limestone is thought to include, at various places, correlatives of the Keyser limestone and of part or all of the Helderberg limestones.

The age of the Catherine limestone is thus somewhat doubtful. It is at least in part Early Devonian in age, since it is in part correlative to the Becraft limestone. If the Keyser limestone is placed in the Devonian following the work of Butts (1940, p. 273), then the entire Catherine limestone is of Devonian age. However, if the Keyser is equivalent to the Manlius limestone in New York, as has been suggested by recent work in that state, then the formation is in part Silurian and in part Devonian. This may cause some uneasiness among those geologists who prefer to think of formations as being time-stratigraphic units rather than stratigraphic units and who would thus favoe splitting the Catherine limestone into two formations separated by the Siluro-Devonian boundary. However, until that boundary problem is more definitely settled and until it can be shown that the Catherine limestone can be separated into two formations on a lithogenetic basis, the present author tends to favor the present usage.

Origin. The generally argillaceous and, in many cases, coarsely clastic character of the Catherine limestone seem to be indicative of relatively near-shore deposition of the material of which the formation is composed. That the water was shallow in addition is indicated by the presence of not uncommon mud-cracks in the shaly limestone layers. Further evidence of such a shallow near-shore environment may be found in the rather great variation in the thickness of the formation and in the different ages which may be assigned to it in different outcrops. Moreover the formation is variable in thickness and appears to include a number of minor disconformities as would be expected.

DISCONFORMITY

A third disconformity within the Paleozoic section can be recognized between the Catherine limestone and the Needmore shale. The youngest formation definitely included in the Catherine limestone is the "Becraft" or Licking Creek limestone, belonging to the upper Helderberg. Thus the Oriskany (Ridgeley) sandstone is absent in this part of the Massanutten Range, although it may be present farther to the northeast.

ROMNEY GROUP

The Romney group as used in this dissertation is synonymous with the Romney shale, which was named by N. H. Darton (1892, p. 17) from the town of Romney in Hampshire County, West Virginia. According to the original description of the unit, it included the "fissile shales, in greater part black or dark brown in color, containing occasional thin beds of sandstone and limestone" which lay between the Monterey sandstone below and the Jennings formation above.

The same term was used later by Stose and Miser (1922, p. 96) to refer to "fissile yellow to buff fossiliferous shale, black where fresh, containing fossils of Marcellus age" in Little Fort Valley in the Massanutten Range northeast of the Mount Jackson quadrangle.

Butts (1940, pp. 305-308) used the term Romney shale in a restricted sense, since the Onondaga shale had previously been separated from it as a separate formation. Butts further stated that the term "Romney shale" should be abandoned and replaced by the names Marcellus, Hamilton, and Naples formations. In the table of formations at the beginning of the 1940 bulletin (Butts, 1940, p. 23) the Romney is referred to as a group consisting of four formations:

Naples shale
Hamilton formation
Marcellus shale
Onondaga shale

It is in accordance with this interpretation that the term Romney shale is used in this dissertation; some of the formation names have been changed and the uppermost formation in the group is absent, but otherwise the same lithologic units are included:

Mahantango formation
"Marcellus" shale
Needmore shale

Other usages are possible, of course, and at least one of these has been used by F. M. Swartz (Bevan et al, 1936, p. 24), Swartz considers the entire group as a single unit and employs Darton's original term Romney shale for its designation. This usage has some advantages, since the units within the group are in most cases distinguished only with difficulty. Another alternative is to use the Romney shale as restricted by Butts; in this case the group would consist of the Needmore shale below and the Romney shale above. In mapping, this alternative has been employed, since it is almost impossible to separate the "Marcellus" shale and the Mahantango formation in most exposures. To the northeast where exposures are somewhat better and the rocks less closely folded, it has been possible to break the group down into three units for mapping purposes (Edmundson, 1950).

Needmore shale

Name. The Needmore shale was named (Willard, 1939, p. 149) from the town of Needmore in Fulton County, Pennsylvania. At the time when the unit was defined, however, no type section for the formation was given.

South of the Pennsylvania border the term has been used by Woodward (1943, p. 278) in West Virginia as equivalent to the unit called the Onondaga shale in Virginia (Butts, 1940, pp. 294-305); in addition, Woodward mentions one exposure of "fossiliferous green-buff Onondaga shale" along National Forest Road 274 south of Camp Roosevelt in the northern Massanutten Range, with the implication that this is the Needmore shale.

Although the name Onondaga shale has been used for some time to designate this shale unit in Virginia, continued usage of this name hardly seems warranted. In its type locality in New York the Onondaga is a limestone, not a shale, and use of the name Onondaga to designate this shale unit some 400 miles from the type Onondaga limestone is not advisable. The Needmore shale, on the other hand, is lithologically like the shale unit in the Massanutten Range, and the name Needmore shale will be used for this lower formation of the Romney group in this dissertation.

Limits. The lower boundary of the Needmore shale is quite sharp; it is drawn at the abrupt change from limestones to gray-green shales. The upper boundary is gradational and will be discussed in more detail in the section on the "Marcellus" shale below.

Character. The Needmore shale is in general a greenish or grayish-green clay shale, in most cases with only poorly developed fissility. Interbedded with this shale are beds of similarly colored soft claystone or mudstone which is distinguished from the shaly material by the total lack of fissility and the greater thickness of the claystone layers. On weathering, the Needmore rocks take on a pinkish or orange color and break down into small chips.

At many places beds of black shale like that in the overlying "Marcellus" shale are found; some have thought this to be the typical unweathered Needmore shale, which has been described as a black shale which is greenish-gray only where deeply weathered. These black shale zones can be seen interbedded with the more typical greenish shales along Passage Creek in Crisman Hollow however, and they are interpreted as local layers of black shale in the Needmore.

Distribution and thickness. The Needmore shale exposures are confined to the synclines of the Massanutten synclinorium. The thickness of the formation is not known with any certainty; probably a good estimate, however, would be 100 feet.

Topographically the Needmore shale occurs in the longitudinal valleys or "hollows" of the Massanutten Range. It is a weak rock, although it is apparently more weather-resistant and hence better exposed than the Bloomsburg formation a few hundred feet below.

Correlation and age. As was mentioned above, the Needmore shale is essentially the unit described by other authors as the Onondaga shale (Butts, 1940; Butts and Edmundson, 1939). It is probably not equivalent to the chert and limestone part of that formation described from southwestern Virginia, however. These latter lithologies are equivalent to the Huntersville chert of Tennessee and are probably equivalent to the Schoharie grit in the New York section (Dunbar, personal communication, 1952), which underlies the Onondaga limestone. Traced northeastward the Needmore shale in Pennsylvania is overlain by limestones called the Selinsgrove limestone: these limestones are probably a lateral facies equivalent of the upper Needmore in Virginia. As was also mentioned above, the Needmore shale is equivalent to the lower part of the Romney shale as originally defined by Darton and as used by Swartz in the Massanutten Range.

The formation belongs to the lower part of the Middle Devonian Series, to the Onesquethaw stage, also known as the Onondagan stage. Prominent fossils include _Phacops rana_ (Green), _Platystoma lineatum_ Conrad, and ?_Machaeracanthus peracutus_ Newberry.

Origin. The Needmore shale represents an accumulation of fine muds swept westward from a landmass into the Appalachian trough. The presence of limestones associated with these shales elsewhere in the Appalachians and the extreme fineness of the material in the shale itself are both indicative of lack of great relief, which would have given rise to coarser detritus than these shales and claystones. The source area of the Needmore shale was probably located somewhere in northern Virginia, east of the Valley, since detrital sediments decrease in abundance to the northeast and southwest, giving way to limestones and cherts indicative of clearer water.

"Marcellus" shale

Name and previous usage. The name Marcellus shale was first used by James Hall (1839, pp. 295-96) to designate the black shales between the Onondaga limestone below and the Hamilton shales above; the name is taken from a town in Onondaga County, New York. Usage of the term in Virginia has been more or less in line with this original definition, the name being applied to the black shale sequence lying between the "Onondaga" shale below and the "Hamilton" formation above (Butts, 1940; Butts and Edmundson, 1939; Bevan et al, 1938).

The original usage of the Marcellus shale in both New York and Virginia was as a lithologic unit. In his classic paper on the Hamilton group in New York, however, G. A. Cooper (1930) has shown that the black shales below the Hamilton-type lithology are actually a facies and cut across the time boundaries. Cooper then redefines the Marcellus as a time-stratigraphic unit, comparable to a stage, which is a subdivision of a still larger time-stratigraphic unit, the Hamilton "group". Thus the revised definition of the Marcellus by Cooper is quite different from the original one, since the Marcellus "formation" of Cooper includes not only black shales but gray siltstones and sandstones as well.

In Virginia, however, even the most recent papers on parts of the Valley that include outcrops of the black shales above the Needmore shale (Onondaga shale of older authors) have treated the Marcellus as a formation (i.e., a stratigraphic unit) rather than as a time-stratigraphic unit. This is not the place to argue over the advisability of redefining the Marcellus as has been done by Cooper, with the apparent implication that formations are time-stratigraphic units. The redefinition has been accepted by a large proportion of Appalachian geologists, apparently. The lithologic unit called the Marcellus shale by earlier workers is not necessarily equivalent to the time-stratigraphic unit called the Marcellus "formation" in New York and a great deal more work will have to be done in this part of the Appalachians before it can be said definitely what the time-stratigraphic relationship between these two units is.

In the meantime the black shales above the Needmore shale in this area remain a mappable lithologic unit, whether this unit is parallel to or inclined to time boundaries, and it is difficult to see any reason why such a unit should not be classed as a formation. The application of the name "Marcellus" to this unit will certainly still lead to confusion, since there will be a strong tendency to think of this unit as equivalent to the Marcellus of New York. Unfortunately, no good section of this unit is exposed in the Mount Jackson quadrangle which might be used as a type section from which the unit could be named. In view of this deficiency, the name Marcellus will be retained, but when applied to the lithologic unit in Virginia (and in neighboring states) the name will be enclosed in quotation marks.

Limits. The lower boundary of the "Marcellus" shale is drawn at the top of the highest layer of olive- or greenish-colored shale in the Romney group. As has been explained in the preceding section, the Needmore shale includes layers of black shale as well as those of the normal gray-green shale, and an arbitrary boundary between the two formations such as is proposed here appears to be necessary. The "Marcellus" shale is overlain by the Mahantango formation into which it grades by increase in sandy material. The boundary here is even more difficult to fix than the lower boundary with the Needmore shale. In mapping, drawing the boundary proved to be quite impossible and, in addition, no measurable section of the units involved was available so that no satisfactory boundary, even an arbitrary one, could be set. It may be suggested that the best method would be to place the top of the "Marcellus" shale at the base of the lowest rusty siltstone or sandstone in the Romney group.

Character. The "Marcellus" shale is a jet-black finely fissile shale in fresh exposures of the formation. Both the bedding and the fissility of the shale are largely concealed by the strongly developed cleavage in the axial portions of the synclines of the Massanutten synclinorium. This sequence of black shales is remarkably homogeneous in character in the Mount Jackson quadrangle, although elsewhere in the Appalachians local limestone lenses are reported from it.

On weathering, the shale takes on a light gray to almost white color; this bleaching is only superficial, however, and even thin weathered chips of the shale have a gray to black interior.

The black shales underlie the lowlands of Fort Valley in the northern part of the Massanutten Range. They are poorly resistant to weathering, but yield only a rather sterile soil, most of the farms in Fort Valley lacking the prosperous appearance of the farms in Page and Shenandoah Valleys.

Distribution and thickness. The "Marcellus" shale is for the most part confined to the synclines in the northern part of the Massanutten synclinorium. The formation is poorly exposed and greatly deformed; no measure of its thickness could be made, although a good estimate would probably be 500 feet.

Correlation and age. The "Marcellus" shale of this dissertation is essentially the same as the Marcellus shale described by Butts (1940) and by Butts and Edmundson (1939). It is included in the Romney shale as originally defined by Darton and as later described by Butts (1933) and by F. M. Swartz (Bevan et al, 1938).

These black shales presumably belong to the upper Middle Devonian or Erian series, to the Cazenovia stage (Cooper et al, 1942). Fossils are completely absent from exposures of the formation in the Mount Jackson quadrangle, or else they have been so distorted by the deformation as to be unrecognizable.

Origin. The origin of the "Marcellus" shale presents somewhat of a problem. The black coloring matter in the shale is probably organic, yet evidence of the abundant life that such a color would seem to indicate are almost completely lacking in the formation and the fossils that are preserved elsewhere in the same formation are all depauperate. Both the depauperate fauna and the abundance of organic matter would seem to indicate deposition in an oxygen-poor environment; the presence locally of pyrite in the shale in other parts of the state would indicate a relatively abundant supply of sulfur compounds, in large part hydrogen sulfide, in the basin of deposition. All this evidence leads to the belief that the "Marcellus" shale was deposited in a basin of restricted deposition. The most commonly suggested environment is that of the lagoon, where muds laden with organic material from the continental areas to the east are deposited and remain undisturbed by circulation of the water of the lagoon. Such an environment has been suggested for the "Marcellus" shale by Butts (1940, p. 492). Another possible environment is tidal flats such as have been described along the North Sea coast of Germany (Hantzschel, 1939, pp. 195-206) and along the Baltic coast (Twenhofel, 1915, pp. 272-80). No detailed evidence for the origin of the formation could be found in the Mount Jackson quadrangle; the black shales were formed from accumulations of black organic muds in essentially stagnant bodies of water, but the geographic relations of this environment remain somewhat of a puzzle. The author feels inclined to consider the black shales as tidal flat deposits around the front of the "Hamilton delta", the main portion of which is represented in part by the overlying formation.

Mahantango formation

<u>Name</u>. The Mahantango formation was named by Bradford Willard (1935, p. from the North Branch of Mahantango Creek in Snyder and Juniata Counties, Pennsylvania.

This formation is synonymous with the Hamilton formation as mapped and discussed by previous workers in the Valley (Butts, 1940) in Virginia Maryland, and Pennsylvania. The Hamilton formation has been redefined by G. A. Cooper (1930)to include that part of the Middle Devonian above the Onondaga limestone in New York, the type area of the Hamilton. As such, the Hamilton includes not only the former Hamilton formation but the underlying Marcellus shale as well. Since the Hamilton and Marcellus of earlier workers in Virginia were considered to be distinct formations, it would introduce a certain amount of confusion to continue using the name Hamilton formation in Virginia for only a part of the sequence which is correlative with the Hamilton group in New York. This possible confusion was seen in 1935 by Willard, who named the Mahantango formation for the purpose of avoiding this confusion.

The name Hamilton formation, like the name Marcellus shale, has become firmly intrenched in Virginia stratigraphy; this, however, in itself will not avoid the possible confusion mentioned above and for this reason the name Mahantango formation will be used instead of Hamilton formation in this dissertation.

<u>Limits</u>. The Mahantango formation grades downward imperceptibly into the "Marcellus" shale and no natural boundary between the two has been located. It is suggested above, however, that the base of the Mahantango formation be drawn at the base of the lowest of the rusty-colored siltstones or sand-

stones in the Romney group.

Character. The Mahantango formation consists chiefly of dark-gray silty shales and fine-grained sandstones, both of these for the most part regularly and thinly bedded. The shales are similar to those in the "Marcellus" shale below and gradation of the Mahantango downward into the "Marcellus" has made separate mapping of the two impossible in this quadrangle. The sandstones are generally finely laminated and quite hard; mineralogically they are low-rank graywackes, consisting largely of quartz and dark-colored rock fragments of slates and phyllites.

Distribution and thickness. The formation is limited to the Fort Valley in the northern part of the Massanutten Range. Exposures are generally poor and much weathered, but one good outcrop of the formation does occur on the east side of Passage Creek where it is crossed by State Road 678.

The top of the formation is absent, since the Mahantango formation is the youngest Paleozoic unit exposed in the quadrangle; no estimate of the thickness could be made.

In the Strasburg quadrangle to the northeast the sandy beds in the Mahantango form low but prominent ridges; no such topographic expression was found in the Mount Jackson quadrangle, however.

Correlation and age. The Mahantango formation corresponds to the Hamilton formation mapped by Butts and Edmundson (1939). It is equivalent to the upper part of the Hamilton group of Cooper in New York, although its exact stratigraphic range in that group could not be determined due to the general absence of fossils.

The formation belongs to the Cazenovia stage of the Erian (Middle Devonian) series (Cooper et al, 1942). Fossils are lacking in exposures of the formation in the Mount Jackson quadrangle; in the Strasburg quadrangle to the northeast, however, the formation contains _Mucrospirifer mucronatus_ (Castelnau), _Pterinea flabellum_ (Conrad), and a number of other forms.

Origin. The Mahantango formation records the initial stages in an influx of clastic material that culminated in the Late Devonian with the formation of the Catskill delta deposits. These early sediments are of finer grain than the later deposits, but they represent an increase in grain size over that of the limestones and shales of the Late Silurian, Early Devonian, and early Middle Devonian. An eastern source for this material is suggested not by evidence within the Mount Jackson quadrangle but rather by the decrease in thickness of the formation to the northwest. The increase in detrital material is interpreted as a reflection of diastrophism in its initial stages in this eastward source area; the source of the material is probably the rocks in the Martinsburg formation which lay to the east of the quadrangle and which were metamorphosed during the Taconian orogeny at or near the end of the Ordovician; the quartz in the Mahantango may be derived from the eastward extensions of the Massanutten sandstone or from the sandy beds within the Martinsburg formation.

PALEOZOIC HISTORY

Cambrian Period. The opening stages of the Cambrian Period came at the end of or just following a period of intense orogenic and volcanic activity. The earliest Cambrian deposits are thus composed of feldspar-rich detritus and are interbedded with basaltic lavas south of the quadrangle. By late Early Cambrian time, however, conditions had become much quieter and similar conditions then prevailed through most of the rest of the Cambrian Period and on into the Early Ordovician. This time of tectonic quiescence was not absolute, however, since minor movements from time to time brought argillaceous sediments or even quartz sands into the seas in this area. Following the Early Cambrian diastrophism, however, there is little or no evidence of a landmass to the east of the area covered by the Mount Jackson quadrangle and such a landmass, if it were present, must have been topographically very low.

Ordovician Period. The Early Ordovician epoch was also a time of extreme quiescence, the amount of detrital material present in the sediments formed during this epoch being even less than that in most of the Cambrian formations. This, however, was but the calm before the storm. At the end of the Early Ordovician there was an apparently minor uplift to the east. The effects of this uplift were slight, however, and the sediments which followed it were again indicative of shallow undisturbed marine conditions. Uplift to the east of the Mount Jackson quadrangle is first recorded at the start of the Black River age, when black muds were poured into the seas in the eastern part of the area. During Black River time, however, the effects of this uplift were fairly well limited to the eastern part of the quadrangle and it is only during the Trenton age that orogenic movement became sufficiently strong to spread the detrital material farther west. In the Late Ordovician diastrophism became even more pronounced and by the Richmond age uplift had become pronounced enough to affect directly the area here discussed. The detrital sediments characteristic of this time were either eroded away from the area or never deposited.

Silurian Period. Although the amount of uplift within the quadrangle reached its maximum during the Late Ordovician, it had not decreased appreciably by the Early Silurian, when coarse sands and gravels were being poured into the Appalachian trough in this area. The detritus was added slowly enough to be well worked, however, and all but the most resistant minerals such as quartz were ground up and swept into the deeper water to the west. During the early part of the Late Silurian, however, the intensity of the orogeny had lessened somewhat and finer detritus was coming westward from the landmass to the east. In addition, the rate of erosion had lessened sufficiently for chemical weathering to produce an appreciable amount of red material which was then swept into the sea to form the red beds of the Bloomsburg formation. By the end of the period, however, the amount of detritus being brought into the sea was slight enough to allow the formation of argillaceous limestones, some rather fossiliferous and indicating fairly clear water.

Devonian Period. To the west the Early Devonian was a time of fair stability, characterized by rather pure lime sands and muds and a large fauna. These sediments are missing in the Mount Jackson quadrangle, however, and the Early Devonian here was apparently a time of crustal unrest. It was followed by further deformation in the Middle Devonian, uplift to the east once more pouring muds into the seas of this region. Uplift continued and increased in intensity in the late part of this epoch, the sediments thus becoming coarser upward and eastward.

STRUCTURAL GEOLOGY

INTRODUCTION

The Mount Jackson quadrangle is situated in a belt of folded and faulted sedimentary rocks that extends from Newfoundland on the north into Alabama on the south. This belt of deformed sedimentary rocks, together with the more highly deformed and metamorphosed belt of rocks bordering it on the east and the less intensely deformed belt of sedimentary rocks to the west, is known as the Appalachian Mountain System. The belt of folded and faulted sedimentary rocks in which the quadrangle lies is known as the Ridge-and-Valley province or, sometimes, as the Folded Appalachians.

The structural characteristics of this belt were recognized as early as 1850; they were quite well summarized by J. D. Dana in 1883 (pp. 276-283) and even now only a little additional information can be added:

> "1. The courses of the flexures and of the outcrops or strike, and those of the great faults, are approximately northeast.....
>
> "2. The folds have their steepest slope toward the northwest, or away from the ocean.....
>
> "3. The flexures are most numerous and most crowded on that side of the Appalachian region which is toward the ocean, and diminish westward.....
>
> "4. The consolidation and metamorphism of the strata are more extensive and complete to the eastward.....than to the westward.
>
> "5. The change of bituminous coal to anthracite, by the expulsion of volatile ingredients, was most complete where the disturbances were greatest — that is, in the more eastern portions of the coal areas....."

Perhaps the most important addition to these structural characteristics of the Appalachian region is the recognition that many of the "great faults" are very low-angle thrust faults.

Regional changes in the structure of the Appalachians consists largely of the greater development of thrust-faulting in the Southern Appalachians, in Georgia, Alabama, Tennessee, and southwestern Virginia.

The classical theory of Appalachian structure is one which has grown up along with the increase in understanding of the structural characteristics of the region. This theory, like the structural character of the Appalachians, was set forth in essentially its present form by Dana in 1883 (pp. 276-83):

> "1. The movement.....was due to lateral pressure, the folding having taken place just as it might in paper or cloth under a lateral or pushing movement."
> "2. The pressure was exerted at right angles to the courses of the folds....."
> "3. The pressure was exerted from the ocean side of the Appalachians; for the results in foldings and metamorphism are most marked toward the ocean."

More recently a somewhat different theory of orogeny, equally applicable in the writer's opinion, has resulted from the study of the structure of the Alps. This theory, commonly called gravitational sliding (l'ecoulement par gravite), ascribes the folds and overthrusts of the Alps to large-scale sliding of the supra-crustal (sedimentary) rocks down slopes with rather small inclinations. The force involved is still a compressional one, so that similar structures would be produced. In this case, however, the structures formed in the sedimentary rocks would be a mere by-product of a greater uplift.

PAGE VALLEY STRUCTURES

Introduction

Folding in the belt between the Blue Ridge and the Massanutten Range is more severe than in the other portions of the quadrangle that were mapped. Even so, the apparent deformation of the strata is not striking and, compared to the structures east of the Blue Ridge, deformation in Page Valley has been relatively mild.

The dip of the formations in Page Valley varies from normal to overturned; in many cases, however, the normal and overturned strata are separated by faults rather than by the axial plane of a fold. Butts (1933; 1940, p. 445) and Edmundson (1945, plate 17) have noted that the strata here show a prevailing dip to the southeast and these writers interpret this as due to "a series of small parallel folds overturned to the northwest" (Edmundson, 1945, p. 136). Fieldwork by the present writer has failed to show such a series of overturned folds in any of the stratigraphic units below the Edinburg formation. Formations older than the Edinburg formation appear to have been deformed by fracture rather than by folding, although this appearance is probably quite deceptive.

In general the structural picture is as follows: The strata in the southeastern part of Page Valley, i.e., those bordering the Shenandoah salient, are overturned and dip at various angles to the east, southeast, or south. In the zone east of the Massanutten Range in the southern part of the valley the Middle and Lower Ordovician carbonate formations are in normal succession and dip to the northwest at angles of 30 to 80 degrees. These normal strata are separated from the overturned ones to the east by the Grove Hill-Newport fault. Between Leaksville and Hamburg the situation is reversed. The New Market-Lincolnshire sequence is overturned, though with nearly vertical dips, in the west, while the zone to the east is composed of the same formations with rather gentle normal dip to the west. North of Hamburg a somewhat similar situation exists, although the explanation of this structure differs somewhat from that of the structure between

Leaksville and Hamburg. In both cases there appears to be good evidence for faulting.

"Blue Ridge overthrust"

The term "Blue Ridge overthrust" is generally applied to a long overthrust fault that forms the western boundary of the Blue Ridge province. This fault has been said by some authors (e.g., Dunbar, 1949, p. 286) to extend "over 700 miles, from Alabama into Pennsylvania". On the geologic map of the Appalachian Valley in Virginia (Butts, 1933) the Blue Ridge overthrust is shown as extending along the Blue Ridge front all the way from the southern to the northern border of the state. In a later publication Butts describes this fault as follows (Butts, 1940, p. 440):

> "One of the main structures in the valley is a great fault extending far along the Blue Ridge, north of Roanoke, probably its full length, and along the northwest front of the Blue Ridge plateau southwest of Roanoke."

The displacement along the fault is generally considered to be great. Butts suggests that "the Valley rocks may extend southeastward beneath parts of the Blue Ridge and the Piedmont" since "it is improbable that such great overthrusts as that of the Montvale cove or that northwest of Mountain City, Tennessee, are of just local extent".

This, then, is the "classical" concept of the eastern boundary of the Ridge and Valley province. Much of it, unfortunately, is due to regional rather than local geologic mapping, and hence much of it is in error for a given local area like the Mount Jackson quadrangle. In many areas the western edge of the Blue Ridge province is bounded by a thrust fault; this has been shown to be the case in much of southwestern Virginia and eastern Tennessee and, indeed, such is the case in the Strasburg quadrangle just to the northeast of the Mount Jackson quadrangle. Near Limeton in the Strasburg quadrangle, for instance, Precambrian granodiorite of the Blue Ridge province has been thrust over the Beekmantown formation; similar relations undoubtedly occur in many parts of the Blue Ridge-Appalachian Valley boundary in northern Virginia. However, the fact that the Blue Ridge in southwestern Virginia is bordered on the west by a thrust fault and that similar conditions exist in the Strasburg quadrangle to the northeast does not make the existence of a similar fault in the Mount Jackson quadrangle a necessary conclusion.

No thrust fault along the western edge of the Blue Ridge could be found in the Mount Jackson quadrangle. Exposures along Hickory Run, which flows out of the Shenandoah salient of the Blue Ridge north of Ingham, are sufficiently complete to show the presence of such a fault if it existed between the Chilhowee group and the Cambro-Ordovician limestones. A traverse along the creek failed to disclose the presence of any faulting of magnitude comparable to that along the "Blue Ridge overthrust". In addition, no thrust fault has been mapped either by Edmundson (1945) or by King (1943). The nearest approach to such a border fault in this quadrangle is the Grove Hill-Newport fault which lies within the limestone sequence to the west.

Grove Hill-Newport fault

In the Mount Jackson quadrangle the fault nearest the western edge of the Blue Ridge actually lies about a mile west and northwest of the mountain front and is confined to the Cambro-Ordovician limestone sequence. It is here named the Grove Hill-Newport fault from two localities bearing those names along the South Fork of the Shenandoah River.

About midway along its trace through the quadrangle the fault is interrupted by the Stanley tear-fault, hence the use of a double name.

Because of the thick cover of Page Valley gravel in the southeastern part of the quadrangle the outcrops of the fault are limited to the stream valleys that cut down through this cover of alluvium. The fault has been exposed in each of these valleys and it would seem fairly safe to infer that it continues on under the gravel that covers the interfluves.

In the south the first exposures of the fault are found in the valley of an unnamed tributary that flows northward into the South Fork west of Crooked Run. North of here the fault trace follows the tributary valley; the Conococheague limestone in the western wall of the stream valley dips 30° W and is in normal sequence; the eastern wall of the valley is composed of much-sheared Elbrook formation which is here overturned. Just east of the junction of the tributary with the South Fork this sheared zone is exposed along the Norfolk and Western Railroad, where it has a traverse width of about 1500 feet. This sheared zone is quite a prominent feature here: the strata are greatly contorted and dips of almost any magnitude and direction can be found; it is usually uncertain, however, whether the dip being measured is that of the bedding planes or of secondary cleavage. Deformation takes the form of numerous overturned isoclinal folds in this exposure of the sheared zone. Across the river the fault can be located in the northern wall of the river valley; here, however, no shearing of any appreciable amount occrs and the fault is marked only by a zone of brecciation and by the sudden change in dip of the strata.

North of this point the fault lies buried beneath the Page Valley gravel until the latter is again removed along the South Fork of the Shenandoah near the mouth of Cub Run east of St. Pauls Church. Just north of the mouth of Cub Run, on the west side of the South Fork, the fault surface is exposed for a few hundred feet at the base of a klippe separated from the main part of the overthrust block by the river. The fault surface is almost horizontal at this locality, with Conococheague limestone thrust westward over Conococheague limestone. Strata in the footwall block have been sheared until they have taken on the character of a platy limestone that was originally mistaken for the Elbrook formation. To the west of this outcrop the strata below the fault lie in normal succession with a dip of 80° W.; those in the hanging-wall block, however, are overturned. A second klippe along the west side of the river occurs a few hundred yards south of the power dam ("Massanutten Power Plant") and north of the first klippe.

At the power plant the fault trace turns to the northeast and probably becomes a tear fault with an almost vertical dip. However, the overthrust plate here is relatively thin and much of it has been removed by erosion by the South Fork, so that the fault trace continues to follow the river to a point beyond Honeyville, where it again disappears beneath the Page Valley gravel.

Along the entire length of its outcrop the Grove Hill-Newport fault is a thrust fault, dipping to the east. The dip of the fault surface is variable: east of Grove Hill the dip is probably rather steep, but near Cub Run the dip is much gentler and at places it is almost flat. Older rocks have been thrust over younger, but in all cases the difference in age of the rocks in the hanging wall and in the foot wall is not great.

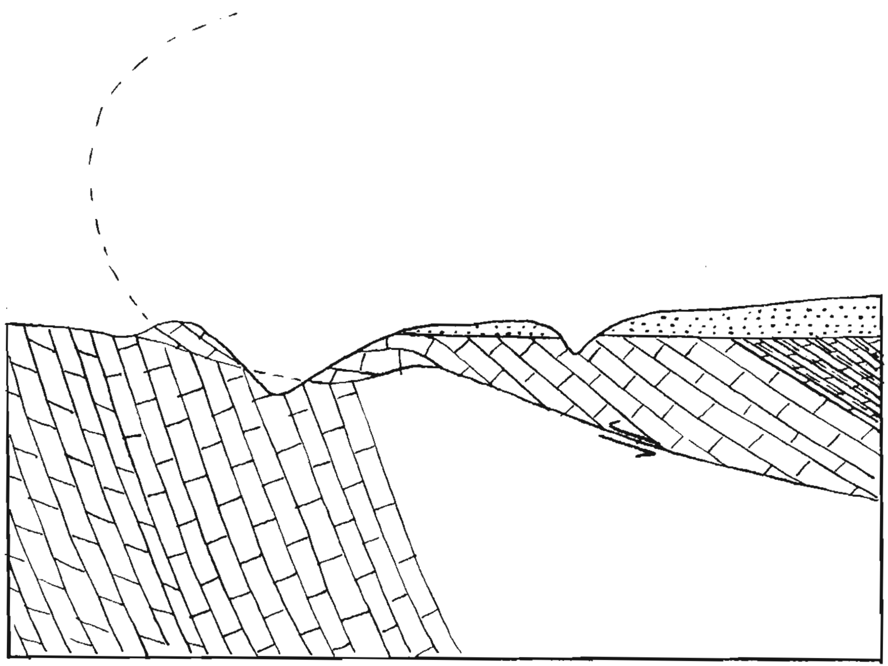
Stanley fault

More or less paralleling the northern edge of the Shenandoah salient is a rather poorly-exposed fault, called the Stanley fault by King (1943). This fault has a nearly vertical dip and a rather constant strike;

unlike the Grove Hill-Newport fault, its trace is not greatly altered by the topography. Movement along the fault appears to have been horizontal, the northern block having been moved to the west relative to the southern block within the overthrust plate of the Grove Hill-Newport fault. However, the Stanley fault appears to extend beyond the latter fault and into the footwall block. West of the Grove Hill-Newport fault the displacement in the strata is in a direction opposite to that east of the fault. These differences in apparent displacement, strongly suggest that movement along the Stanley fault was at least in part vertical, the northern fault block having moved up with respect to the southern block. A further difficulty encountered in assuming horizontal displacement arises from the change in direction of the fault as it passes beyond the western border of the Shenandoah salient. It would seem to be rather difficult for the fault to "turn a corner" if movement were horizontal, whereas vertical movement would not meet any such difficulty.

If displacement along the Stanley fault has been vertical, the dip of the Grove Hill-Newport fault apparently becomes less steep with depth, thus accounting for the lower dip of the fault surface near Cub Run than east of Grove Hill. Since the dip of the strata in the overthrust plate show a similar relation to the Stanley fault, it seems evident that the fault is more or less paralleling the bedding of the formations; this, of course, is not exactly correct, since the formation along the sole of the Grove Hill-Newport fault at Cub Run is the Conococheague limestone, while that east of Grove Hill is the Elbrook formation. Thus the Grove Hill-Newport fault is cutting across the bedding of the formations, but probably at a low angle. A critical exposure in this case would be that of the Grove Hill-Newport fault near the Stanley fault; this area, however,

a. Recumbent fold in the Edinburg formation. Looking north into quarry on South Fork south of U. S. Highway 211.



b. Cross-section of Greve Hill-Newport fault north of Cub Run. Not to scale.

is covered by several tens of feet of gravel.

Folds between Newport and Alma

Northeast of Newport the New Market-Lincolnshire outcrop belt, which has followed a rather straight course northeastward from the southern border of the quadrangle, makes a sharp swing to the east, then southeast, and finally back to northeast again. Here is a pair of folds, an anticline in the west and a syncline in the east, both of which plunge to the northeast. The effect of these folds is not great and they cannot be traced far either to the north or to the south. The folds are asymmetrical to overturned, with the steeper limb of the anticline on the west and of the syncline on the east.

Mill Creek syncline

Structurally the Page Valley area can be divided into two parts along the line joining the towns of Alma and Stanley. The structures south of this line have been in large part discussed above; the following sections will describe for the most part structures north of this line. On a large scale the structures north of the line consist of two folds, the Mill Creek syncline on the east and the Leaksville anticline on the west. These two major structures, oddly enough, are the least clearly defined. They are much complicated by minor faulting which affects the New Market-Lincolnshire sequence and, because of this, the faults are more easily recognized. In time, if the upper Beckmantown can be broken into smaller units, it may be possible to outline these major structures more satisfactorily.

The syncline is for the most part covered by the Page Valley gravel within this quadrangle. It is best exposed along State Road 633 southeast of Leaksville. This road crosses the axis of the syncline a few hundred feet west of its junction with State Road 638. Dips along the western limb of the fold are relatively gentle, on the order of 20°SE. The eastern limb of the fold is quite steep, however, with dips ranging from vertical to overturned (80° SE). The fold is confined to strata in the upper and chert members of the Beekmantown formation.

Leaksville anticline

The axis of the anticline to the west of the Mill Creek syncline passes about half a mile east of the town of Leaksville, after which the fold was named. It is somewhat better exposed than the syncline to the east, but only the upper Beekmantown is exposed in both the eastern and western limbs, making it difficult to map.

The anticline is asymmetrical, with the axial plane of the fold dipping to the southeast at an undetermined angle. A rather well-developed joint set southwest of Hamburg shows a dip of 30° E, but it is rather doubtfully related to the fold. Dips of beds along the western limb of the fold range from 20-80° SE; on the eastern limb the dips are less, averaging about 10-20° SE. The crest of the fold is rather broad. The anticline plunges to the northeast at about 15 degrees.

The western limb of the fold is complicated by faulting which will be discussed in the following sections.

"River Bend" klippe

The name "River Bend" klippe is applied to this outlier for lack of any other suitable name. The klippe is located on a sharp bend in the

South Fork of the Shenandoah north-northwest of Hamburg. The strata of which the klippe is composed are of Early and Middle Ordovician age, including the Beekmantown, New Market, Lincolnshire, and Edinburg formations. These beds are overturned, with dips of 20-40° SE. Near the eastern edge of the klippe, however, the beds become horizontal, then begin to dip to the northwest, having passed through a broad open syncline.

Contact with the normal bedrock is exposed only along the eastern edge of the outlier; it can be traced entirely across the meander from the edge of the river on the north side to the river's edge on the south side of the bend. West of the point of the meander the bedrock is hidden by stream gravels and it is possible that the Martinsburg formation is also included in the klippe.

Lithologically the strata in the klippe are identical with those in the normal section a few hundred yards to the east; the only difference observed is in the thickness of the formations: both the New Market and Lincolnshire limestones are thicker in the normal section than in the klippe and the basal member of the Edinburg formation appears to be absent in the klippe. The source of this outlying block of limestones, dolomites, and shales is somewhat of a problem. The only exposures of these formations east of the klippe are in the normal section just to the east, and it is difficult to picture any possible way in which these two sections could be related. West of the klippe these formations are not exposed east of the Massanutten Range. The only source for this block, then, would appear to be a part of this Middle and Lower Ordovician sequence that has since been entirely eroded. Thus, the syncline that lies to the southeast of the klippe, beyond the edge of the quadrangle, must once have contained beds of these formations in addition to the Beekmantown formation now exposed there. Similarly, the anticline which has been described by Butts still farther to the east probably originally included these same formations. However, no thrust fault has been mapped to the east of the klippe with the exception of a rather small one at Hamburg.

Interpretation of the origin of this klippe should, perhaps, be left for a later section in this dissertation. However, since the interpretation may make the whole structural picture in Page Valley somewhat clearer, it will be included here as well. The klippe is thought to be an "erratic block", that is, a mass of rock that has broken off some higher topographic feature and slid down into its present position. It is, essentially, a landslide block. Its source may have been the overturned anticline to the east which probably marked a topographic high before it was so extensively eroded. The klippe may have been derived from the overturned limb of this anticline, or the overturning of its stratigraphic sequence may have occurred during its movement. There is some evidence for an eastern source of the material besides that of elimination of others. The thickness of the Lincolnshire and New Market limestones and of the basal Edinburg formation are less in the klippe than in the normal sequence to the west. A decrease in thickness would be the expected change to the east, since this is the general change elsewhere in the quadrangle.

Leaksville-Hamburg fault

The fault begins in the north in the valley of Mill Creek, northwest of Hamburg, where it is marked by a brecciated zone in the north wall of the creek valley. From this point the fault follows a rather straight course south-southwestward to a point about one-half mile west of

Leaksville, where it passes under the Page Valley gravel.

Along the entire trace of the fault the strata on the east are in normal sequence, with dips of 20-80° NW. The strata west of the fault, on the other hand, are overturned, with dips of 30-70° SE. In general beds of the Edinburg formation on the east are in contact with those of the Beekmantown formation west of the fault.

The Leaksville-Hamburg fault probably dips to the east at a high angle. A thrust fault dipping east at this position could bring Beekmantown and Edinburg strata in contact, but the Beekmantown in this case would be in the eastern block instead of in the western one. A fault dipping to the west would fail to bring overturned and normal sequences into contact.

A similar structure has recently been described by John Sanders (1952) from Tennessee. Mr. Sanders describes this feature as an overturned backthrust. A backthrust is a thrust fault in which the dip of the fault plane is in the direction opposite to that of most of the thrust faults in the region. Thus, in the Appalachians the large majority of the thrust faults dip to the east; a backthrust in this region, then, would dip to the west. If such a backthrust were later subjected to folding and eventually overturned, the fault would dip to the east and the fault would take on the appearance of a normal fault.

Structure in the Edinburg and Martinsburg formations

The Edinburg and Martinsburg formations are the most incompetent formations in the Page Valley area and hence the structures developed in them are likely to be more complex than those developed in the more competent beds. In these formations overturned and even recumbent isoclinal folds are common and rock cleavage in these strata is so well developed parallel to the axial planes of the folds that the rocks are in many places slaty in character. One such fold has been reported from this area by Edmundson (1945, plate III-b). The fold is exposed in a quarry in the Edinburg formation along the east bank of the South Fork of the Shenandoah south of U. S. Highway 211. The Edinburg formation here is composed largely of thin- to thick-bedded argillaceous limestones; it has been folded into a relatively small recumbent anticline that is overturned to the west (Plate 30). At the west end of the quarry face a minor thrust (?) fault is also exposed in the Edinburg formation. The fault dips about 30° W; the hanging-wall block appears to have moved down. This may be a klippe like that northwest of Hamburg, but no additional evidence was available.

Minor faulting in the Edinburg formation is also exposed along Virginia Highway 12 west of Alma, where several west-dipping faults are exposed along the road.

Overturned isoclinal folds appear to be even more common in the Martinsburg formation. Along Cub Run, where almost complete exposures can be seen for half a mile west of the top of the Lincolnshire formation, the Martinsburg formation shows a variety of dips, all of them very steep, and it is impossible to measure a complete section of the formation here.

MASSANUTTEN SYNCLINORIUM

Introduction

The term synclinorium was first introduced by James D. Dana; its original usage was somewhat different from the general present usage and it will probably be of some interest if we refer to this original usage of the term before proceeding any further in its present usage. In 1880 Dana included the following statement in the third edition of his Manual of Geology (p. 821):

> "The mountain range, begun in a geosynclinal, and ending in a catastrophe of displacement and upturning, is appropriately named a synclinorium, it owing its origin to the progress of a geosynclinal....."

Thus, in the original meaning, the entire Appalachian mountain system would be considered a synclinorium. Since Dana's time, however, the term has undergone a considerable change in meaning, a change which seems to be characteristic of geologic terminology. Thus Billings (1942, p. 51) defines a synclinorium as "a large syncline that is composed of many smaller folds". Similar definitions are given by Nevin (1942, p. 33), Lahee (1941, p. 168), and other American geologists without any reference to the original usage of the term.

Ideally it might be better to revert to the original usage of the term and use instead the term "composite syncline" for the structure here referred to. However, definitions of the type given by Billings have been more or less completely accepted by geologists for the past several decades and not much would be gained by using the term "synclinorium" according to the original definition.

The exact delimitation of the Massanutten synclinorium is somewhat difficult. Previous workers have tended to draw its outer boundaries at the base of the island-like mass of Martinsburg shale sying in the Valley of Virginia west of the Blue Ridge. Others seem to have included in the synclinorium the ridges of the Massanutten Range and the Valleys between them. Neither of these definitions, however, is quite acceptable. The term "synclinorium" is a structural term and as such should not be given either stratigraphic or topographic boundaries. If, for instance, Short Mountain, the western ridge of the range, is included in the synclinorium, will it not be necessary to include as well that portion of the Short Mountain syncline that lies south of U. S. Highway 211? The term Massanutten syncline used by Butts (1940, pp. 443-44) and by Edmundson (1945) does not appear to be applied to either the Endless Caverns anticline or to the Smith Creek syncline, both of which are southward continuations of structures within the Massanutten Range which these authors appear to accept as part of the Massanutten syncline.

As used in this report, the term Massanutten synclinorium will be limited to three folds: the Catherine-Duncan syncline, the Morgan-Catback anticline, and the Pitt Spring-Crisman syncline. Topographically it will be restricted to the belt between the east slopes of Massanutten and First Mountains on the southeast and the west slopes of Kerns and Massanutten Mountains on the northwest.

The Massanutten synclinorium presents a peculiarly interesting area for study in that it contains formations as young as Middle Devonian farther east — that is, nearer the Blue Ridge — than any other area of outcrop in the entire region. Structurally as well the synclinorium presents some interesting problems. As early as 1835 William Barton Rogers recognised the significance of the area when he wrote that

> "the investigation of the materials and structure of the Massanutten mountains cannot fail to prove interesting to the geology of the state. Such an examination, moreover, promises more than any other to reveal the geological relations of the valley (of Virginia) to the regions bounding it on either side, and thus to solve some of the most curious problems with which the student of our geology cannot fail to be embarassed." (Rogers, 1835, p. 93)

In 1892 Bailey Willis described the structure as a syncline which

> "contains strata from the Martinsburg shale.....to the lower Devonian black shales. Northeast and southwest the basin

> extends beyond the mountain and is represented by an area of Martinsburg shale in the middle of the great limestone valley. Its length as a grand structural feature....is about 150 miles; its width through the Massanutten is five to six miles. This long, narrow trough, extending parallel to the shore of the Silurian sea and but a few miles from it, may well correspond with an alongshore belt of maximum deposit and its resulting syncline of deposition....."

As late as 1940 the impression that the structure was in general a simple one was commonly held and Butts (1940, pp. 443-44) describes the structure as a syncline, saying that "it has not been possible on any of the traverses across the syncline outside of Massanutten Mountain to locate the axis of the overturned syncline or the axial plane of division between the northwest and southeast limbs." Earlier in this same section, however, Butts shows that he recognizes the syncline as not being a simple one: "the syncline is not a single symmetrical trough but is affected by several subordinate anticlines and synclines".

As is often found to be true of geologic work in the Appalachian Valley and elsewhere, the earlier workers seem to have had a clearer conception of the situation than the more recent workers. The description of the structure by Rogers (1838) is well worth quoting in this respect:

> "The Massanutten mountains, forming the group of parallel ridges stretching from the neighborhood of Strasburg to the peak near Keezletown, in all a distance of nearly 50 miles, may be regarded as one great compound synclinal mountain tract resting in the trough of slate."

The impression seems to have prevailed, nevertheless, that the structure was nothing more than a simple syncline somewhat complicated by minor folding. This is probably due to the fact that from most of the highways near these mountains the range looks more like a single ridge than a group of ridges and it is only after entering the range itself that the actual state of affairs becomes evident. That this has too often been the case may be seen from the above excerpts from the work of Willis and Butts, in which they speak of a mountain, not of mountains.

The synclinorium, then, is composed of two synclines and an anticline. In addition, the structure in the northern part of the synclinorium is complicated by thrust-faulting, and between the northern and southern parts of the synclinorium is an anticline at New Market Gap.

Catherine-Duncan syncline

The easternmost fold of the synclinorium is the Catherine-Duncan syncline, so named from Catherine Furnace and Duncan Hollow which are situated along the axial trace of the syncline.

The syncline is isoclinal or nearly so, with overturning to the northwest. The general dip of both limbs of the fold is 70° SE, while the general trend of the fold axis is N 35° E, parallel to the regional trend of the other structures within the Mount Jackson quadrangle. The overturned isoclinal character of the fold is most easily seen in the southern part of the syncline, southwest of Mountain Run, where neither of the limbs of the fold has been disrupted by faulting. Northeast of Mountain Run, however, the eastern limb of the fold has been broken by a reverse fault, the Massanutten Mountain fault, which will be discussed below. The most competent and most resistant formation included in the fold is the Massanutten sandstone; it is the attitude of this formation that makes the isoclinal character of the syncline most conspicuous. In the northern part of the syncline the Massanutten sandstone on the inverted limb of the fold has been largely removed by faulting, and hence evidence for the isoclinal character of the fold is somewhat obscured. The strata of the weaker Bloomsburg formation are in overturned sequence here, however, with a dip of about 60° SE, so that we are here dealing with the same type of fold as is found southwest of Mountain Run.

Southwest of Mountain Run the Catherine-Duncan syncline is confined to strata ranging from Upper Ordovician to lower Middle Devonian, that is, from the Martinsburg formation to the Needmore shale. There is some possibility that the "Marcellus" shale also is present here, but it seems more likely that these black shales are a local development in the Needmore shale. Northeast of Mountain Run the syncline becomes deeper and wider; near the northern edge of the quadrangle the "Marcellus" shale and the Mahantango formation appear along the axis of the fold.

Northeast of Catherine Furnace the southeastern part of the fold is complicated by the presence of a minor anticline involving the Massanutten sandstone and the Bloomsburg formation and possibly even younger formations as well. This minor fold parallels the trend of the main syncline and is expressed mainly by a tongue-like projection of the Massanutten sandstone southwestward from the eastern limb of the main syncline northeast of Roaring Run.

Near Mountain Run the fold is separated into two parts by the New Market Gap cross-anticline. To the northeast of this cross-anticline the syncline plunges to the northeast; to the southwest, it plunges to the southwest. The syncline appears to reach its deepest point (stratigraphically, its highest point) in the southern part of the fold along a cross axis paralleling Pitt Spring and Cub Runs.

Cleavage is generally well developed along the trough of the syncline, with dips of 60-70° SE, thus paralleling the dip of the limbs and axial plane of the fold. In the center of the syncline this cleavage is confined to the strata younger than the Catherine limestone, i.e., to the Romney group. It also occurs in the Martinsburg formation along the flanks of the fold and in New Market Gap. At most places in the Romney group the cleavage makes an appreciable angle with the bedding, since the strata along the trough line of the syncline have gentler dips than those along the limbs of the folds. In these same beds the cleavage is generally better displayed than the bedding. In the Martinsburg formation on the flanks of the fold, on the other hand, the bedding and cleavage are nearly or quite parallel.

Topographic expression of the syncline is quite marked, as might be expected of a syncline that includes a resistant formation such as the Massanutten sandstone. The syncline takes the topographic form of two U-shaped valeys, one to the southwest of Mountain Run (Catherine Hollow) and the other to the northeast (Duncan Hollow). These valleys are in line with one another and are bounded on either side by ridges of Massanutten sandstone which converge as New Market Gap is approached. Reflecting the plunge of the syncline away from the New Market Gap cross-anticline, the valleys decrease in altitude and increase in width northeast and southwest of Mountain Run. Within the two valleys any topographic expression of minor differences in lithology is masked by the large amount of sliderock from the sandstone ridges on either side. The minor anticline northeast of Catherine Furnace, however, forms a small interrupted ridge owing to the presence in the fold of the Massanutten sandstone.

Massanutten Mountain fault

The eastern ridge of the Massanutten Range north of New Market Gap is called Massanutten Mountain; it is formed of a thrust block of Massanutten sandstone. The plane of this thrust fault dips steeply to the east and is probably slightly steeper than the axial plane of the Catherine-Duncan syncline to the west. The hanging-wall block contains strata belonging to the Bloomsburg and Martinsburg formations as well as to the Massanutten and Cub sandstones. The footwall block of the fault, where exposed, consists of the Bloomsburg formation in most places, although locally beds of the Massanutten sandstone also are included.

The fault is not well exposed and in general the eastern ridge of the range along which the fault occurs is rather inaccessible except where it is crossed by the Burners Gap trail and by the road from Fort Valley to Luray. In most places the position of the fault is obscured by sliderock from the Massanutten sandstone; in addition, a thick cover of rhododendron and mountain laurel make it almost impossible to see an outcrop from a distance of more than a few feet.

At Burners Gap the presence of a fault is quite evident, although the trace of the fault itself is probably not exposed. At the top of the ridge, beds of red sandstone belonging to the Bloomsburg formation are exposed; the dip of these beds is 60° SE, the formation here lying on the overturned limb of the syncline. If the sequence were unbroken, these red sandstones would appear to be overlain by white sandstones which would have a similarly overturned relation. In going east from the crest of the ridge, however, the Bloomsburg strata at the top of the ridge are followed by a short covered interval, then by beds of red sandstone dipping to the northwest. Below these lie the white Massanutten sandstones in normal succession, overlying the Cub sandstone. The Bloomsburg beds exposed at the crest of the ridge are slickensided and it seems probable that the surface of the fault is closely parallel to these red sandstones. Bloomsburg and Massanutten strata have here been thrust upward from a position

MASSANUTTEN MOUNTAIN FAULT

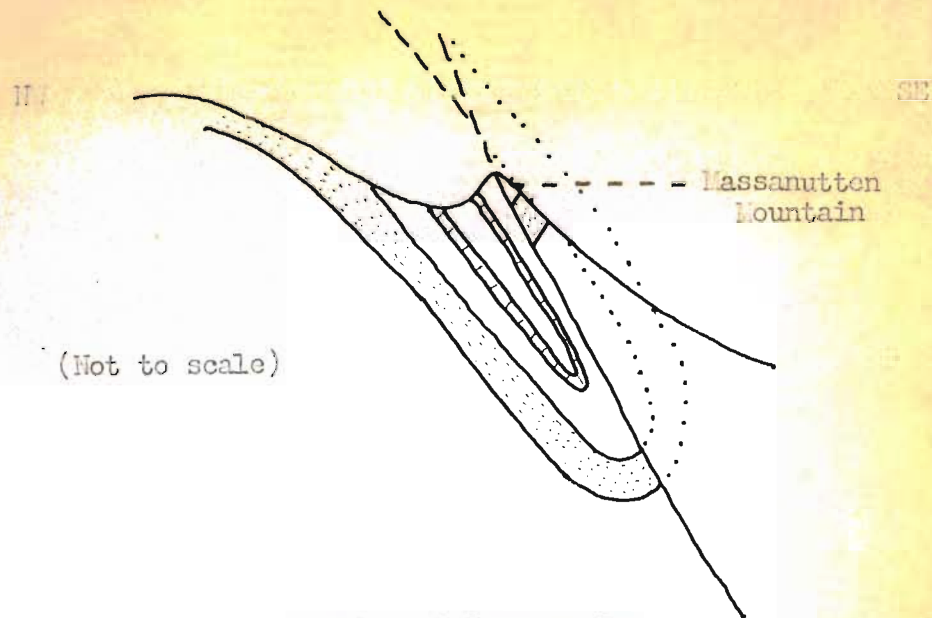


Fig. 1 Structure section at Turners Gap

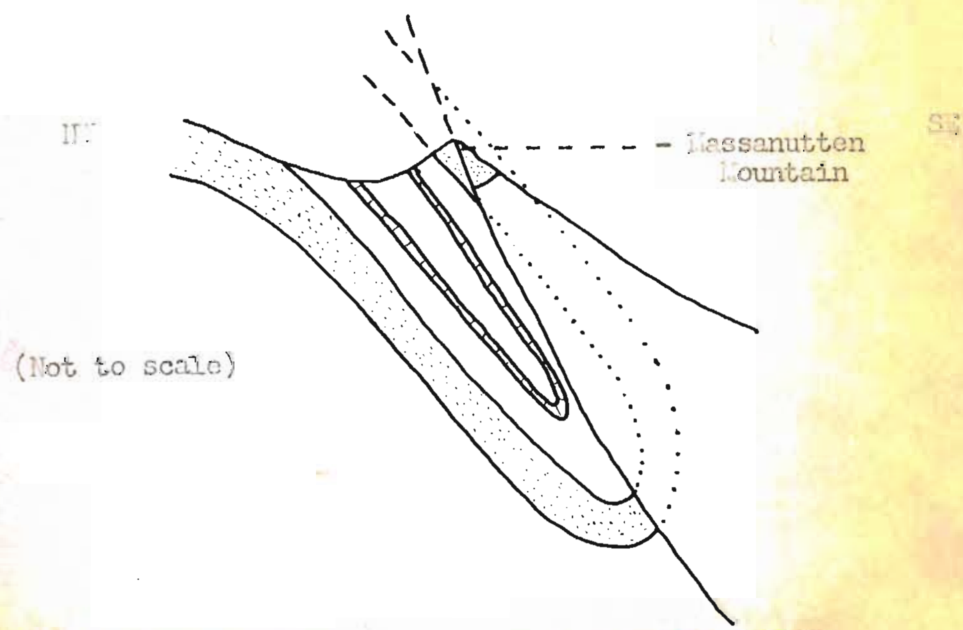
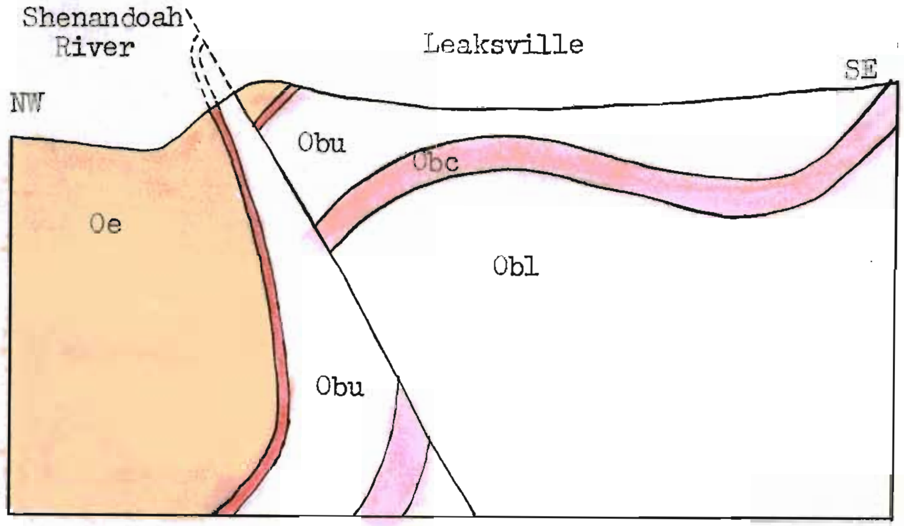


Fig. 2 Structure section near Fort Valley-Luray Road



a. Cross-section showing interpretation of Leaksville-Hamburg fault as an overturned backthrust. Not to scale

b. Series of northwest-southeast sections from Strickler Knob northward, showing the gradual elimination of the eastern ridge by faulting. Northernmost section to the left.

east of the trough of the Catherine-Duncan syncline and have thus been brought into juxtaposition with the overturned sequence farther up on the eastern limb of the fold. This interpretation is shown diagrammatically in Plate 31.

On the road leading eastward from Fort Valley to Luray additional evidence for faulting along the eastern ridge of the range can be seen. As the road climbs up the western slope of Massanutten Mountain the strata can be seen dipping to the southeast; this is the overturned limb of the syncline. The beds exposed in these cuts include both the Bloomsburg and Massanutten formations in overturned sequence. At the very top of the ridge there are no outcrops, but along the eastern slope the Massanutten sandstone is again exposed. Here, however, the strata dip to the northwest and are underlain in normal sequence by the Cub sandstone and the Martinsburg formation. The structural relations here are analogous to those at Burners Gap, but the displacement here is greater than farther south (Plate 31).

Some evidence for faulting can be gained from the topography of the mountain, especially at its southern end near Strickler Knob. The two ridges that occur east and west of Crisman Hollow are composed of the Massanutten sandstone. As they are followed to the southwest they converge as the New Market Gap cross-anticline is approached. The western of these two ridges extends beyond their junction, however, while near their junction the eastern ridge loses its distinctness and gives way to a more or less flat area where the two ridges join, this flat area being dominated by the western ridge. Here the west-dipping Massanutten sandstone in the hanging-wall block of the fault has been removed by erosion; the flat area below the western ridge is underlain by the Massanutten sandstone in the trough of the syncline. (See Plate 32).

A similar structure apparently exists in the Strasburg quadrangle, to the northeast, where the eastern ridge of the range appears to be double; this double character of the ridge is probably due to thrust faulting similar to that in the Mount Jackson quadrangle.

Morgan - Catback anticline

The Morgan-Catback anticline is the middle fold of the Massanutten synclinorium, lying between the Catherine-Duncan syncline to the east and the Pitt Spring-Crisman syncline to the west. The fold is named after Catback Mountain in the northern part of the Massanutten Range and Morgan Knob in the southern part of the range.

The oldest strata exposed in the core of the fold belong to the Martinsburg formation. The flanks of the fold are composed of the Massanutten sandstone and the Bloomsburg formation.

In one respect, at least, this anticline differs quite radically from the normal Appalachian fold. The dip of the strata along the eastern limb of the anticline is about 65° SE; that of the beds along the western limb, 35-40° NW. The fold is thus asymmetrical, not an uncommon feature in the Appalachians; however, in this case the axial plane of the fold dips to the northwest, not to the southeast as in the great majority of Appalachian folds. This asymmetry of the fold is indicated not only by the dip of the limbs of the fold, but also by the topography. Perhaps the best topographic expression of this asymmetry is seen in Catback Mountain, an anticlinal mountain, in which the slope of the southeast side is noticeably steeper than that of the northwest side. The asymmetry of this fold can be seen not only in the northern part of the range, but also south of New Market Gap and along U. S. Highway 211 as well. Examples of the dip of the limbs of the fold are given below:

	SE limb	NW limb
Koontz Hollow	70 SE	20 NW
Pitt Spring Run	90 SE	40 NW
U. S. 211	50 SE	35 NW
South of Duncan Knob	60 SE	30 NW
Fort Valley	40 SE	30 NW

In addition, a single measurement of the altitude of cleavage in the Martinsburg formation within the fold gives a strike of N 30° E and a dip of 80° NW; this is probably at least indicative of the dip of the axial plane of the anticline.

Topographically the anticline is marked by the central ridge or ridges of the Massanutten Range. In the southern part of the range the anticline forms a single ridge, broken intermittently by water gaps, that extends from the southern edge of the map northward to beyond the gorge of Pitt Spring Run. Beyond that point the Massanutten sandstone has been breached by erosion and the weaker Martinsburg formation below has been cut into an anticlinal valley, bordered on the southeast and northwest by ridges of Massanutten sandstone. In the northern part of the range the anticline is also marked by a valley carved in the Martinsburg formation as far north as Duncan Knob, beyond which the Massanutten sandstone along the crest of the fold has not been eroded. Farther north the anticline is followed by Catback Mountain, an anticlinal mountain whose long slope to the northeast is a reflection of the plunge of the anticline in that direction.

A section completely across the anticline is rather well exposed in the gorge by which Pitt Spring Run reaches Cub Run in the southern part of the range. Another section across the anticline can be seen along U. S. Highway 211, although the only indication of the fold here is in the change in dip of the Martinsburg formation.

Pitt Spring - Crisman syncline

The Pitt Spring-Crisman syncline is the westernmost fold in the synclinorium; it takes its name from Pitt Spring at the western end of the Pitt Spring Run gorge in the southern part of the range and from Crisman Hollow north of New Market Gap. The fold is a simple one in the southern part, but north of the gap it is complicated by minor folding and thrust faulting.

The dip of the strata along the eastern limb of the fold is 20-45° NW at most places north and south of New Market Gap. The western limb, however, shows a somewhat more unusual character. In the northern part of the range the dip of the strata in the western limb is in many places greater than that of the eastern limb, indicating that at least locally the axial plane dips to the northwest; this relation, however, is not as consistent as in the anticline on the east. South of New Market Gap, however, and more particularly south of Bird Knob, the dip of the western limb is considerably greater than that of the eastern limb. Southward from the power line crossing southeast of Endless Caverns the strata pass from vertical to overturned, with dips of 45-75° NW not uncommon. East of Athlone the strata of the western limb are once more in normal sequence.

The plunge of the syncline is related to the New Market Gap cross-anticline: north of the gap the plunge of the fold is 15° NE and south of the gap, 10° SW.

Topographically the syncline is represented by a valley or "hollow" northeast and southwest of New Market Gap: as in the case of the eastern syncline the valleys are bordered by ridges composed of Massanutten sandstone and as the gap is approached from the north or south the ridges converge. Coincidentally with this convergence the elevation of the valley floor increases until the bordering ridges have converged into a single ridge, a synclinal mountain. At the gap this synclinal mountain has been broken by erosion.

Like the eastern syncline, the Pitt Spring-Crisman syncline includes strata as high as the Mahantango formation north of the gap and as high as the Needmore shale south of the gap.

Passage Creek fault

The Passage Creek fault is named after Passage Creek in the northern part of the Massanutten Range, along which it is best exposed. The fault separates beds of the Massanutten sandstone from younger beds along most of its length, the Massanutten sandstone lying along the fault in the hanging-wall block. The fault dips to the east at a rather steep angle.

The fault represents a broken minor anticline branching off the Morgan-Catback anticline; the crest of the anticline has been cut out by the faulting.

Moreland Gap folds

Southeast of Moreland Gap, in the northern part of the Massanutten Range, the Pitt Spring-Crisman syncline is complicated by a subsidiary anticline that plunges to the northeast away from the gap. Between this anticline and the western ridge in the synclinorium (Bowman Mountain) lies a minor syncline that contains strata of the Bloomsburg formation.

New Market Gap cross-fold

The cross-fold at New Market Gap is a rather broad upwarp along an axis trending about N 30° W. The upwarp affects all three of the major folds in the synclinorium, but none of its effects can be detected in structures to the east or west of the synclinorium. In effect this is a "culmination" (Billings, 1942, p. 49).

The effects of the cross-fold can be seen best in the topography. The highest points reached by the Massanutten sandstone along the axial planes of the folds in the synclinorium will lie along the crest of this cross-fold. This structural elevation has made the Massanutten sandstone here more subject to erosion than elsewhere and it is thus along this line that the Massanutten sandstone has been removed by erosion, exposing the weaker Martinsburg formation below and producing a topographic low at New Market Gap.

SHENANDOAH VALLEY STRUCTURES

Endless Caverns-Hyden Spring anticline

The Endless Caverns-Hyden Spring anticline lies just to the west of the Massanutten synclinorium. Some authors appear to consider it a part of this synclinorium, but some evidence derived from the present work make it more logical to consider the fold as separate from the synclinorium. One good reason for this usage is the behavior of the anticline at the point where it is crossed by the axis of the New Market Gap cross-fold: whereas the folds included in the synclinorium plunge away from this cross-fold, the Endless Caverns-Hyden Spring anticline is unaffected by it and continues its northward plunge across the entire quadrangle. In addition, the folds in the synclinorium are generally fairly tight folds and relatively narrow, whereas this anticline is a broad one. Finally, faulting within the synclinorium is of the high-angle reverse type and is not of great areal extent. The Endless Caverns-Hyden Spring anticline, on the other hand, is broken by a low-angle thrust fault (Lincoln Hill) which is rather important areally.

The name of the anticline is taken from Endless Caverns southwest of the town of New Market and from Hyden Spring in the valley between Short Mountain and Kerns Mountain. Both of these localities lie on the axial trace of the fold. The double name is used because of the apparent (not real) absence of the fold between Endless Caverns and Hyden Spring. Actually the outlines of the fold are reflected in the attitude of the Martinsburg formation between these two points.

The oldest formation exposed in the core of the anticline is the Conococheague limestone, the upper 600 to 700 feet of which are brought to the surface. The youngest beds involved in the fold belong to the New Market and Lincolnshire limestones.

Being situated just to the west of the Massanutten Range, the eastern limb of the fold is not well exposed because of the rather thick cover of sliderock and alluvium brought down from the ridge to the east. Like most of the folds in the area, this anticline is asymmetrical, with the axial plane of the fold dipping to the southeast. Dips on the eastern limb average about 50-60° SE; along the western limb, however, the beds are locally overturned southwest of Endless Caverns and in general dip more steeply than the strata on the eastern limb.

The western limb of the anticline is broken at two horizons by reverse faults, the "Staunton" fault to the east and the Lincoln Hill fault to the west. In addition to these reverse faults, the anticline is complicated by several small folds along the western limb. Only a few of these folds are large enough to show on a geologic map, but in addition there are innumerable smaller folds that serve to still further confuse the picture. This is especially true in the vicinity of the faults. In most cases the minor folds plunge to the north parallel to the plunge of the main anticline. One notable exception to this was mapped northeast of Lincoln Hill, however.

"Staunton" fault

On the Geologic Map of the Appalachian Valley in Virginia (Butts, 1933) the Staunton fault is shown as terminating in the north in the Endless Caverns-Hyden Spring anticline. In the present work a thrust fault has been mapped in the approximate position shown by Butts; whether this thrust fault or another one to the west is actually the Staunton overthrust, however, will have to be decided by work now in progress in the Harrisonburg quadrangle to the southwest. Following the usage of Butts, the fault nearest the crest of the Endless Caverns-Hyden Spring anticline will be called the Staunton fault, though in this case it might be wiser if the name were inclosed in quotation marks as has been done above.

Attitude of the fault. No good exposure of the fault was found in the Mount Jackson quadrangle; the nearest approach to such an exposure was found along State Road 807 at the south end of Phillips Hill. Here is exposed a small area of black limestone, probably part of the Beekmantown formation, which has been sheared and the shear fractures later filled with white calcite. The exposure is located at about the point where the fault crosses the road, since outcrops of the Conococheague limestone occur some yards to the east and the Beekmantown formation is exposed just to the west. The shearing, if it did not occur along the fault, is at least closely related to it.

A second possible exposure of the fault occurs along State Road 798 between Bielers School and Union Chapel, both of which have been converted into farm houses since the base map was made. A chert zone was found at this point in the bank on the north side of the road; the dip of this chert layer is about 45° SE and it may represent a silicified zone along the fault. The exposure here, like the one at the south end of Phillips Hill, is rather poor.

Stratigraphic displacement. Because of the absence of good exposures of the fault itself, mapping of the fault was based entirely on stratigraphic criteria. As can be seen from the map, the fault along most of its length separates the Conococheague limestone in the hanging wall block from the Beekmantown formation in the footwall block. Northeastward the displacement along the fault becomes less and at its northeast end the fault is confined to the Beekmantown formation. Even in the southwest, however, the displacement probably is no more than 700 to 1000 feet.

The strata to the east and to the west of the fault are in normal succession, those in the hanging wall (eastern) block dipping to the east and those in the footwall block dipping to the west. The fault also has an eastward dip and is more or less parallel to the dip of the strata in the hanging wall block.

Lincoln Hill fault

The Lincoln Hill fault is similar to the "Staunton" fault which lies to the east of it in that it cuts the Endless Caverns-Hyden Spring

a. Outcrop of the contact surface along the east edge of the "River Bend" klippe, showing normal sequence to the east (right) and overturned strata of klippe to the west (left).

b. Sheared zone along the Lincoln Hill fault. Northern end of Lincoln Hill, Rockingham County.

anticline. Beyond this point, however, almost all similarities between the two cease. Northward the fault can be traced as far as the entrance road to Endless Caverns, about three and a half miles south of New Market, where the sheared zone generally associated with this fault is exposed along the road west of Smith Creek. Southward the trace of the fault roughly parallels the course of the stream, lying to the west of that stream from the Endless Caverns road to the north end of Lincoln Hill. Along the west front of Lincoln Hill, which is situated to the southeast of Tenth Legion and after which the fault was named, the fault trace lies along the east side of the stream and follows it very closely for about one-half mile south of the hill. Here the stream course shifts to the west and the outcrop of the fault continues in a generally south-southwest direction.

Structural relations. The dip of the fault is variable. In most localities the fault dips to the southeast; the angle of dip ranges between 30 and 60 degrees. Locally, however, north of Lincoln Hill the fault appears to be vertical or even to dip to the west at a steep angle. The generally low southeast dip is indicated quite well by the manner in which the trace of the fault is affected by the topography south of Lincoln Hill.

Throughout most of its length the fault is marked by a well-developed zone of shearing that reaches a maximum thickness of 500 to 700 feet along State Road 798 at the north end of Lincoln Hill. At this point the road reaches the valley of Smith Creek by means of a rather long cut in the eastern valley wall and a good exposure of the sheared zone can be seen in this cut. Brecciation along the fault, as indicated by the presence of angular fragmental material, is minor. For the most part the rocks, generally shaly limestones or shales, have been altered to a shaly appearance, the slabs of which are generally 1/2 to 1-1/2 inches thick.

In addition, thicker layers of crystalline calcite are present and lie parallel to the shear planes. Occasional blocks of thicker-bedded limestone are also present and probably represent thicker, more competent beds in the sheared rock.

Stratigraphic relations. Within the Mount Jackson quadrangle the fault is not well marked stratigraphically, although southwest of this area stratigraphic criteria are clearer. North of Lincoln Hill the Edinburg formation has been thrust over the Martinsburg formation and the only stratigraphic evidence of any offset is the absence of the Oranda formation. South of the north end of the hill, however, the Oranda formation is present and for the remainder of its outcrop in the quadrangle the fault is confined to the Martinsburg formation.

Relation to folding. The Lincoln Hill fault breaks across the overturned beds in the western limb of the Endless Caverns-Hyden Spring anticline about halfway between the crest of this fold and the trough of the syncline to the west. During the Appalachian revolution the beds of the syncline were deformed into an overturned syncline which, with further application of compression, broke along the overturned limb, along a zone where shearing stress reached a maximum. Before such a breakage could occur, however, the Edinburg and Martinsburg formations above the shear zone were greatly deformed. The dip of these formations is now apparently to the east; however, closer examination reveals that they have been thrown into a series of isoclinal folds, thus accounting for the greatly increased thickness of the Edinburg formation east of the fault. The two formations are notably incompetent and such deformation and thickening of the units was necessary before they could be capable of transmitting the compressional stress and thus be thrust westward over the stratigraphically higher beds. To this pre-faulting epoch of isoclinal folding in the Edinburg formation the anomalous minor fold in the New Market and Lincolnshire limestones east of Lincoln Hill may be ascribed.

A second possible origin for this fold is as a drag fold of somewhat abnormal character. As noted above, the fault north of Lincoln Hill cuts out the Oranda formation; south of the north end of the hill, however, the Oranda is present. Thus it appears that the displacement north of the hill is greater than that along the front of the hill or south of it. Because of this greater displacement the formations must make a sharp swing to the west at the north end of the hill.

Topographic expression. In general the trace of the fault is marked by a zone of weakness, as would be expected along a fault characterized by a prominent sheared zone. Along most of its length the outcrop of the fault is followed by a series of valleys. Along the front of Lincoln Hill the valley is occupied by Smith Creek, but southwestward and northeastward the streams in this fault-line valley are minor tributaries to Smith Creek.

Lincoln Hill itself represents a rather peculiar topographic expression of the fault. The hill is composed of Martinsburg shale, a weak rock that normally forms lowland areas throughout the rest of the quadrangle. Apparently the shearing at the base of the hanging wall block was accompanied by local silicification or calcification, in either case increasing the resistance of the rock to erosion. A second hill lying to the east of the fault is located on the west side of Smith Creek about half a mile south of Fairview Church. In this case the hill is composed of beds of the Edinburg formation, but its resistance to erosion reflects causes similar to those in the case of Lincoln Hill.

Relation to the Staunton fault. Along most of its outcrop southwest of the Mount Jackson quadrangle the Staunton fault appears to be a relatively low-angle thrust fault of the type commonly called an overthrust in the Appalachians. In Geology of the Appalachian Valley in Virginia (Butts, 1940, fig. 8) the Staunton fault in the Harrisonburg quadrangle southwest of the area here discussed is shown as being associated with an overturned fold. Elsewhere in the Valley southeast of this area windows have been eroded through the hanging wall block of the Staunton fault and outliers of this block have been separated from the main thrust mass by erosion: such features are characteristic of a rather low dip of the fault. The fault mapped in the Mount Jackson quadrangle as the Staunton fault by Butts ("Staunton" fault of this paper) does not correspond well to the description above. On the other hand, all the features named might be related to the Lincoln Hill fault, which is a low angle thrust fault associated with an overturned fold.

Traced southwestward into the Harrisonburg quadrangle, the Lincoln Hill and Staunton faults appear to converge; such an explanation would more easily solve the problem of how to get the beds on either side of the Staunton fault to dip in the same direction, i.e., to the southeast. In the Broadway quadrangle east of the Mount Jackson quadrangle the Lincoln Hill thrust mass over-rides the axis of the Smith Creek-Short Mountain syncline, so that the west-dipping Edinburg formation rests on the Martinsburg formation which here dips to the east; still farther to the southwest the thrust block rests on the Edinburg formation. With progressive westward displacement, increasingly younger beds would appear in the hanging-wall block and thus the Beekmantown formation in this block would rest on the Edinburg formation in the footwall block, as is the case. Actually, the entire western limb of the Endless Caverns-Hyden Spring anticline has been cut out to the southwest. With final convergence of the two faults, the eastern limb of the Endless Caverns-Hyden Spring anticline comes to rest on the western limb of the Smith Creek-Short Mountain syncline and the strata in the hanging-wall block therefore dip in the same direction as those in the footwall block.

Work now in progress in the Harrisonburg quadrangle should show more fully the exact relation between the two faults.

It would seem, then, that the Lincoln Hill fault originated in an overturned anticline. The "Staunton" fault is a later feature formed as a branch of the main overthrust and with a somewhat higher dip.

Smith Creek-Short Mountain syncline

The syncline to the west of the Endless Caverns-Hyden Spring anticline is called the Smith Creek-Short Mountain syncline after Short Mountain, which is the topographic expression of the northern end of the fold, and Smith Creek, which follows the axis of the fold in the southwest. Like the anticline to the east, this syncline has been included by others at least in part in the Massanutten synclinorium; for reasons similar to those given in the section on that anticline, however, the fold is here excluded from the synclinorium.

Strata included within the syncline range from the Massanutten sandstone, which lies along the axis of the fold in the northeast, to the New Market and Lincolnshire limestones on the eastern and western limbs of the fold.

The fold is asymmetrical, but for the most part neither limb is overturned. The general dip of strata on the western limb is 20-30° SE;

that of strata on the eastern limb, 70-90° NW. Locally in the southwest the eastern limb of the fold is overturned and associated with faulting as described above.

The syncline plunges to the north at an angle about the same as that of the anticline to the east. The northward plunge is indicated in part by the presence of older strata along the axis of the fold to the northeast, where beds as high stratigraphically as the Massanutten sandstone are present; however, this portion of the syncline is also higher topographically than the portion southwest of U. S. Highway 211 and the presence of stratigraphically higher beds might possibly be due to this difference in elevation. A second possible criterion for the northward plunge of the syncline is the narrowing of the gap between the New Market and Lincolnshire limestones on opposite limbs of the fold; however, the dips of the strata on the eastern limb of the fold increase in this same direction and southwest of Endless Caverns the syncline is narrowed by thrust faulting, and either of these two causes could account for this southward narrowing of the syncline, probably about equally as well as a northward plunge. Finally, at one or two localities the actual plunge of the fold could be measured by (1) the dip of the lineation due to the intersection of rock cleavage and bedding and (2) the dip of beds striking at about right angles to the trend of the fold. In these cases the plunge was found to be about 15° NE.

In most places where exposures along the axial trace of the fold are accessible, the exposed strata belong to the Martinsburg formation. This formation is rather weak and in all outcrops rock cleavage superimposed on the strata during their deformation is quite strikingly developed; in most cases it is far more obvious than the bedding of the formation. The cleavage in such cases has a strike of N 25-35° E and a dip of 35-55° SE. The excellent parallelism of the strike of such cleavage to the general trend of the axis of the fold would make it seem fairly safe to infer that its dip is parallel to the dip of the axial plane of the fold.

Minor folding marginal to the syncline is present in the southern part of the area south of U. S. Highway 211. Here the structure of both the eastern and western limbs of the main fold is complicated by a number of small folds on both the eastern and western limbs. Those on the western limb that are important enough to be shown on the map are two in number. They appear to be more or less symmetrical and they plunge to the northeast at about the same angle as the main syncline. Their presence only in the southern part of the fold may be indicative of a greater compressive stress here than in the northeast; such a stress is further indicated, of course, by the thrust faulting along the eastern limb of the fold.

Mount Jackson anticline

The Mount Jackson anticline is a rather curious structure when compared with the folds that lie farther to the east. It is quite broad and open, whereas the others are narrow, at places tight folds; it shows no definite plunge, whereas the eastern folds do; it has no well-defined axial plane or even axial trace as do the folds to the east.

The anticline is named from the town of Mount Jackson, which lies within the fold at the northern margin of the map. The trend of the fold is to the southwest and it includes most of the hilly region between the north Fork of the Shenandoah and State Highway 42. The oldest formation exposed in the anticline is the Conococheague limestone, the sandy beds in which form this hilly terrain.

The eastern limb of the fold has a general dip of 20-30° SE. The axial trace of a fold can be followed from near the intersection of State Roads 698 and 767 west of Quicksburg through the hill east of Pine Hill, northwest of New Market Station. This may well be the axial trace of the Mount Jackson anticline, but the structure of the fold has been further complicated to the west and this cannot be stated with certainty. The strata west of this axial line dip to the northwest, but not too far to the northwest they pass through a minor syncline and the dip is reversed.

The minor folding by which this major upwarp is complicated are further expressed in the outcrop pattern of the chert member of the Beekmantown formation along the western limb of the fold.

3 South of Holman Creek two subsidiary synclines complicate the structure along the western limb of the major fold. The one to the northwest is the better of the two in topographic expression. The prominent hill north of Kipps School ~~(Plate 19)~~ is a direct result of this syncline, since it is capped by a remnant of the chert member of the Beekmantown in the trough of the syncline. The Conococheague limestones are flat-lying where the axial trace of this syncline crosses State Road 767. The plunge of the fold is to the southwest. The second minor fold is less conspicuous topographically; it lies southeast of the first one. It also is indicated in the outcrop pattern of the Beekmantown chert member and its trough is marked by the flat-lying limestones in the valley of the tributary to Holman Creek one mile WNW of Quicksburg.

North of Holman Creek the anticline appears to be beset with two minor synclines. Actually the two apparent synclines are probably one and the same; the one to the west is in the Beekmantown chert member, while the one to the east is its extension into the Lincolnshire-New Market limestones. The plunge of this fold is to the northeast. Topographically it is represented by the hill northwest of Williamsville.

Along the western limb of the main anticline the strata are overturned for a rather large part of the distance. The northernmost outcrop of overturned beds was at the foot of the large conical hill west of Williamsville, where the dip is 55° SE; southward, overturned strata were observed as far as one mile south of Forestville. The western limb of the fold, in addition, is broken by a thrust fault (Saumsville fault, below).

Following this rather rambling account of the structure, an interpretive summary should be added. The axial trace of the Mount Jackson anticline strikes NNE, crossing State Road 767 about half a mile northwest of Quicksburg. A second minor anticline is separated from the main Mount Jackson fold by a syncline, the axial trace of which crosses State Road 767 about three-quarters of a mile farther west; this syncline is further expressed by the "kink" in the Beekmantown chert member on the west limb of the fold south of the county line. The syncline dies out to the northwest. A second, more important syncline deflects the outcrop belt of the Beekmantown chert member north of Williamsville and again east of Kipps School. This syncline is doubly plunging, reaching a culmination along the line marked by Holman Creek. To the west of this syncline lies another anticline; it is actually the western limb of this anticline that is overturned, not the western limb of the Mount Jackson anticline proper.

Structures near Forestville

The area to the northeast and southwest of the town of Forestville is one of some structural complexity which, however, shows a certain degree of unity. These structures consist in the first place of a thrust fault which passes to the east of the town; between it and the western limb of the Mount Jackson anticline are squeezed in two long narrow synclines that are separated by an equally long and narrow anticline. West of the fault the Edinburg formation is greatly deformed. Only locally, however, is the structure reflected in the mapping of the strata; in these cases the Oranda formation is contained in elongate narrow synclines.

The thrust fault has been named the Saumsville fault. The folds to the east of the fault will be considered as one unit and those to the west as another.

<u>Eastern folds</u>. The strata to the west of the Mount Jackson anticline have been thrown into a rather tight asymmetrical syncline the axial plane of which dips to the southeast. The fold includes beds as young as the upper member of the Edinburg formation. Dips along the eastern limb of the fold range from normal to overturned; they are generally higher than 45°. The dip of the western limb of the fold is less.

To the west of the syncline lies a long narrow anticline, the presence of which southwest of State Road 720 is expressed mainly by a narrow strip of the basal Edinburg formation that extends as far southwest as the junction of State Roads 733 and 42. The anticline plunges to the southwest, but apparently the angle of plunge is low, thus accounting for the great distance through which the basal Edinburg formation is exposed at the crest of the fold. Towards the northeast the two limbs of the fold diverge and beds of the upper Beekmantown formation are included along the axial trace of the fold at the northern margin of the map. Southwest of the last outcrop of the basal Edinburg formation in that direction the anticline can be followed to the western margin of the area mapped by noting the change in dip of the beds of the upper member of the formation.

Between this anticline, which we may call the Forestville anticline, and the Saumsville fault there occurs a second syncline near the northern map boundary. This fold includes beds as high as the upper member of the Edinburg formation. The syncline plunges to the southwest, but in this direction it is cut off by the Saumsville fault.

Saumsville fault. This is a high-angle thrust fault which passes through the eastern edge of the town of Forestville and thus lies west of the folds mentioned above. It was named the Saumsville fault by Edmundson (1945).

No actual exposure of this fault could be found in the Mount Jackson quadrangle. In the Edinburg quadrangle to the north, however, exposures of the fault do occur. The best of these occurs in a low road cut along Virginia Highway 263 about three miles west of the town of Mount Jackson and about half a mile north of the quadrangle boundary. The fault here is marked by a sheared zone in the Edinburg formation; the cleavage in this zone dips at 60° SE and is almost certainly parallel to the plane of the Saumsville fault. A similar dip can be inferred from relations along the trace of the fault in the Mount Jackson Quadrangle.

Along most of its trace in the Mount Jackson quadrangle, the fault is bordered on both sides by the Edinburg formation, and it is generally difficult to locate the fault. In most places it is indicated only by a sudden change in the dip of the Edinburg formation. At its southern end, at the last place where the fault could be definitely located, a minor syncline west of the fault contains at least the lower part of the Oranda formation; about 100 feet east of this syncline in the Oranda formation is exposed the top of the basal clastic member of the Edinburg formation. The distance between the base of the Oranda formation and the top of the basal member of the Edinburg formation in this locality is too small to include the entire thickness of the upper member of the Edinburg formation; the cause of this shortening of the section here is thought to be the Saumsville fault.

About two miles north of Forestville the fault cuts westward across the axis of the western syncline referred to in the section above. Since this syncline lies east of the fault, the Edinburg formation in the footwall block is overthrust successively by beds of the Edinburg, Lincolnshire, New Market, and Beekmantown formations.

In the southwest the fault originates in a small asymmetric syncline in the Edinburg formation; that is, the western limb of the Forestville anticline is broken by the fault, the axis of the anticline having been thrust to the westward over the trough of the syncline adjacent to it. The trace of the fault continues to parallel the axial trace of the Forestville anticline for about five miles, beyond which it turns somewhat to the west, as was mentioned above. The syncline east of the fault along the northern map bordered is interpreted as the northern extension of the syncline west of the fault at its southern end.

Still farther to the northeast the Saumsville fault joins the North Mountain fault near the town of Saumsville. It appears to be a minor branch of this somewhat more impressive North Mountain fault.

Western folds. The folds west of the fault consist of a number of tight overturned or asymmetric anticlines and synclines. The structures are confined to the Edinburg, Oranda, and Martinsburg formations; only where there is stratigraphic criteria for the folds, however, are they shown on the map. Thus, on the map they are represented by elongate elliptical strips of the Oranda formation southwest and west of Forestville. These, then, are synclines which may contain strata belonging to the basal Martinsburg formation as well as to the Oranda formation.

Three elliptical areas of Oranda formation are shown in this belt along the western side of the fault. Of these, the southwestern two are probably part of the same fold; the separation of the Oranda formation into two strips is due to the topography, the two areas being separated by a valley. The axis of the northeastern area of Oranda formation, however, is offset to the northwest of the prolongation of the axis of the southwestern fold. The presence here of the southwestern fold is indicated to the southeast of the northern one by a change in dip in the Edinburg formation.

The northeastern fold is apparently a simple syncline which is overturned to the northwest.

The southwestern fold is somewhat peculiar. About three-fourths mile southwest of Forestville it is split into two synclines which are separated by a narrow doubly-plunging anticline; farther to the southwest, where the anticline again disappears, the two synclines are again joined into a single fold. The syncline is overturned to the northwest, with the axial plane dipping about 65° SE, as indicated by cleavage developed in the Oranda formation.

Cleavage is quite well developed in the strata to the west of the Saumsville fault, and in many places it is such as to almost obscure the bedding of these formations. In the belt east of the fault, on the other hand, the cleavage is less marked.

Moores Store syncline

The northwestern-most structure of any major importance in the quadrangle is the Moores Store syncline, the axial trace of which lies about one mile northwest of Forestville. The fold is named from Moores Store in the Broadway quadrangle to the west.

The syncline includes beds as high as the lower Martinsburg formation. It is overturned to the northwest: along State Road 729 the eastern limb has a dip of 60° SE, the western limb a dip of 40° SE. Rock cleavage is quite prominent in the Oranda and Martinsburg formations. Westward the dip of the strata decreases, reaching 25° SE in the northwestern corner of the map. Just beyond this point, about half a mile beyond the map border, is the trace of the North Mountain fault.

AGE OF THE STRUCTURES

There is evidence within the quadrangle of at least two and probably of three Paleozoic or later episodes of mountain building. One of these is indicated by the actual structures into which the strata have been deformed. The other two are indicated by the influx of coarse clastic material into the Appalachian trough. The first two epochs of deformation can be closely date; the third is about as vague in time relations as can be imagined.

Taconian disturbance. The first epoch of montain building occurred in the Late Ordovician and Early Silurian; this is the Taconian orogeny. It is represented by the detrital sediments now consolidated into the Martinsburg, Cub, Massanutten, and Bloomsburg formations. The area of maximum uplift lay to the east of the present exposures of these formations, since they were structurally unaffected by this deformation. The area was not entirely neglected, however: uplift here was great enough to cause the erosion or non-deposition of the Juniata and much of the "Oswego" formations. Similar stratigraphic relations exist in the vicinity of Harrisburg, Pennsylvania, where G. W. Stose (1930) has found an angular unconformity between the Martinsburg formation and the Tuscarora sandstone. Intensive search within the Mount Jackson quadrangle, however, has failed to reveal such a relation here. The angular unconformity at Harrisburg coupled with similar relations farther north in New York shows that the uplift was orogenic, not epeirogenic. The chain of mountains resulting from this orogeny is generally conceded to have reached "at least as far south as New Jersey" (Dunbar, 1949). On the basis of the disconformity at the base of the Silurian in this quadrangle and the analogy between the Massanutten sandstone and the Shawangunk conglomerate in New York, the former extent of the Taconic uplift can be extended at least into central Virginia. To the east, in the Virginia Piedmont, the metamorphic and igneous rocks of which that province is composed may in part represent the roots of Taconian mountains. Igneous activity in this region appears to have taken place during this time interval: uraninite from pegmatites associated with granitic intrusions in North and South Carolina give ages of 320-350 million years for this episode of magmatic activity, which would date this activity as Late Ordovician. (Rodgers, 1952, pp. 419-20)

Acadian disturbance. The initial stages of a second epoch of orogenic deformation to the east of the Massanutten synclinorium is represented by the detrital sediments of the Romney group in the synclinorium. These rocks are of Middle Devonian age, and the sequence here is analogous to the Middle

Devonian of New York, Pennsylvania, and western Virginia. In the latter areas these Middle Devonian formations are followed by still coarser sedimentary rocks in the Upper Devonian; in the Massanutten synclinorium, however, these Upper Devonian rocks are lacking. It seems probable, however, that the folding and faulting of the rocks within the quadrangle did not originate during this period of uplift. The character of the Upper Devonian strata in western Virginia is not what would be expected if mountain building had taken place in the Mount Jackson quadrangle in the Late Devonian. Facies changes in the Upper Devonian in the Appalachians indicates rather that the uplift responsible for this Upper Devonian detritus had its center farther to the northeast, probably in eastern Pennsylvania and eastern New York. The Upper Devonian formations show a progressive expansion of the area of subaerial deposition during the course of the Late Devonian epoch; the amount of continental deposits decreases toward the west and south from the central New York-Pennsylvania region. This might be thought of as due to greater depth of the water in the geosyncline in these directions; however, at the same time there is a decrease in the thickness of the Upper Devonian in these same directions. The effects of the Acadian orogeny in eastern Virginia, as indicated by the sediments poured into the trough to the west, seem to have been less severe than those of the Taconian orogeny.

Appalachian revolution. As has been noted by a number of geologists, the term applied to a given episode of diastrophism depends to a large extent upon the effects of that episode which are to be seen in a given area. Thus, eastern geologists have developed a strong tendency to speak of the orogenic epoch which gave rise to the Sierra Nevada as the "Nevadian disturbance" (e.g., Dunbar, 1949, p. 336). It cannot be doubted that a Californian, on the other hand, would call this episode the Nevadian revolution. The terminology is subjective; the present writer accepts it as such and feels no necessity for refraining from "plugging" the most spectacular of the episodes of orogeny represented in the Mount Jackson quadrangle, the "Appalachian Revolution".

The two episodes of mountain-building of which we have evidence from the rocks in the quadrangle have been more or less certainly eliminated as the cause of the structures mapped in this area. As mentioned above, the ages of these two disturbances can be rather closely dated. It is somewhat unfortunate — one might almost say embarassing — to be confronted with the fact that the orogenic movements represented by the structures within the quadrangle can be only poorly dated from evidence within the quadrangle and can be only roughly approximated from evidence gathered elsewhere in the Appalachians.

Within the Mount Jackson quadrangle, the youngest unit affected by the folding and faulting characteristic of the Appalachians is the Mahantango formation of Middle Devonian age; the oldest unit unaffected by these structures is the Page Valley gravel of Cenozoic (probably Pleistocene) age. Thus, deformation of the Paleozoic formations must have taken place sometime between the Middle Devonian and sometime in the Cenozoic. We are thus faced with a range of one entire era and parts of two others!

Within the State of Virginia the evidence is somewhat more definite, serving to narrow this range considerably. The Newark basin in the vicinity of Leesburg, in the northern Virginia Piedmont, contains a basal conglomerate composed largely of blocks and boulders of Cambro-Ordovician limestones in a red sandy matrix. The transportation of such limestone blocks over a distance of some ten miles from their source would require streams of rather great carrying power; blocks of this size are not being carried at present even by the strongest streams in the Appalachians. The occurrence of blocks of limestone, furthermore, argues for rapid erosion in the source area. If the climate of the area in the Triassic was humid and tropical, as has been inferred from the red color of the matrix, limestone would scarcely be a resistant rock type. Under present conditions these same limestones underly the valleys in the Appalachians; yet, during a period of intense chemical weathering, these limestones formed an area of sufficiently great relief to be subject to more violent stream erosion than can be presently found in this region. Such features can be most readily ascribed to a recently uplifted mountainous area.

This, then, gives us an upper limit for the orogenic uplift that was probably responsible for the Appalachian structures. It should be emphasized, however, that this is the upper or youngest age which can be ascribed to the structures: they may have been formed at an earlier date, with uplift of the area into a mountainous terrain coming later. That is, these Triassic conglomerates give us evidence of mountainous uplift, but not of structure. However, the two may be closely related in time.

The youngest formation in the Appalachians of Virginia that is affected by strong folding is the Mississippian (Chesterian) Pennington formation. Younger Pennsylvanian formations are folded less sharply and are cut by faults in southwest Virginia. These basal Pennsylvanian strata are quite coarse-grained, however, apparently indicating some sort of disturbance to the east. In addition, a quite considerable hiatus exists between the Mississippian and Pennsylvanian in southwest Virginia (Butts, 1940, p. 407). Thus, it is quite possible that much of the folding in the Appalachians in Virginia took place at the close of the Mississippian period, and from the landforms resulting from this deformation much of the detritus now represented in the Pennsylvanian and Permian formations was derived. However, later deformation must also have occurred, since the Pennsylvanian itself is somewhat folded and faulted. It was quite possibly as a result of this deformation that the Triassic redbeds to the east were formed.

Elsewhere in the Appalachians the situation is somewhat different. In Pennsylvania, for instance, beds as young as Pottsville (Early Pennsylvanian) are involved in the typical Appalachian folds, while the post-Mississippian (Early Pennsylvanian) disturbance noted in Virginia is apparently very slight here. In Pennsylvania also the folded Lower Paleozoic formations are overlain unconformably by the Triassic redbeds. In western Pennsylvania the oldest deformed strata belong to the Lower Permian Dunkard group, which is conformable with the Upper Pennsylvanian strata, and which may thus represent a lower limit for the age of the folding in Pennsylvania.

CENOZOIC DEPOSITS

Introduction

The most recent and by far the most complete study of the Cenozoic deposits in the Valley of Virginia is that of P. B. King (1949). King discusses the character and the thickness of the deposits of alluvium and residuum in the Elkton area, including in this study the southern part of Page Valley. Most of the field work done by the author on these deposits was finished before he became aware of King's work and it is gratifying to find that the alluvial units mapped by the author accord closely with those mapped by King.

The term Cenozoic deposits covers a variety of material. The oldest material included is the high-level stream gravels in Page and Shenandoah Valley, including a pediment or rock fan along Cub Run. Younger than these high-level gravels, but topographically lower, are the stream terraces along both the North Fork and the South Fork of the Shenandoah River: these terraces do not differ from one another other than in elevation, but on this basis several terraces can be recognized. Still younger than these terraces are the features of the valley floors of the North and South Forks. Finally, a feature which perhaps should be included as valley floor features is the travertine (or tufa) terraces or dams that are found in various parts of the Shenandoah Valley.

These Cenozoic deposits are interesting in themselves, but even more interesting is the sequence of events which can be inferred from them. Much has been written concerning peneplanes in the Valley of Virginia and elsewhere; the study of these deposits throws light on at least one of these surfaces.

High - level stream gravels

Deposits of rather coarse-grained alluvium now situated at altitudes considerably above the stream courses in the valleys are present both to the east and to the west of the Massanutten Range. The greater part of the material occurs in Page Valley, however, with only scattered remnants locally in Shenandoah Valley.

These high-level gravels are divided into three units by King (1949): the ancient gravel unit, the older gravel unit, and the intermediate gravel unit. The present writer has encountered difficulty in separating the older and intermediate units in the Mount Jackson quadrangle, and the two have been mapped as a single unit. The ancient gravel unit can be recognized at one locality, but is too small to be shown on the map.

Ancient alluvium. The ancient alluvial material (Ancient gravel unit of King) is localized at the northern end of Roundhead Ridge, in the open pit of the Stanley manganese mine. The gravel consists of fragments of rock derived from the Blue Ridge imbedded in a reddish clay matrix; the gravel has been intensely weathered and the rock fragments can be cut easily with a strong knife. The gravel has been mineralized; it contains nodules of manganese ore scattered through it and many of the rock fragments in the gravel have been in part replaced by manganese oxides. The gravel is said to rest in a basin in the older residuum overlying the Tomstown dolomite (King, 1949) and it is overlain unconformably by the younger gravel unit.

Page Valley gravel. The Page Valley gravel of this dissertation includes the older and the intermediate gravel units of King (1949). The older and intermediate units can be separated locally, as along U. S. Highway 211, but in general the topographic expression of the two is so similar as to give no hint of two stages of gravel deposition.

The gravel is concentrated in the southern part of Page Valley near the Shenandoah salient. Thinner gravels occur to the west along the front of the Massanutten Range, but their occurrence is so erratic and their thickness so small that no attempt was made to map these gravel bodies. Erosional remnants of the Page Valley gravel are found north of Leaksville, but these are small in area compared to the gravel south of Leaksville.

The gravel is composed of cobbles and boulders of quartzite in a reddish sandy matrix. The material is derived largely from the formations in the Chilhowee group in the Blue Ridge, although near the Massanutten Range some Massanutten sandstone fragments are also found. The fragments are subangular; rounding is sufficient, however, to give the impression that the gravel is stream-deposited rather than composed of sliderock. The matrix of the gravel is probably derived from the shaly strata in the Chilhowee group (Harpers shale) or from the Catoctin greenstone below the Chilhowee; the Catoctin greenstone on weathering gives rises to a sandy clay of reddish color which is quite similar to the interstitial material in the gravel.

The surface of the Page Valley gravel rises in a sweeping curve toward the Blue Ridge, the gradient steepening rapidly as the front of the mountains is approached. The elevation of the outer limit of the gravel ranges from 880 to 960 feet, decreasing northeastward in accordance with the fall of the South Fork of the Shenandoah. The thickness of the gravel is probably about 100 feet, although the thickness will vary greatly from place to place depending on the original thickness of the gravel and the amount that has subsequently been removed by erosion. The gravel reaches its greatest thickness near the edge of the Shenandoah salient.

Along the front of the Shenandoah salient the Page Valley gravel apparently forms a number of alluvial fans that spread outward from the mountain front to form an alluvial plain near the river. The form of these fans in profile can be seen from many places north of the Shenandoah salient. The increase in thickness of the gravel toward the mountains is additional evidence of this character.

Along Cub Run at the front of the Massanutten Range another fan-like features occurs. Here the fan is well expressed topographically. Similar fan-like features can be seen farther south at Runkles Gap and Harshberger Gap. However, the gravel in these fan-like forms occurs as a relatively thin veneer over a bedrock surface which has the actual fan shape seen in the topography. Such a feature is generally called a pediment or a rock fan. Pediments have been described from many areas in the Great Basin country of the west, but as far as the writer knows the term has not yet been applied in the Appalachians. Nevertheless, the term is applicable to these features along the east front of the range. Since their formation the pediments here have been dissected by the streams flowing down their slopes. The streams have maintained the divergent pattern possessed by the original rills and streams on the pediment surface, emphasizing the fan-like character of the surface. The erosion that has taken place since the pediments were formed has also removed a large part of the alluvium with which they were originally covered. Valleyward the pediment of Cub Run ends rather abruptly in a scarp of some one hundred feet, below which lies the present surface of the Page Valley gravel. Thus the pediment gravels would probably belong to the Older gravel unit of King (1949) while the Page Valley gravel below the scarp probably is his Intermediate gravel unit; this is one of the few places where the two units can be separated.

a. Page Valley gravel in abandoned manganese mine at the north end of Roundhead Ridge, Page County.

b. Page Valley gravel resting on deeply weathered Conococheague limestone at Shenandoah, Page County.

a. Page Valley gravel in roadcut along U. S. Highway 211 near Hamburg, Page County.

b. Page Valley gravel, showing the presence of two distinct gravel units; locality same as above.

A distinct break within the Page Valley gravel can also be seen along U. S. Highway 211: in the new roadcut southwest of Hamburg the Page Valley gravel is well exposed and, at the time of this writing, had not yet been seeded by the Department of Highways. At several places along the cut two gravels can be seen; the upper, younger gravel is less decomposed than the underlying one, though in neither has decomposition seriously affected the quartzite fragments. The younger of these two gravels contains indistinct layering which is parallel to the surface of the older gravel (Plate 35).

Shenandoah Valley gravels. West of the Massanutten Range the highest terrace gravels occur along the crest of a ridge which leads south from Rudes Hill, about 2-1/2 miles south of Mount Jackson, and in a roadcut on the north side of the North Fork of the Shenandoah, opposite Plains Mill on Virginia Highway 260. In both localities the material consists of isolated patches of alluvium; the character of the gravel at Rudes Hill and Plains Mill is quite different, however.

At Rudes Hill the gravel is composed of cobbles of white medium-grained orthoquartzite, probably derived from the slopes of the Massanutten Range and deposited here by the ancestor to present Smith Creek. The gravel rests on an erosional surface on the Ordovician carbonate rocks at an altitude of about 980 feet.

The Plains Mill gravel is exposed only in one locality, in a roadcut about 100 yards long on State Road 616 near its intersection with State Road 617. The deposit is quite striking in appearance: it consists of angular slabby fragments of carbonate — or originally carbonate — rocks that range from one to eight inches in maximum diameter. The platy character of the fragments appears to be due to the original thin bedding of the

a. Plains Mill gravel, showing resistant ledge of partly cemented material. Across the South Fork of the Shenandoah from Plains Mill, Shenandoah County.

b. Plains Mill gravel, same locality as above, showing a closer view of the gravel.

rocks; the angular character of the fragments is undoubtedly due to the absence of any hard sandstone fragments which would soon have rounded off the corners of the carbonate fragments. Some sandstone fragments do occur, but these are not composed of hard orthoquartzite like the Tuscarora sandstone cobbles which comprise the modern stream gravels in the area. The sandstone fragments in the Plains Mill gravel was derived most probably from the sandstone layers in the Conococheague limestone: they are composed of gray medium-grained calcareous sandstone or sandy limestone. Other detrital rock types represented among the gravel grains include yellowish or greenish finely laminated siltstone, the type of material formed by the weathering of the Elbrook formation. Slabs of aphanitic light-colored platy dolomite are not uncommon; this is the typical unweathered Elbrook formation. Carbonate rocks from the Conococheague limestone are also represented: blocks of limestone or dolomite breccia, often with a sandy matrix, occur in the gravel as well as fragments of the more common dark-gray limestone. Reddish aphanitic limestone fragments in the gravel may have originated in the Edinburg formation, which locally has been found to contain such material, or it may more probably represent some of the red layers in the Elbrook formation. One puzzling aspect of this gravel is the absence of any lithology similar to that of the Ordovician limestones and dolomites which are closer to the deposit than the Elbrook formation, at least. It would seem that at least some chert from the Beekmantown formation should be present; however, no Beekmantown chert is present in even the modern stream gravels, and it may be that the chert weathered out of the Beekmantown forms too large fragments to be carried by the stream. Certainly one glance at an area underlain by the Beekmantown chert member is sufficient to convince one that a large part of the chert still covers the surface of the ground.

In the two tables below are listed various types of lithology represented in the Plains Mills and in the modern stream gravels; the samples of modern stream gravel were taken from the channel of the North Fork of the Shenandoah west of New Market

Lithology of the Plains Mill gravel

	a	b
Light-colored laminated siltstone	35.0%	25.0%
Gray platy silty limestone	19.0	17.5
Sandy gray limestone or calcareous sandstone	17.0	20.0
Light-colored aphanitic dolomite	14.0	12.5
Dark gray limestone	7.0	—
Red aphanitic limestone	3.0	5.0
Gray aphanitic limestone	3.0	5.0
Limestone or dolomite breccia	1.0	15.0

a Count of 100 pebbles 1 to 3 inches in diameter
b Count of 40 pebbles over 4 inches in diameter

Lithology of modern stream gravel

	a	b
Yellowish- or brownish-green sandstone	31%	14%
Red and reddish-brown sandstone	25	10
Gray-green sandstone	18	24
White quartzite	13	18
Purple quartzite	6	8
Gray quartzose conglomerate	2	8
Light-colored aphanitic limestone	2	-
Gray quartzite	1	4
Light-brown sandstone	1	4
Gray fine-grained sandstone	-	2
Tan siltstone	1	-
Yellowish dolomite	-	2
Yellowish sandstone	-	6

a Count of 100 pebbles 1 to 3 inches in diameter
b Count of 50 pebbles over 3 inches in diameter

The source area for this Plains Mill gravel must have lain east of Little North Mountain, since no formation lying in or to the west of Little North Mountain is represented in the rock fragments in the gravel. On the other hand, all of the rock fragments in the Plains Mill gravel can be correlated with formations which are exposed to the east of the mountain.

Since it seems to be rather certain that the gravel was deposited by the North Fork of the Shenandoah or by an ancestor of the present North Fork and not by the small tributary flowing down the valley just southwest of the gravel deposit, the ancestral North Fork did not cut through Little North Mountain at the time the gravel was deposited.

It cannot be stated with certainty that the Rudes Hill and Plains Mill gravels are of the same age. They lie at about the same altitude, the base of the Rudes Hill gravel being slightly lower, but the great distance between them would make it hazardous to correlate them. That the Rudes Hill gravel is dominantly of quartzite fragments is not too significant, since these rock fragments were probably derived from the Massanutten Range rather than from Little North Mountain and this gravel may well have been deposited by Smith Creek rather than by the North Fork of the Shenandoah.

Stream terraces

Stream terraces are bench-like land forms of erosional origin that are found along stream courses and which occur at altitudes above the present valley floors of these streams; furthermore, they are remnants of former valley floors once occupied by the streams and as such indicate rejuvenation of the streams. The floor of a stream valley may be either erosional or depositional in origin; similarly, the terraces along the stream may be either cut from the bedrock of the region or they may be cut from a former valley fill. The former are strath terraces; the latter, "fill terraces". The terraces on opposite sides of a stream may be paired or non-paired; that is, they may lie at the same elevation on opposite sides of the valley or they may lie at different elevations. Even in a series on non-paired terraces, however, the uppermost terrace level will consist of paired terraces.

As was stated above, stream terraces are evidence of rejuvenation of the stream. This rejuvenation may be due either to regional or local diastrophism or to climatic changes, such as increase in precipitation. If rejuvenation of a stream proceeds from the mouth of the stream towards its source, that is, if rejuvenation is not simultaneous along the entire length of the stream, at some point along the stream's course there will be a break in its gradient at the point where the new valley floor resulting from rejuvenation intersects the former valley floor. Such a break in the stream profile has been called a knickpoint. Downstream from this knickpoint the former valley floor will be represented by a stream terrace; the vertical distance between this terrace and the new valley floor will decrease headward until, at the knickpoint, the two will coincide. The Appalachians, with their trellis type of drainage, offer a good opportunity for the development of such features. Thus, uplift taking place along an axis parallel to the general trend of the Appalachians would rejuvenate the streams flowing southeastward simultaneously along the entire course of the stream seaward from the axis of uplift. Streams flowing along the longitudinal valleys of the Appalachians and hence parallel to the axis of uplift, however, would not be directly rejuvenated by this uplift. Instead, rejuvenation of these streams would proceed headward from their junction with the master streams in order to keep pace with the downcutting of the master streams.

Examples of all of the features mentioned above can be seen within the Mount Jackson quadrangle. The stream terraces in this area are best developed along the North Fork of the Shenandoah, but terraces are not by any means lacking along the South Fork.

North Fork terraces. The terraces along the North Fork of the Shenandoah, along with those of its tributary Smith Creek, are much better developed than the South Fork terraces. Along the North Fork the development of the terraces shows no relation to the lithology of the underlying bedrock.

The highest of the North Fork terraces lies at an elevation of about 60 feet above the present floor of the valley of the North Fork. It is best preserved in the vicinity of Shenandoah Caverns, south of Mount Jackson. Other possible remnants of this terrace, however, occur in the relatively flat area across the railroad from Quicksburg and on the bend of the river east of St. Martins Church. At these last two localities the upper surface of the terrace is uneven and the terrace, if present here, has been modified by later erosion since it was formed. The terrace surface is locally covered with a thin gravel veneer and is essentially a strath terrace; this same statement can be applied to the other terraces in this area.

About 20 feet below the surface of this upper terrace lies the top of a second terrace. This second terrace is more perfectly preserved than the 60-foot terrace above and in addition is present on both sides of the river; that is, the 40-foot terrace is composed of two paired terraces. The best-preserved remnants of this 40-foot terrace can be seen to the east of New Market from Virginia Highway 260 (Plate 37), on the east side of the stream, and along State Road 730 between Shenandoah Caverns and U. S. Highway 11, on the west side of the river. Bedrock exposures are common in the scarp below the terrace. The 40-foot terrace is better preserved east of the river, as can be seen from the map, not necessarily because it was better developed here originally, but at least in part because it has been destroyed largely west of the river in the cutting of

a. Strath terrace along the South Fork of the Shenandoah River west of New Market, Page County.

b. Strath terrace along the South Fork of the Shenandoah west of Rudes Hill, Shenandoah County.

the next lower level.

The third terrace along the North Fork, the 20-foot terrace, is developed best to the west of the river. No remnants of this terrace occur on the opposite side of this stream south of Rudes Hill. The terrace is interpreted as due to a gradual shifting of the channel of the stream to the northwest following the cutting of the 40-foot terrace, thus destroying in part the 40-foot terrace west of the river. On the other hand, it is equally well explained by a shift of the stream channel to the southeast after the cutting of the 20-foot terrace.

The 20-foot terrace is found for some distance along Smith Creek, which flows into the North Fork south of Mount Jackson, as well. Development of this terrace, however, is limited to that part of the stream valley north of the Rockingham-Shenandoah county line. The last remnant of this terrace on Smith Creek is seen about half a mile north of the county line. This disappearance of the 20-foot terrace is interpreted as a knickpoint such as was described above. The valley floor surface south of the county line is then correlated with the 20-foot terrace level to the north along Smith Creek. The valley floor surface north of the knickpoint is then younger than the similar surface to the south. At one time a similar break in profile must also have been present in the channel of the North Fork. However, because of the greater volume and hence the greater erosive ability of the North Fork, the knickpoint along that river has migrated headward to a point beyond the borders of the Mount Jackson quadrangle. Along Smith Creek, with its lesser volume, headward migration of the knickpoint has been slower.

South Fork terraces. The terraces along the South Fork of the Shenandoah differ in some of their aspects from those along the North Fork. Along the

South Fork the development of stream terraces is much more restricted than along the North Fork, where the river was bordered by terraces along almost its entire course through the quadrangle. Along the South Fork the relation between the size of the stream terraces and the lithology of the bed rock is quite remarkable. With a few very minor exceptions the terraces are limited to that part of the stream's valley that is cut into the Martinsburg and Edinburg formations. These two formations, then, being of quite similar lithology, are the least resistant to stream erosion of the entire Cambro-Ordovician sequence.

One of the more unusual geomorphic features emphasized by the mapping of the South Fork terraces is the abandoned meander on the west side of the river south of U. S. Highway 211. Topographically the meander consists of a broad, rather flat-bottomed horseshoe-shaped valley circling a small elongate hill. The valley is now drained by two streams, both of which are much too small to have been responsible for the cutting of the valley. Three terraces can be distinguished inside the meander as well as elsewhere along the South Fork.

Between Grove Hill and Alma, both of which lie on Virginia Highway 12, the South Fork flows across an area underlain by the Cambro-Ordovician limestones and stream terraces are lacking throughout this distance; thus the terraces can be divided into two groups, a southern group and a northern group.

In the southern terrace group, which lies along the river between the southern map boundary and Grove Hill, only one terrace is present. This is developed locally along the north sides of the meanders of the river and has an elevation of 20 feet above the valley floor. It is a strath terrace, but with a thin gravel cover over its surface.

Three terraces can be distinguished in the northern terrace group, which is best developed between Alma and U. S. Highway 211. The upper terrace in this group has its surface at an elevation of 60 to 80 feet above the valley floor; it is not too well preserved. The terrace remnants alternate on the two sides of the river, a feature common to all of the terraces in this group. Apparently the processes operating here have been tending to intensify the meanders along the river, that is, there has been a tendency for the radius of curvature of the meanders to decrease with the passage of time (i.e., in lower terrace levels) and in one case the process has "gone to completion", since the stream has cut across the meander neck and abandoned the meander.

The next lower terrace lies at an elevation of 40 feet above the valley floor and is confined to the abandoned meander south of U. S. Highway 211 and to the area north of Alma; like the upper terrace, it is a strath terrace. Below the 40-foot terrace lies a third terrace at an altitude of 20 feet above the valley floor. The meander mentioned above was cut off at sometime between the formation of this terrace and the one above it.

The relation between the terraces in the northern and southern groups is quite uncertain. It would be unjustified, for instance, to correlate the 20-foot terrace in the southern group with that in the northern group.

Valley floors

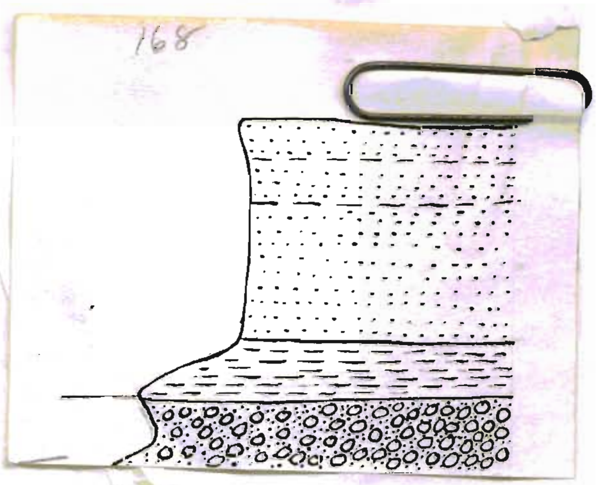
The valley floor is the flat bottom portion of a stream valley; the term is not necessarily synonymous with the flood plain of a stream, a more commonly used term. The flood plain of a stream is the portion of a valley floor that is subject to overbank floods. In the case of the two forks of the Shenandoah River floods are rather uncommon and the determination of what part of the valley floor is subject to flooding was impossible.

A valley floor is present along at least a part of the North Fork and the South Fork. Differences between the valley floors of these two streams are similar to the differences between their terraces.

North Fork. Along the North Fork of the Shenandoah the valley floor is, in many cases, half a mile or more in width. In addition, a valley floor is present along the entire course of the stream in the quadrangle; that is, at no place is the entire valley floor occupied by the channel of the stream. At its narrowest point, one and a half miles north-northwest of New Market, the width of the valley floor is only about two hundred yards; at its widest point, in Meems Bottom south of Mount Jackson, the valley floor is some 2300 yards wide.

Along most of its course the North Fork has carved its valley floor out of the bedrock of the area, so that it is in general a valley strath rather than a valley fill. Bedrock outcrops are quite common in the channel of the stream and along its banks southwest of the town of Quicksburg.

Northeast of Quicksburg, however, the character of the valley floor changes and at least one of the banks of the channel is composed of alluvium. A few hundred yards south of State Road 730 a good section of this valley fill is exposed along the west bank of the river. Just below the level of the river the sediment



composing the channel's side is a gravel consisting of cobbles of sand-stone and quartzite, all well-rounded, similar to those found in the "bars" in the channel at the present time. The total thickness of this gravel layer is not known; the thickness measurable at the locality mentioned above is two feet. The gravel bed is overlain by about three feet of orange-colored sandy clay, somewhat more resistant than material above, which forms a sloping shelf down to the edge of the stream. This shelf is about four feet wide. At the top of the section are eleven feet of light orange-brown clayey sand which compose the river cliff here. Within this upper eleven feet are two minor breaks of uncertain origin, possibly old soil layers. They lie about two feet apart, the upper one being about two feet below the top of the scarp. Similar material appears to underlie the rest of the valley floor to the north, and such material almost certainly forms the fertile lowland of Meems Bottom at the confluence of the North Fork and Smith Creek.

<u>South Fork</u>. Along many parts of the South Fork of the Shenandoah a distinct valley floor is lacking; that is, along much of the course of this stream the entire valley floor is occupied by the channel of the stream. Like the strath terraces along this stream, the valley floor shifts from one side of the stream to the other. Like the terraces also, the valley floor is generally limited to portions of the stream valley underlain by the Martinsburg and Edinburg formations, although this restriction is less effective tahn in the case of the terraces. Where present, the valley floor has an average width of 450 to 500 yards; at its widest point just south of U. S. Highway 211 it is 1300 yards wide. For the most part the valley floor along the South Fork is cut from the bedrock, although locally

it flows over a valley fill. The largest area of alluvium lies along the south bank of the river about a mile north of the town of Shenandoah. Here a large sand pit is now being operated in the light yellowish sand. No lower gravel layer such as was found along the North Fork occurs here. The sand seems to have been deposited along the slip-off side of the meander as the river shifted to the north.

Tufa deposits

Tufa, according to Pettijohn (1949, p. 308), is a spongy porous limestone that forms a thin surficial deposit about springs and seeps and exceptionally in rivers. It is to be distinguished from travertine, which is more dense and banded. The deposits found in the Valley of Virginia are commonly called travertine by workers there, but are actually tufa according to the definition given above. The tufa occurs in two different ways, although in both cases it is a stream deposit. Large amounts of the material are deposited as dams across some of the smaller streams at points where the stream channel widens abruptly; such dams are rather spectacular features, reaching heights of up to four feet. Tufa is also deposited in concretionary masses, generally formed around small pebbles or pieces of wood, so that the floor of the stream channel appears to be covered with white pebbles of rather uniform size.

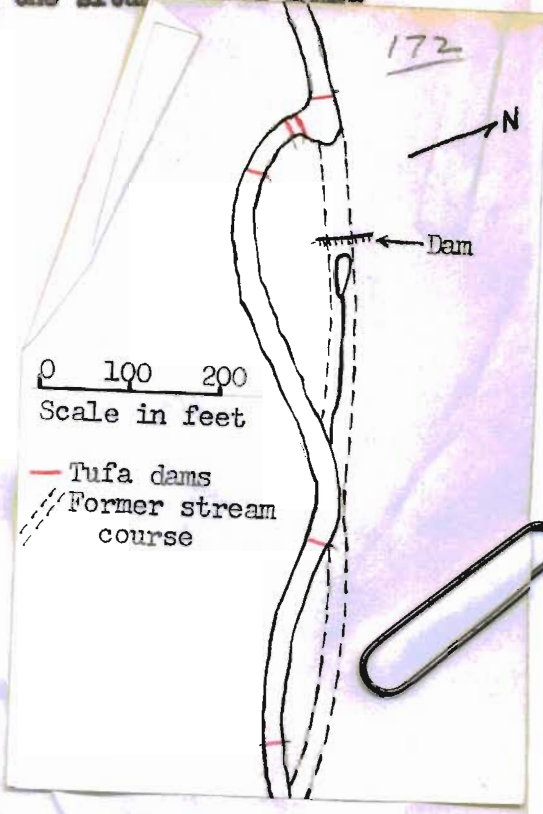
Within the Mount Jackson quadrangle, tufa dams are found along Smith Creek and Holman Creek west of the Massanutten Range; tufa pellets occur along a small tributary to Passage Creek in the northern Massanutten Range.

Holman Creek tufa. The first tufa dam crosses the stream at the east side of Forestville just below the abandoned mill on State Road 767. The dam appears to be still growing. It is composed of soft, porous limestone, apparently of algal origin, which forms the rounded structures of which the dam is built. In some cases imprints of leaves and other apparently organic structures such as root molds are found. The surface of the dam has a greenish-yellow color due to the presence of a thin film of algae over the damp parts of the rock. Pockets and basins along the front of the dam contain dark-green filimentous algae of undetermined identity. The occurrence of this first tufa dam appears to be controlled by an outcrop of Edinburg limestone that crosses the stream just above the dam.

The second dam occurs about half a mile downstream from the first one. It is about one foot high, i.e., water flowing over it falls a distance of about one foot, and in other respects it is quite similar to the first one.

No tufa occurs through the next two miles of the stream's course. The next dam is found a few hundred feet downstream from the point where State Road 698 crosses the creek, and from this point to the Southern Railway bridge over the creek a series of tufa dams can be seen. The first dam in the series is four to five feet high and apparently lacks any stratigraphic control. It is composed of soft brown or yellow porous limestone, locally containing impressions of leaves of sycamore trees such as are still growing along the banks of the stream. At places parts of this dam are overlain by as much as four feet of alluvial clay, but other parts of the dam seem to be still growing. About eighty feet downstream is a second dam, this one only about one foot high. At the edge of the stream channel it is overlain by seven feet of alluvium. At places the tufa is conglomeratic, consisting of stream gravels cemented by travertine. This dam does not appear to be actively growing at present. Other dams, ..., with approximately the same features, occur downstream all the way to the railroad bridge.

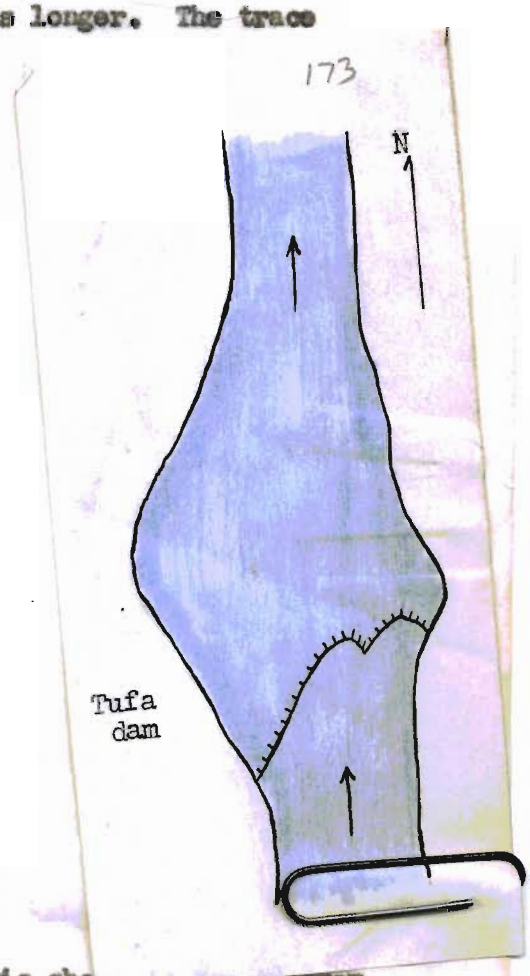
In the case of these dams near Quicksburg the situation is somewhat unique. Just below the first dam in this group, the dam east of State Road 698, Holman Creek turns abruptly to the south, cutting its channel through a fill terrace, then turning slowly northward until it again flows to the east. Further investigation shows that the former stream channel is a rather straight east-west extension of its course above the first tufa dam. At some time in the historic past a dam was built across the creek just below the first tufa dam



and the water of the stream was diverted into a millrace northeast of the stream to operate a small mill that lay downstream from the artificial dam. From this mill, now represented only by its stone foundations, the water was returned to the stream. The stream has since succeeded in bypassing the dam, however, by overflowing onto the fill terrace to the southwest and cutting a new channel down through this fill. In the process of cutting its new channel, however, the stream has uncovered a series of tufa dams which were formerly buried beneath the alluvium in the fill terrace. It would thus appear that most of the tufa dams now exposed along the creek near Quicksburg are ancient ones, the building of which was followed by a period of alluviation. No such alluviation is indicated in the case of the tufa dams farther upstream, however, and deposition would appear to be limited to the mouthward parts of the stream.

Smith Creek tufa. The tufa dams along Smith Creek are not so numerous as those along Holman Creek; they are, however, more impressive in both height and width. The dams occur along the creek from a point just south of State Road 608 to a point about half a mile south of State Road 698. Thus tufa formation here is restricted to a smaller part of the stream's course than along Holman Creek.

The terraces here are much like those along Holman Creek in the character of the material of which they are constructed. Like the Holman Creek dams, they are in some cases overlain by alluvium along the banks of the stream, although this alluvial cover is generally only about one foot thick. The creek here is wider and the dams are thus longer. The trace of the dams across the stream is often quite sinuous and the dams are generally formed just a few feet upstream from especially wide parts of the stream's channel. The height of these dams is generally about four feet; they were visited during a period of high water, however, and they may be larger than this.



The first of these dams, that is, the one farthest upstream, is located just south of the bridge on State Road 608, from which it is clearly visible. The second tufa dam, apparently the largest of the group, is located about 400 yards upstream from the bridge on State Road 698. Its form is sho[wn in the] diagram produced above. Downstream from this bridge three more tufa dams are found, only the last one being of any appreciable size.

from the valley slopes and then later in dissection of these minor valley fills by the streams as a result of decrease in load.

GEOLOGIC SECTIONS

Page Valley

The floor of Page Valley being covered by a thick blanket of alluvium near the Shenandoah salient, exposures are somewhat limited in this area. For this reason, no sections could be measured which included anything below the upper Beekmantown. No sections of the Edinburg or Martinsburg formations were measured because of the relative weakness and complex folding of these two formations.

North of Hamburg two sections of the lower Middle Ordovician limestones were measured. The first of these lies within the Shenandoah River klippe; the strata here are overturned, with a strike of about N 40° E and a dip of 30-40° SE. The formations included are the lower Edinburg formation, the Lincolnshire and New Market limestones, and the upper part of the Beekmantown formation. The basal clastic member of the Edinburg formation is probably present in the covered interval (Bed 36). Note also the thinness of the New Market limestone and the characteristic lithology of the upper Beekmantown: alternating limestone and dolomite.

<u>Geologic section 6</u>. In field 1.1 miles NNE of Hamburg, Page Co.

Edinburg formation (Lower 14 ± feet)
- 38. Limestone, black, fine-grained, beds 1 to 4 inches thick, with intercalated shale bands
- 37. Limestone, black, fine-grained, beds 2 to 4 inches thick. . . . . .14 feet

Lincolnshire limestone (22 to 67 feet)
- 36. Covered. 45
- 35. Calcarenite, gray, medium-grained, thin- and wavy bedded. 22

New Market limestone (3 feet)
- 34. Limestone, dove-gray, aphanitic; contains very irregular siliceous partings, weathers to a rough surface 3

Beekmantown formation (Upper 350 feet)

33.	Dolomite, light-gray, fine-grained, thin-bedded, with nodules of white chert.	41
32.	Limestone, dove-gray, fine-grained, with irregular inclusions of dolomite.	10
31.	Dolomite, brownish-gray, fine-grained, massive	10
30.	Limestone, gray, fine-grained, with wavy laminae.	4
29.	Limestone, dove-gray, aphanitic, massive.	5
28.	Dolomite, brownish-gray, fine-grained, massive	58
27.	Covered	5
26.	Limestone, dove-gray, aphanitic, massive.	6
25.	Dolomite, brownish-gray, fine-grained, massive. .	5
24.	Limestone, dove-gray, aphanitic, massive.	5
23.	Dolomite, light-gray, medium- to coarse grained, weathers brown	27
22.	Covered	18
21.	Dolomite, brownish-gray, fine-grained, massive. .	5
20.	Limestone, dove-gray, fine-grained, with irregular dolomite inclusions	12
19.	Covered	14
18.	Limestone, dove-gray, fine-grained, with dolomite inclusions	3-1/2
17.	Dolomite, brownish-gray, fine-grained, massive. .	11
16.	Limestone, dove-gray, fine-grained, with irregular dolomite inclusions	5
15.	Dolomite, brownish-gray, fine-grained, massive. .	6-1/2
14.	Limestone, dove-gray, fine-grained, with irregular dolomite inclusions	12
13.	Dolomite, very light-gray, aphanitic, weathers white	5
12.	Covered	6
11.	Limestone, dove-gray, fine-grained, with irregular dolomite inclusions	8
10.	Limestone, gray, fine-grained, with wavy laminae.	3-1/2
9.	Dolomite, brownish-gray, fine-grained, massive. .	2-1/2
8.	Limestone, dove-gray, aphanitic, massive.	6-1/2
7.	Dolomite, brownish-gray, fine-grained, massive. .	6
6.	Limestone, dove-gray, fine-grained, with irregular dolomite inclusions	5
5.	Dolomite, light-gray, aphanitic	3-1/2
4.	Limestone, dove-gray, aphanitic, with very irregular partings.	6-1/2
3.	Dolomite, light-gray, aphanitic	13
2.	Limestone, dove-gray, fine-grained, with irregular dolomitic inclusions.	2-1/2
1.	Covered	

East of the klippe a normal (i.e., not overturned) section of these same units is exposed. It will be noted that the Lincolnshire and

New Market limestones here are thicker than in the klippe. Locally near this section, however, the New Market limestone is completely absent. The upper 50 feet of Bed 6 is probably the basal clastic member of the Edinburg formation.

<u>Geologic section 7</u>. In field 1.0 mile north of Hamburg

Edinburg formation (Black limestones and shales)
Lincolnshire limestone (176 ± feet)
6. Calcarenite, gray, coarse-grained, contains occasional pebbles of limestone, especially near the top. 122 feet
5. Limestone, dark gray, fine-grained, irregularly bedded, with irregular nodules of black chert. . . 42
4. Covered. 23
New Market limestone (43 ± feet)
3. Limestone, dove-gray, aphanitic, contains *Tetradium*. 27
2. Breccia of dolomite fragments 1/2 to 2 inches in diameter in a limestone matrix. 4
Beekmantown formation
1. Dolomite, light-gray, fine-grained

Along Mill Creek northwest of Hamburg the lower Champlainian limestones again outcrop. The following section is taken from Edmundson (1945, Geologic Section 99). Bed 3 is the basal clastic member of the Edinburg formation; the Lenoir limestone is essentially the Lincolnshire limestone of this dissertation and the Mosheim limestone is the New Market limestone.

<u>Geologic section 8</u>. Along Mill Creek half a mile northwest of Hamburg, Page County, Virginia

Lenoir limestone (73 feet)
3. Limestone, dark-gray, medium grained, nodular. . . 28 feet
2. Limestone, dark-gray, medium grained; contains black chert. 45
Mosheim limestone
1. Limestone, dove-gray, compact; a few impure beds near base. 55
Beekmantown formation

About one mile southwest of Hamburg the New Market limestone is again exposed, showing a good development here of the basal conglomerate.

Geologic section 9. In field 1.1 miles southwest of Hamburg and 1.3 miles north of Leaksville, Page County

Lincolnshire limestone (Lower 36 ± feet)

5. Limestone, dark-gray, granular, much sheared, with red argillaceous partings.	24 feet
4. Covered	22

New Market limestone (109 ± feet)

3. Interbedded dolomitic and calcitic limestone, dove-gray, aphanitic, weathers light gray	28
2. Conglomerate of pebbles, cobbles, and boulders of limestone and dolomite in a dolomitic matrix . .	70

Beekmantown formation

1. Dolomite, light-gray, fine-grained, weathers mottled buff and gray

Along Cub Run, between Newport and Grove Hill, is a good section of the Edinburg formation, the Lincolnshire and New Market limestones, and the Beekmantown formation. The entire Beekmantown formation outcrops along the creek, but good exposures are found only in the upper 1100 feet given here. The basal Edinburg formation and the Lincolnshire limestone are probably both represented in Bed 90.

Geologic section 10. Along Cub Run west and east of Virginia Highway 12, Page County

Edinburg formation

91. Black shale and black fine-grained limestone

Lincolnshire limestone and/or basal Edinburg formation (31 feet)

90. Limestone, gray, medium-grained, clastic.	31 feet

New Market limestone (14 feet)

89. Limestone, light-gray, fine-grained, with irregular shaly partings; weathers whitish; contains numerous bryozoans	6
88. Limestone, dove-gray, aphanitic, with shaly partings.	5
87. Limestone, dove-gray, aphanitic, with irregular shaly partings.	3

Beekmantown formation (Upper 1100 feet)

86. Dolomite, gray, fine-grained, laminated; weathers buff	2
85. Limestone, dove-gray, aphanitic, massive.	7
84. Dolomite, dark-gray, fine-grained; weathers light-gray.	6-1/2
83. Limestone, dove-gray, aphanitic, with shaly partings.	1
82. Dolomite, gray, fine-grained, laminated; weathers buff	2

81. Limestone, dove-gray, aphanitic, with shaly partings.	1/2
80. Dolomite, light-gray, fine-grained, laminated; weathers light-gray	6
79. Limestone, dove-gray, aphanitic, with irregular siliceous partings; contains some layers of dolomite.	15
78. Dolomite, gray, medium-grained, laminated; weathers buff or grayish.	7
77. Limestone, dove-gray, aphanitic, with irregular dolomite inclusions	1
76. Limestone, dove-gray, aphanitic; contains thin bands of dolomite.	1
75. Dolomite, gray, thin-bedded; weathers gray; lower contact quite irregular	1-1/2
74. Dolomite, calcitic, dark-gray, laminated; weathers light-gray; becomes more calcitic toward base; lower contact irregular	5-1/2
73. Limestone, dark-gray, fine-grained; shaly toward top.	3
72. Dolomite, light-gray, fine-grained, laminated; weathers gray.	1/2
71. Limestone, gray, aphanitic, massive; weathered surface pitted; fossiliferous	2-1/2
70. Dolomite, dark-gray, fine-grained; weathers light-gray.	3
69. Limestone, dove-gray, aphanitic, with irregular dolomite inclusions	13-1/2
68. Dolomite, dark-gray, aphanitic; weathers white. .	1/2
67. Limestone, dolomitic, gray, fine-grained, irregularly laminated	2
66. Dolomite, light-gray, fine-grained, laminated, weathers buff	1/2
65. Limestone, dove-gray, aphanitic; contains thin dolomite layers.	4
64. Dolomite, light-gray, aphanitic; weathers dove-gray; lower contact irregular, marked by breccia and clastic dikelets	2-1/2
63. Limestone, dove-gray, aphanitic, with shaly partings; bands of dolomite near base	6-1/2
62. Dolomite, light-gray, fine-grained, laminated; broken by minor penecontemporaneous faulting. . .	1/2
61. Limestone, dove-gray, aphanitic, massive; fossiliferous	6
60. Conglomerate; contains limestone and dolomite boulders up to 6 feet across.	16
59. Limestone, dolomitic, light-gray, fine-grained; contains lenses of limestone and dolomite	23
58. Breccia composed of dolomite fragments.	20
57. Limestone, dove-gray, aphanitic, massive; shaly near base	5
56. Limestone, gray, medium-grained, massive.	10
55. Dolomite, light-gray, fine-grained, massive . . .	6-1/2
54. Limestone, gray, medium-grained, massive.	3-1/2

53. Dolomite, light-gray, aphanitic to fine-grained. . .	50 feet
52. Covered.	300
51. Dolomite, light-gray, fine-grained; weathers buff. .	2
50. Dolomite, gray, fine-grained, with occasional limestone pebbles.	7
49. Dolomite, light-gray, fine-grained; weathers buff. .	1
48. Dolomite, gray, medium-grained	2-1/2
47. Limestone, gray, fine-grained, with irregular partings	2
46. Dolomite, light-gray, fine-grained, massive.	13
45. Covered.	19
44. Dolomite, light-gray, fine-grained, massive.	21
43. Dolomite, striped light- and dark-gray, medium-grained.	7
42. Dolomite, light-gray, aphanitic.	10-1/2
41. Breccia composed of dolomite fragments	2
40. Dolomite, gray, medium-grained, massive.	3
39. Dolomite, gray, fine- to medium-grained, massive . .	168
38. Limestone, dark-gray, fine-grained; contains irregular dolomite inclusions.	3
37. Dolomite, light-gray, fine-grained, massive.	3
36. Limestone, dark-gray, fine-grained, with irregular inclusions of dolomite	5
35. Dolomite, dark-gray, fine-grained, massive	3-1/2
34. Limestone, dove-gray, aphanitic, with irregular partings	2
33. Dolomite, light-gray, medium-grained, laminated. . .	11
32. Limestone, gray, fine-grained, irregularly laminated.	1
31. Dolomite, dark-gray, medium-grained.	12
30. Limestone, dove-gray, fine-grained, irregularly laminated.	4
29. Dolomite, light-gray, medium-grained, massive. . . .	21-1/2
28. Limestone, gray, fine-grained, irregularly laminated.	1
27. Dolomite, light-gray, medium-grained, massive. . . .	4
26. Limestone, dove-gray, aphanitic, massive	2
25. Dolomite, light-gray, fine- to medium-grained. . . .	43
24. Covered.	70
23. Dolomite, gray, fine- to medium-grained, massive . .	32-1/2
22. Dolomite, dark-gray, medium-grained, irregularly banded	8
21. Limestone, dark-gray, fine-grained, with irregular siliceous partings	8
20. Dolomite, gray, fine- to medium-grained, massive . .	2
19. Limestone, dark-gray, fine-grained, with irregular inclusions of dolomite	2
18. Limestone, dark-gray, with wavy laminae.	11
17. Dolomite, light-gray, fine-grained, massive.	2
16. Limestone, dark-gray, with wavy laminae.	9
15. Dolomite, light-gray, fine-grained, massive.	1
14. Interbanded limestone and dolomite	3
13. Covered.	3

12. Dolomite, grayish, shaly. . . . . 2 feet
11. Limestone, dark-gray, with wavy laminae 2
10. Limestone, gray, medium-grained, thin-bedded, clastic 3
9. Dolomite, light-gray, fine-grained, massive 3
8. Limestone, gray, medium-grained, thin-bedded, clastic; grades laterally into fine-grained laminated limestone 3
7. Dolomite, gray, medium-grained; contains stringers of black chert. 2-1/2
6. Limestone, gray, medium-grained, thin-bedded, clastic; grades laterally into fine-grained thin-bedded limestone 7-1/2
5. Limestone, dark-gray, fine-grained, with irregular inclusions of dolomite. 5-1/2
4. Dolomite, light-gray, fine-grained, irregularly laminated 5
3. Limestone, dark-gray, with wavy laminae 1
2. Dolomite, light-gray, fine-grained; contains nodules of black chert. 7
1. Dolomite, light-gray, granular

Still farther south, about a mile southwest of Grove Hill, the same sequence is again exposed. The New Market-Lincolnshire sequence here differs quite considerably from that elsewhere in the area: the top of the Lincolnshire limestone and the base of the New Market limestone can be fixed rather closely, but between these two horizons relations with recognized stratigraphic units is puzzling. Edmundson (1945, geologic section 106) has measured a parallel section along the banks of the North Fork of the Shenandoah a few hundred yards to the south, which is reproduced here as section 12.

Geologic section 11. In field 0.7 mile SSW of Grove Hill, Page County

Edinburg formation (Lower 20 feet)
40. Black thin-bedded limestone and shale
39. Limestone, gray, medium- to coarse-grained, irregularly bedded (basal clastic member). . . 20 feet
Lincolnshire and New Market limestones (123 feet)
38. Limestone, fine-grained, dark-gray, with flattened nodules of black chert 64
37. Limestone, medium-grained, clastic, thin-bedded; contains yellow argillaceous partings and occasional pebbles of limestone; no chert. 3

36.	Limestone, gray, coarse-grained, fossiliferous.	11 feet
35.	Limestone, dark-gray, fine-grained, nodular; contains argillaceous partings and no chert. .	9
34.	Siltstone, black	1
33.	Limestone, argillaceous, light-gray, fine-grained, massive; weathers buff.	18
32.	Breccia, composed of blocks of dolomite and dolomitic limestone up to 5 feet across. . . .	17

Beekmantown formation (Upper 608 feet)

31.	Limestone, dove-gray, aphanitic.	4
30.	Dolomite, light-gray, fine-grained; weathers buff	8
29.	Limestone, dove-gray, aphanitic, shaly	1-1/2
28.	Limestone, dove-gray, aphanitic.	2
27.	Dolomite, light-gray, fine-grained; weathers grayish	4
26.	Limestone, dove-gray, aphanitic.	1-1/2
25.	Limestone, dark-gray, aphanitic; intergrown with dolomite, light-gray, granular.	15
24.	Limestone, dark-gray, thinly laminated, with argillaceous partings	3-1/2
23.	Limestone, dark-gray, fine-grained, thinly laminated.	6
22.	Limestone, dove-gray, aphanitic.	2
21.	Dolomite, gray, thinly laminated; weathers light gray	2
20.	Limestone, dark-gray, aphanitic, intergrown with granular dolomite	20
19.	Dolomite, light-gray, granular; contains thin lenses of fine-grained limestone.	2
18.	Dolomite, light-gray, aphanitic; weathers white.	1/2
17.	Limestone, dove-gray, aphanitic.	4
16.	Dolomite, light-gray, fine-grained; weathers buff.	5
15.	Limestone, dark-gray, aphanitic, massive . . .	6
14.	Limestone, dove-gray, aphanitic, laminated . .	1-1/2
13.	Dolomite, light-gray, granular	3
12.	Dolomite, gray, thinly laminated; weathers light-gray.	1
11.	Dolomite, light-gray, fine-grained; contains calcite "eyes"	4
10.	Limestone, dove-gray, aphanitic.	10
9.	Dolomite, light-gray, fine-grained; weathers buff.	5
8.	Covered.	4
7.	Dolomite, light-gray, granular	4
6.	Dolomite, light-gray, fine-grained	4
5.	Covered.	8
4.	Limestone, dove-gray, aphanitic.	10
3.	Dolomite, light-gray, fine-grained	4
2.	Limestone, dove-gray, aphanitic.	10
1.	Dolomite, light-gray, fine-grained	10

Geologic section 12. Bluff along South Fork of Shenandoah River about 1-1/4 miles northeast of Shenandoah, Page County (Edmundson, 1945, p. 149)

Beekmantown formation (upper part, 1033 feet)

30. Dolomite, gray, fine-grained.	54 feet
29. Limestone, light-gray, compact.	12
28. Dolomite with thin layers of bluish-gray limestone	21
27. Limestone, bluish-gray, impure, slightly banded; a few thin layers of dolomite	75
26. Dolomite, gray, fine-grained.	9
25. Limestone, bluish-gray.	9
24. Largely covered; a few thin beds of limestone and dolomite.	63
23. Limestone, light-gray, compact.	10
22. Dolomite and impure banded limestone.	120
21. Limestone, light-bluish-gray.	12
20. Dolomite, gray, fine grained.	30
19. Limestone, banded, impure	18
18. Dolomite and impure banded limestone.	51
17. Dolomite, gray, fine grained.	21
16. Limestone, light bluish-gray.	6
15. Dolomite, light-gray, fine grained.	180
14. Dolomite, gray, medium grained.	12
13. Dolomite, light-gray, fine grained.	120
12. Limestone, mottled light- and dark-gray	3
11. Dolomite, gray, fine grained.	12
10. Limestone, bluish-gray.	3
9. Dolomite, fine grained; a few thin beds of limestone	90
8. Limestone, mottled light- and dark bluish-gray. .	6
7. Dolomite, gray, fine-grained.	2
6. Limestone, mottled light- and dark-gray	6
5. Dolomite, gray, fine grained.	3
4. Limestone, bluish-gray.	5
3. Dolomite, gray, fine-grained.	20
2. Limestone, bluish-gray, impure.	10
1. Dolomite, gray, fine-grained.	50

Massanutten Range

The geologic sections measured in the Massanutten Range include only three formations, the Massanutten sandstone, the Tonoloway limestone, and the Catherine limestone. The Bloomsburg formation is usually covered by float from the Massanutten sandstone and the Romney group is generally poorly exposed and complicated by minor folding.

Two sections of the Tonoloway and Catherine limestones were measured in the northern part of the Massanutten Range. The first of these is exposed along Passage Creek for several hundred yards south of the bridge on State Road 616. The strata here have a very gentle dip and the base of the Tonoloway limestone is not exposed. A number of different lithologic types are included in the Catherine limestone in this section; here it is apparently largely Keyser in age. Some of the higher strata in the section may belong to higher units in the Helderberg, however.

Geologic section 13. Along Passage Creek south of State Road 616.

Needmore shale (Dark olive-gray shale)
Catherine limestone (73 feet)

35. Limestone, dark-gray, fine-grained, irregularly bedded.	1 foot
34. Calcarenite, light-gray, medium-grained, with occasional clay chips; weathers buff . . .	1/2
33. Limestone, very argillaceous, liver-brown, fine-grained.	1
32. Limestone, brown and gray, fine-grained, laminated, argillaceous	3-1/2
31. Limestone, olive-brown, aphanitic, shaly. . . .	2
30. Limestone, brown and gray, fine-grained, laminated, argillaceous	2-1/2
29. Covered.	4-1/2
28. Calcarenite, dark-gray, medium-grained.	3
27. Covered	1/2
26. Calcarenite, dark-gray, medium-grained; contains corals, brachiopods, bryozoans, and crinoid fragments	1-1/2
25. Covered	11
24. Mudstone, brownish-gray, mud-cracked; contains thin layers of medium-grained calcarenite	2
23. Mudstone, greenish-gray, shaly, very fossiliferous	1
22. Calcarenite, gray, fine-grained; contains irregular nodules of black chert; weathers to pitted surface	3
21. Limestone, gray, fine-grained, irregularly bedded, with red clayey partings.	4
20. Calcarenite, gray, medium-grained, spotted with red.	2
19. Calcarenite, gray, medium-grained; contains shale fragments.	1-1/2
18. Mudstone, red; contains irregular nodules of gray fine-grained calcarenite	1

17. Calcarenite, gray, medium-grained.	1/2 foot
16. Covered.	2
15. Limestone, gray, shaly; weathers white	1-1/2
14. Covered.	7-1/2
13. Mudstone, grayish-green; contains nodules of gray limestone.	3
12. Calcarenite, gray, medium-grained.	1/2
11. Covered.	3-1/2
10. Mudstone, ocher-brown, very irregularly bedded, fossiliferous; contains limestone nodules.	4
9. Limestone, light-gray, fossiliferous; with very irregular shaly partings	6
8. Limestone, brownish-gray, fine-grained; with irregular shaly partings.	1-1/2
7. Covered.	1/2
Tonoloway (?) limestone (Upper 19 feet)	
6. Limestone, gray-green, thin-bedded, shaly, mud-cracked	1
5. Limestone, dark-gray, medium-grained, with irregular shaly partings.	1/2
4. Limestone, dark-gray, medium-grained, compact.	1/2
3. Limestone, dark-gray, medium-grained, thin-bedded, mud-cracked, with irregular shaly laminae.	6
2. Limestone, light-dove-gray, aphanitic, with irregular laminae.	6
1. Limestone, olive-gray, fine-grained, with irregular laminae.	5

Woodward (1943) gives a section of these same limestones which he states was measured along the headwaters of Passage Creek 1.5 miles east of Moreland Gap. This would seem to be the same section as is given above, but the exposures must have been remarkably better when Woodward measured the section than they are at present.

A second section of these Siluro-Devonian limestones is exposed along Passage Creek farther to the southwest, about seven miles from New Market Gap. The upper bed in this section is somewhat peculiar, being a red mudstone with limestone nodules; compare this with Bed 18 in the section above. The Catherine limestone here is at least in part of Becraft age, containing specimens of Spirifer concinnus listed by Butts from the

Becraft limestone elsewhere in Virginia. (Butts, 1941, p. 167).

Geologic section 14. Along Passage Creek 6.9 miles northeast of New Market Gap, Page County.

Needmore shale	
8. Interbedded black and olive-gray shales	
Catherine limestone (33 feet)	
7. Mudstone, reddish; contains layers of limestone nodules.	9 feet
6. Limestone, gray, fine-grained, argillaceous, with shaly partings.	19
5. Shale, ocher-yellow, calcareous; contains fossils of Becraft age	5
Tonoloway limestone (?) (48 feet)	
4. Limestone, gray, aphanitic, shaly; contains mud-cracks and irregular laminae; weathers yellow	3-1/2
3. Covered.	11-1/2
2. Limestone, gray, aphanitic, shaly, mud-cracked	33
Bloomsburg formation	
1. Red siltstones and sandstones	

Two sections of the Massanutten sandstone were also measured in the northern part of the range. The first of these, at Burners Gap, was given above in the section on the Massanutten sandstone. The second section is located just north of New Market Gap; it is incomplete, the lower part of the formation being covered at this locality. The section shows the presence of silty shale layers in the sandstone similar to those recorded in the Burners Gap section.

Geologic section 15. Along National Forest Road 274 just northeast of New Market Gap, Page County.

Massanutten sandstone (Lower 300 feet)	
12. Quartzite, white, medium-grained, wavy-bedded. .	27 feet
11. Shale, greenish-gray.	1/2
10. Quartzite, white, medium-grained.	1-1/2
9. Shale, greenish-gray, sandy; contains thin beds of shaly gray quartzite.	1/2
8. Quartzite, white, medium-grained.	17
7. Covered	13
6. Quartzite, pinkish, medium-grained.	10
5. Covered	140
4. Quartzite, pinkish, medium-grained; in places distinctly cross-bedded.	31
3. Covered, with scattered exposures of white quartzite	35

2. Covered.	24 feet
Cub sandstone	
1. Brown sandstones and siltstones	

In the southern part of the Massanutten Range two sections were measured. The first, a section of the Siluro-Devonian limestones, is the type section of the Catherine limestone and is given as Geologic section 5 under that heading. The second section includes the type Cub sandstone (Geologic section 3), but contains the upper Martinsburg formation as well. It is located just east of Catherine Furnace.

Geologic section 16. Along National Forest Road 65 on east side of First Mountain, Page County.

Cub sandstone	
30. Sandstone, olive- to orange-colored, fine-grained.	4-1/2 ft.
Martinsburg formation	
29. Interbedded shale and sandstone, olive.	2
28. Sandstone, olive-brown, slabby, cross-bedded; weathers purplish	6
27. Interbedded sandstone and shale, olive.	4
26. Sandstone, greenish, fine-grained, blocky . . .	1
25. Interbedded sandstone and shale, olive.	19-1/2
24. Sandstone, olive-brown, fine-grained, slabby, cross-bedded; contains occasional shale layers.	14
23. Shale, sandy, olive, micaceous.	1-1/2
22. Sandstone, olive-colored, slabby.	1
21. Shale, sandy, olive-colored, micaceous.	1/4
20. Sandstone, olive-brown, fine-grained, slabby, cross-bedded; contains occasional shaly layers.	13
19. Interbedded shale and sandstone, olive-colored, thin-bedded.	7
18. Sandstone, greenish, fine-grained, hard	4
17. Shale, sandy, olive-colored	2
16. Sandstone, olive-colored, fine-grained, hard, blocky.	3-1/4
15. Siltstone, sandy; contains pebbles.	2
14. Sandstone, olive-colored, slabby, contains shale chips.	6
13. Shale, olive-colored, manganese-stained, micaceous	2
12. Sandstone, silty, olive-colored, micaceous, slabby.	9-1/4
11. Interbedded sandstone and shale, olive-colored, thin-bedded.	3
10. Sandstone, olive-gray, fine-grained, hard . . .	1-1/2

9. Siltstone, olive-colored; contains shale chips.	1-1/2 ft.
8. Interbedded sandstone and shale, olive-colored.	8-1/2
7. Sandstone, brown, fine-grained, slabby	3
6. Sandstone, dark-gray-green, hard, blocky, fossiliferous.	25
5. Shale, olive-colored, with some sandy layers and pyrite concretions	3
4. Sandstone, silty, olive-brown, blocky.	6
3. Shale, olive-colored	1-1/4
2. Sandstone, olive-brown, slabby	1
1. Interbedded shale and sandstone, brown, with local thin layers of earthy manganese ore.	245

Shenandoah Valley

West of the Massanutten Range a number of sections were measured. These sections include the Oranda and Edinburg formations, the Lincolnshire and New Market limestones, and part of the Beekmantown formation. The lower part of the Beekmantown is not well exposed and only the upper part of the Conococheague limestone has been brought to the surface here.

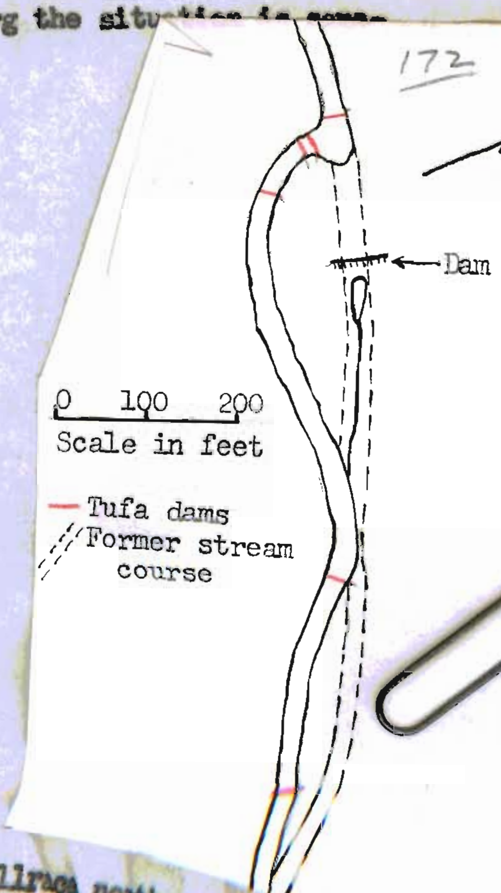
Only one section was measured along the west limb of the Endless Caverns anticline; this section is located about a mile and a half northwest of Phillips Hill.

<u>Geologic section 17</u>. In field 1.4 miles NNW of Phillips Hill, Rockingham County

Lincolnshire limestone	
7. Limestone, clastic, light-gray, medium-grained.	
New Market limestone (87 feet)	
6. Covered.	7 feet
5. Limestone, dove-gray, aphanitic; contains irregular nodules of calcite	11
4. Limestone, dove-gray, aphanitic, with irregular widely spaced argillaceous partings.	16
3. Limestone, dark-gray, fine-grained	2
2. Limestone, dove-gray, fine-grained; contains dolomite layers near the base; weathers to a rough surface.	55
Beekmantown formation	
1. Dolomite, light-gray, fine-grained, thin-bedded; weathers light gray	

with approximately the same features, occur downstream all the way to the railroad bridge.

In the case of these dams near Quicksburg the situ[illegible] what unique. Just below the first dam in this group, the dam east of State Road 698, Holman Creek turns abruptly to the south, cutting its channel through a fill terrace, then turning slowly northward until it again flows to the east. Further investigation shows that the former stream channel is a rather straight east-west extension of its course above the first tufa dam. At some time in the historic past a dam was built across the creek just below the first tufa dam and the water of the stream was diverted into a millrace northeast of the stream to operate a small mill that lay downstream from the artificial dam. From this mill, now represented only by its st[illegible] foundations, water was returned to the stream. The stream has sinc[illegible] ceede[illegible] in byp[illegible] ing the dam, however, by overflowing onto the fill terra[illegible] the south and cutting a new channel down through this fill. In t[illegible] p[illegible] its new channel, however, the stream has uncovered a ser[illegible] o[illegible] which were formerly buried beneath the alluvium in the f[illegible] would thus appear that most of the tufa dams now exposed [illegible] near Quicksburg are ancient ones, the building of which wa[illegible] period of alluviation. No such alluviation is indicated i[illegible] tufa dams farther upstream, however, and depos[illegible] limited to the mouthward parts of the stream.



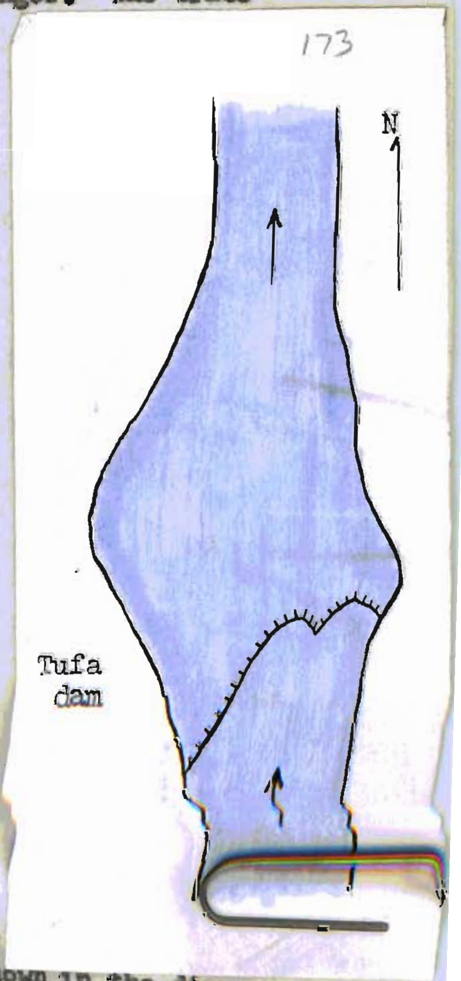
a. Tufa dam on Smith Creek near the northern end of Lincoln Hill, Page County.

b. Tufa dam several hundred yards downstream from the one shown above.

Tufa dam on Holman Creek west of Quicksburg, Shenandoah County.

Smith Creek tufa. The tufa dams along Smith Creek are not so numerous as those along Holman Creek; they are, however, more impressive in both height and width. The dams occur along the creek from a point just south of State Road 608 to a point about half a mile south of State Road 698. Thus tufa formation here is restricted to a smaller part of the stream's course than along Holman Creek.

The terraces here are much like those along Holman Creek in the character of the material of which they are constructed. Like the Holman Creek dams, they are in some cases overlain by alluvium along the banks of the stream, although this alluvial cover is generally only about one foot thick. The creek here is wider and the dams are thus longer. The trace of the dams across the stream is often quite sinuous and the dams are generally formed just a few feet upstream from especially wide parts of the stream's channel. The height of these dams is generally about four feet; they were visited during a period of high water, however, and they may be larger than this.



The first of these dams, that is, the one farthest upstream, is located just south of the bridge on State Road 608, from which it is clearly visible. The second tufa dam, apparently the largest of the group, is located about 400 yards upstream from the bridge on State Road 698. Its form is shown in the diagram produced above. Downstream from this bridge three more tufa dams are found, only the last one being of any appreciable size.

Fort Valley tufa. A much smaller, but somewhat different deposit of tufa was found along an east-flowing tributary to Passage Creek about a half-mile northeast of Camp Roosevelt. The stream is small and intermittent, but the deposit is of some interest. Small tufa dams hav been formed at various points along the stream and are apparently still active; they are controlled in occurrence by outcrops of the Romney shale. In addition the floor of the stream is covered by vast numbers of smal white pellets ranging in size from two to fifteen millimeters. These pel s show a rather poorly developed concentric structure and have at their center rains of sand or, sometimes, pieces of wood. The deposition of tufa is b ht about by even the slightest irregularity in the stream channel; roo leaves, sticks, pebbles, etc., all have at least a thin covering of th material.

Source of the tufa. In all three areas of tufa deposition the material is deposited from a stream at points downstream from where the stream crosses a fault. In two of the cases (Holman and Smith Creeks) the fault actually cuts through limestone layers where it outcrops; in the third case, it is probable that the fault cuts or at least shatters limestone formations below the surface. The calcium carbonate is brought to the surface by underground waters circulating in the fault plane or fault zone; the crushed condition of the limestones makes their solution easy. Travertine terraces have not been found in this quadrangle along streams which cross these same formations where they are not affected by faulting and they have not been found along these same streams headward from the fault zones.

The cause of deposition of the tufa is another problem. Along Holman Creek in many cases the dams were found to be covered with algae, which may or may not be responsible for the formation of the tufa. The algae may be present because of the abundance of dissolved calcium carbonate. Some of the dams appear to be controlled by bedrock outcrops. Water saturated in calcium carbonate would lose some of its dissolved carbon dioxide on flowing over irregularities in the channel, and this in turn would reduce the solubility of the calcium carbonate, causing some of it to be deposited. The process would be self-accelerating; the higher the dam is built, the more tufa will be precipitated. In other cases the tufa dams are associated with wide spots in the stream channel. Sudden widening of the stream would expose more of the water to the air and to the sun; this increase in heated surface would cause some reduction in the dissolved carbon dioxide and perhaps bring about deposition of tufa.

Peneplanes and Erosion Surfaces

The concept of peneplanation has been applied extensively in the Ridge-and-Valley province in the past, largely because the crests of the ridges characteristic of this region show a strikingly apparent levelness. In recent years, however, it has been shown that the height of these ridges varies with (1) the dip of the strata, (2) the proximity of major drainage lines, (3) the thickness of the resistant strata, and (4) the degree of cementation of the resistant strata. This levelness of the ridge crests is thus due to the relative constancy of these four factors rather than to an earlier cycle of peneplanation.

In his bulletin on the Appalachian Valley Butts (1940, pp. 506-511) has recognized three peneplanes. The upper one, the Summit peneplane, has an elevation of 3900 to 4600 feet and is represented only by scattered high summits in the western part of Virginia. Below this lies the Schooley peneplane at an altitude of 2500 to 4500 feet. The lowest of these erosion surfaces, the Harrisburg or Valley-Floor peneplane, lies at an altitude of 500 to 1000 feet in the northern part of the Valley.

Within the Mount Jackson quadrangle evidence of peneplanation is open to other interpretations as well. No elevations within the area can be correlated with the Summit peneplane. The ridge-tops which were formerly correlated with the Schooley peneplane are narrow; these ridges have probably been considerably reduced since the uplift of the Schooley surface as indicated by their sharpness and by the abundant taluses on their slopes. The somewhat broader and higher peaks at the junctures of these ridges, however, may represent remnants of this peneplane. These peaks lie at an altitude of 2600-2800 feet in the Mount Jackson quadrangle, with some higher points reaching 3000 feet. Northward the altitude of these broader peaks falls to about 2000 feet at the northern end of the range, while southward the elevation rises to about 3000 feet at the southern end of the range.

The Harrisburg peneplane should be well-developed in this area; if "minor irregularities" in the floors of Page and Shenandoah Valleys are neglected, there does appear to be a relatively flat surface sloping away from the mountains and towards the major streams. More detailed study, however, has shown that these "minor irregularities" cannot be neglected and that in a large part of these areas the flat surface is the upper surface of the gravel deposits and is depositional, not erosional.

C E N O Z O I C H I S T O R Y

Schooley surface. The first event of which there is any record following the Appalachian revolution in the Mount Jackson quadrangle is the development of an erosion surface that has been correlated with the Schooley peneplane. As previously explained, evidence of the existence of this surface within the quadrangle is not good. Elsewhere in the Virginia Appalachians, however, there is evidence of large-scale base-leveling which formed a widespread erosion surface that probably extended into this quadrangle. Above this erosion surface stood scattered hills or monadnocks composed of resistant rocks; the tops of Catback Mountain and Morgan Knob in the Massanutten Range may be the remnants of such monadnocks. The age of this erosion surface is rather uncertain; it is probably of Cenozoic age, though some authors would date it as early as Jurassic.

Massanutten drainage. The formation of this peneplane or erosion surface was followed by regional uplift which caused rejuvenation of the streams and dissection of the erosion surface. It was probably during this cycle of erosion that the cross-axial streams in the southern Massanutten Range were fixed in their present courses. Two possible origins for this cross-axial drainage can be suggested.

At the time of formation of the Schooley surface the oldest formation exposed in the Morgan-Catback anticline was the Bloomsburg formation, a rather weak unit, and it may be supposed that the drainage within the range at that time was not greatly affected by the structure of the Bloomsburg formation. With uplift and rejuvenation these streams cut down through the Bloomsburg formation and were thus superposed upon the more resistant Massanutten sandstone below. Such an explanation, however, would not explain the present trellis-type drainage too satisfactorily, unless the original streams were to some extent controlled by transverse and longitudinal joints in the Bloomsburg formation. At least locally such structural superposition appears to have occurred: the course of Roaring Run across the monor anticline northeast of Catherine Furnace appears to have originated in this manner.

The alternative origin involved stream capture. The part of Pitt Spring Run which now runs through Pitt Hollow originally flowed southwestward and left the Range at Fridleys Gap in the Elkton quadrangle, flowing into the North Fork of the Shenandoah by way of Smith Creek. The former course of Cub Run was about the same as its present one, while the anticlinal valley southwest of Morgan Knob and in the Elkton quadrangle was drained by a stream flowing to the southwest, then around the nose of the Catherine syncline and into the South Fork of the Shenandoah. Streams like Cub Run and, in the Elkton quadrangle, Boones Run, which flow directly into the South Fork, would thus have an advantage over the streams to the northwest of Catherine Hollow. East-flowing tributaries to Cub Run would thus have a greater erosional power than the west-flowing tributaries to the stream in Pitt Hollow; in addition the tributary entering Cub Run closest to its gap through First Mountain would be stronger than tributaries farther from the gap, since its gradient would be steeper. As a result of headward erosion by this tributary, the drainage of Pitt Spring Run northeast of Pitt Spring was diverted into Cub Run. This increase in discharge of Cub Run would then result in more rapid downcutting by the stream east of Catherine Furnace, which in turn would produce a steeper gradient for the part of Cub Run southwest of Catherine Furnace. This increase in gradient would then produce accelerated downcutting by the other east-flowing tributaries to Cub Run and other segments of the southwestward drainage in Pitt Hollow would be captured. Boones Run has apparently captured part of the drainage of the anticlinal valley southwest of Morgan Knob in the same manner.

The factors controlling the occurrence of the gaps through the border ridges are uncertain. The gaps do not appear to be associated with zones of structural weakness due to faulting or jointing, as has been suggested for some of the water gaps in the Appalachians, nor are they controlled by the thickness of the resistant Massanutten sandstone, as has also been suggested.

High-level gravels. The dissection of the Schooley surface was interrupted at least twice by periods of alluviation represented by the Older and Intermediate gravel units of King (1949). A third, earlier period of deposition is represented by the Ancient gravel unit on Roundhead Ridge. In the Shenandoah Valley similar events may be inferred from the Plains Mill and Rudes Hill gravels, though it is uncertain here whether more than one period of alluviation is represented. The gravels in Page Valley are thought to have been formed at or near the ends of the glacial ages of the Pleistocene epoch. The gravels are all of geologically late date: little evidence of more than surficial decomposition is noted, though the few fragments composed of rock types other than quartzite are in many places entirely destroyed.

The cobbles and boulders present in the Page Valley gravels are larger than those being carried by the streams at present, even at times of flood. The ability of the streams to transport their load depends upon the volume and gradient of the stream, among other things. During the glacial ages the rainfall in the Valley of Virginia was probably greater than at present. Such an increase in rainfall has been established in the arid regions of the western United States and elsewhere in the world (Flint, 1947, pp. 467-483) and there would be little reason not to expect a similar increase in the area here discussed. With such an increase in the amount of rainfall the volume of the streams would be increased, enabling them to carry large rock fragments far beyond the foot of the Blue Ridge in which these streams have their sources. With the retreat of the glaciers, however, the carrying power of the streams would decrease as their volume decreased and the material formerly carried far downstream would now be dropped nearer the front of the Blue Ridge to form large valley fills. Finally, of course, the carrying power of the streams would decrease to a point where the larger fragments could not be carried even in the mountain tracts.

With re-expansion of the ice sheets, however, the rainfall would again increase in volume, bringing about an increase in the volume of the streams once more and thus increasing their carrying power. The streams would then cut down through the alluvial fill formed at the end of the preceding glacial age and into the bedrock below. With waning of the ice sheet, however, the former cycle would be repeated and a second valley fill would be formed. The upper surface of the second fill would lie below that of the first fill because the stream would have lowered its valley floor during the second glacial advance.

One major difficulty is present in this interpretation. The present is generally interpreted as the end of a glacial age (or sub-age) or the beginning of an interglacial age (or sub-age). If this is true, then the streams in Page Valley might be once more expected to be flowing over a valley floor; instead, the streams are flowing in valleys cut in the bedrock. The anomaly is not too difficult to explain, however. The greatest part of the material of which the Page Valley gravels are formed is quartzite from the Blue Ridge. Such rock is extremely resistant and it is probable that the fragments in the Page Valley gravels represent material that had been broken up by weathering, perhaps long before the advent of the moister climate which increased the carrying-power of the streams. Thus the "reservoir" of quartzite fragments was not inexhaustable; when all but the coarsest material, which now remains as talus on the slopes of the Blue Ridge, had been removed the streams were limited to downward erosion of their valleys; this downcutting into the shales and limestones did not yield sufficient coarse detritus to record a change in the climate.

Thus the writer would tend to correlate the Older and Intermediate gravel units of King (1949) with the ends of the earlier glacial ages. The Older gravel unit may correspond to the end of the Nebraskan glacial age and the Intermediate gravel unit to the end of the Kansan age. The Mount Jackson quadrangle lies far beyond the drift border, however, and no direct correlation is possible.

The Cub Run pediment was evidently formed prior to or at the same time as the Older gravel unit was being deposited. It seems likely that the cutting of the pediment preceded the deposition of the gravel and that it took place during the moist glacial age. The gravel veneer would thus have been formed later as the volume and carrying-power of the stream decreased.

It is probable that the present meandering form of the South Fork of the Shenandoah was acquired after the deposition of the Intermediate gravel unit and was the result of the low gradient imposed on the stream as a result of alluviation. Subsequent increase in the volume of the stream has caused the meanders to become ingrown.

Post-gravel erosion. The deposition of the intermediate gravel unit in Page Valley and of the gravels in Shenandoah Valley was followed by a period of stream erosion which resulted in the formation of a series of stream terraces along the North Fork and the South Fork of the Shenandoah River.

However, between the time when the Plains Mill gravel was deposited and the time when the terraces were formed, a considerable change took place in the drainage system of the North Fork. At the time when the Plains Mill gravel was deposited, the area drained by the North Fork lay entirely to the east of Little North Mountain. At the time of formation of the terraces along the North Fork, however, the drainage basin included much of the area to the west of Little North Mountain, as is indicated by the occurrence of abundant pebbles and cobbles of the Siluro-Devonian detrital formations which are found in and west of Little North Mountain. The North Fork had thus broken through Little North Mountain at some time prior to the cutting of the terraces, capturing a large part of the headward drainage of Lost River, which flows northeastward into the South Fork of the Potomac River. This case of stream capture is supported by other evidence in addition to the sudden appearance of the Siluro-Devonian detritus along the terraces of the North Fork of the Shenandoah. In the Orkney Springs quadrangle, which lies northwest of the Mount Jackson quadrangle, the divide between the head of Lost River and the head of the North Fork lies in a prominent synclinal valley; the divide itself is very low and the two streams are separated from one another by only a few hundreds of yards at their sources. In addition, the valley floor of the Lost River near its source appears to be much too wide to have been cut by the small present Lost River; it would be more easily accounted for if a large part of the headward drainage of the North Fork had at one time flowed through the valley.

Downward erosion along the North and South Forks was accompanied by lateral shifting of the streams, with the result that most of the terraces formed are non-paired terraces. During this period of downward erosion the meander, now abandoned, along the South Fork south of U. S. Highway 211 was formed. The configuration of the terraces bordering the meander seem to indicate that it was formed entirely during the period of downward erosion and was not superposed in its observed form from the Page Valley gravel surface. Successively lower terraces along the sides of the meander show a decrease in the radius of curvature of the meander until eventually the radius of curvature became so small that the meander bend was cut off from the main course of the river. This would thus appear to be a good example of a first-cycle meander.

Some evidence can be found for ascribing the rejuvenation of the streams after the deposition of the high-level gravel units to deleveling. The evidence is largely the occurrence of a knickpoint along Smith Creek, but it seems quite probable that other such features may be found elsewhere along the North Fork and perhaps also along the South Fork.

Valley-floor features. The two most recent developments are the formation of the present valley floors and the building of the tufa dams across several of the streams. The valley floors for the most part are erosional in origin, although parts of the valley floors along both of the main streams are composed of alluvium and are thus depositional rather than erosional. As has already been mentioned, the valley floor along the North Fork of the

Shenandoah is more extensive than that along the South Fork, where it is generally narrow and largely restricted to areas underlain by the Edinburg or Martinsburg formation. Since the South Fork is the larger of the two streams and since it in general flows over weaker rocks than the North Fork, this relationship seems somewhat anomalous. That the limestones are a more resistant rock type than the shales is well illustrated in Page Valley, where the stream has developed a valley floor only where it flows over the shale formations. One possible explanation for the observed relations is as follows: The valley floor along the North Fork of the Shenandoah is correlative to one of the terrace levels along the South Fork. Following a rather recent uplift, the South Fork, a stronger stream flowing over weaker rocks, has cut its channel into this former valley floor; the process of downcutting is still dominant over lateral erosion and the present valley floor is consequently restricted in its occurrence. Along the North Fork this incision of the stream into the valley floor has not proceeded as rapidly, because the North Fork is not as large a stream as the South Fork and because it is flowing over more resistant strata, at least within the Mount Jackson quadrangle. If such were the case, some substantiating evidence should be found outside the boundaries of this quadrangle. In the Edinburg quadrangle north of the one mapped the North Fork of the Shenandoah enters a rather steep-sided valley just south of the town of Edinburg; from this point to its juction with the South Fork near Front Royal the North Fork is bordered by a rather narrow valley floor quite similar to that along the South Fork in the Mount Jackson quadrangle. At this same point south of Edinburg there is a rather indistinct but noticeable break in the gradient of the stream: for about a mile or more the stream gradient is almost twice as steep as it is either southwest or northeast of this point.

Abandoned, rather high-level meanders are found along the North Fork downstream from Edinburg, but none are found upstream from that town; if the course of the stream northeast of Edinburg is younger than to the southwest, this relation is quite easily explained: the meanders southwest of Edinburg have not yet had a chance to be abandoned and left above the level of the stream. Thus it would appear that there is here a second knickpoint, and that headward rejuvenation of the North Fork has not yet reached the Mount Jackson quadrangle, while the South Fork has been so rejuvenated throughout the quadrangle.

The tufa dams were formed under somewhat drier conditions than are now found in the area and at some time after the cutting of the present valley floors along Holman and Smith Creeks. The deposition of tufa on the dams appears to have stopped almost completely in both of these cases, and some of the terraces are partly covered by alluvium. An increase in humidity would tend to decrease the rate of deposition of calcium carbonate from the streams, since an increase in the amount of water in the stream would decrease the proportion of calcium carbonate in the stream. A drier climate, on the other hand, would bring about a concentration in the amount of calcium carbonate dissolved in the streams, resulting in its eventual precipitation. It is thus quite conceivable that these dams were formed during the Post-Glacial Thermal Maximum ("Climatic Optimum"). This thermal maximum is thought to have lasted for some 2000 years, perhaps from 6000 to 4000 years ago; it was characterized by higher temperatures and lower humitity than prevails at present.

Since the time of tufa deposition the climate has become cooler and more humid, resulting first in the aggradation of the river channels as the mantle formed during the Thermal Maximum was poured into the streams

To the west two sections were measured along the east limb of the Mount Jackson anticline. The first of these is just north of Cedar Grove Church, between New Market and Mount Jackson; it includes the Oranda formation and the upper part of the Edinburg formation. The same section was measured by Edmundson (1945, geologic section 41). A more detailed section of the Oranda formation here is given as Geologic section 1.

<u>Geologic section 18</u>. In abandoned quarry and field north of Cedar Grove Church, Shenandoah County.

Oranda formation	
12. Shale, calcareous, with layers of nodular fossiliferous limestone.	55 feet
Edinburg formation	
Upper argillaceous member	
11. Covered.	21
10. Limestone, black, irregularly bedded	2
9. Covered.	7
8. Limestone, black, fine-grained, thin- and wavy bedded.	7
7. Limestone, dark-gray, medium-grained, clastic, massive	3
6. Limestone, light-gray, fine-grained, wavy-bedded	2
5. Limestone, black, fine-grained, thin- and wavy-bedded.	19
4. Limestone, black, fine-grained, wavy-bedded, in beds 8 to 12 inches thick	8-1/2
3. Limestone, black, fine-grained, wavy-bedded, in beds 2 to 3 inches thick.	14
2. Limestone, black, fine-grained, in beds 4 to 12 inches thick	70
1. Limestone, black, fine-grained, in beds 4 to 6 inches thick, with argillaceous partings. .	520

The Madden quarry west of New Market is the type locality of the New Market limestone. The section here has been measured previously by Edmundson (1945, geologic section 27) and by Cooper and Cooper (1946, geologic section 9). A somewhat less detailed section of this exposure is given below.

<u>Geologic section 19</u>. Madden quarry west of New Market, Shenandoah County.

Lincolnshire limestone (Lower 31 feet)	
33. Limestone, black, fine-grained, thin- and wavy-bedded; contains nodules and stringers of black chert.	31 feet
New Market limestone	
32. Limestone, black, fine-grained.	1/2
31. Limestone, black, fine-grained, wavy-bedded; weathers light gray	2-1/2
30. Limestone, dove-gray, aphanitic, massive, contains much crystalline calcite; weathers white.	16-1/2
29. Limestone, brownish-gray, aphanitic, massive; contains angular fragments of limestone	3
28. Limestone, dove-gray, massive, aphanitic	7
27. Limestone, dove-gray, aphanitic, thin-bedded; contains layers of clastic limestone.	1
26. Limestone, brownish-gray, fine-grained, with much clastic material; in beds 6 to 12 inches thick; contains *Tetradium*	5
25. Limestone, dove-gray, aphanitic, laminated.	1-1/2
24. Limestone, dove-gray, aphanitic, massive.	4-1/2
23. Limestone, light-gray, fine-grained, laminated	1/2
22. Limestone, dove-gray, aphanitic, with wavy laminae and clay partings; contains pyrite.	1-1/2
21. Limestone, gray, aphanitic, irregular bedding	5-1/4
20. Limestone, gray, coarse-grained, laminated, argillaceous and clastic.	1
19. Limestone, dove-gray, aphanitic, massive.	3-1/4
18. Limestone, dove-gray, aphanitic, with irregular laminae	2-1/4
17. Limestone, dove-gray, aphanitic, massive.	1-1/2
16. Limestone, dove-gray, aphanitic, with irregular laminae	3
15. Limestone, dove-gray, aphanitic, massive, with thin layers of clastic limestone	7-1/2
14. Limestone, light-gray, fine-grained, thin bedded, with clayey partings.	1/2
13. Limestone, dove-gray, coarse-grained, thin-bedded, clastic	1/4
12. Limestone, dove-gray, aphanitic, with irregular laminae	1-1/2
11. Limestone, dove-gray, coarse-grained; a conglomerate composed of fragments of aphanitic limestone in a coarse-grained matrix.	1/2
10. Limestone, dove-gray, aphanitic, with irregular laminae	1/2
9. Limestone, gray, aphanitic, laminated, with clayey partings.	1
8. Limestone, coquinoid, gray.	1-1/2

7. Limestone, brownish-gray, aphanitic, with argillaceous laminae.	1
6. Limestone, dove-gray, aphanitic, stylolitic	1
5. Limestone, light-gray, aphanitic, laminated, mud-cracked	5
4. Breccia, composed of fragments of dolomite and limestone in an aphanitic dove-gray limestone matrix	2
3. Limestone, banded gray and dove-gray, aphanitic.	5-1/2
2. Dolomite, calcitic, light-gray, fine-grained; weathers light-gray.	1-1/2
1. Limestone, gray, aphanitic, thin-bedded, contains lenses of dolomite; weathers light gray .	4

Beekmantown formation

Along the west side of the Mount Jackson anticline two sections of the lower Champlainian limestones were also measured. The first of these was measured about one-half mile east of Forestville and includes, besides the New Market and Lincolnshire limestones the lower part of the Edinburg formation above the basal clastic member. Within this sequence occurs one bed belonging to the shale facies of the formation (Bed 12); the occurrence of a calcarenite layer above the basal clastic member is also recorded (Bed 16).

<u>Geologic section 20</u>. In field northwest of Holman Creek and 0.4 mile east of Forestville, Shenandoah County.

Edinburg formation

Upper argillaceous member (Lower 150 feet)

19. Limestone, black, very-fine-grained; contains bands of yellowish clayey material.	4 feet
18. Covered	14
17. Limestone, black, very fine-grained; contains bands of yellowish clayey material.	15
16. Calcarenite, gray, medium-grained, thin- and wavy-bedded	19
15. Covered	7
14. Limestone, black, very fine-grained; contains bands of yellowish clayey material.	28
13. Covered	13
12. Shale, dark-gray, calcareous.	3
11. Covered	7
10. Limestone, black, very fine-grained; contains bands of yellowish clayey material.	32
9. Covered	17

Basal clastic member (45 feet)
8. Calcarenite, gray, medium-grained, thin- and wavy-bedded. . . . . 7 feet
7. Covered. 60
Lincolnshire limestone (74 feet)
6. Calcarenite, gray, medium-grained, massive; contains nodules of black chert. 4
5. Limestone, dark-gray, fine-grained, massive; contains nodules of black chert. 40
New Market limestone (168 feet)
4. Limestone, dove-gray, aphanitic, massive 69
3. Limestone, dove-gray, aphanitic; contains thin bands of clayey material. 42
2. Limestone, dove-gray, aphanitic; contains layers of dolomite 57
Beekmantown formation
1. Dolomite, light-gray, medium-grained . . . .

The second section on the west side of the anticline is in a ravine north of State Road 615 and east of Virginia Highway 42. The lower impure member of the New Market limestone is quite thick here.

Geologic section 21. In ravine north of State Road 615 and east of Virginia Highway 42, Shenandoah County.

Edinburg formation
Basal clastic member (64 feet)
7. Limestone, dark-gray, medium-grained, thin- and wavy-bedded. . . . . 54 feet
6. Covered. 19
Lincolnshire limestone (64 feet)
5. Limestone, black, fine-grained; contains nodules of black chert 54
New Market limestone (223 feet)
4. Limestone, dove-gray, aphanitic, massive 140
3. Limestone, dove-gray, aphanitic; contains shaly bands 4 to 6 inches apart. 67-1/2
2. Limestone, gray, medium-grained, clastic; contains intercalated dolomitic bands. 16
Beekmantown formation
1. Dolomite, gray, aphanitic, massive; weathers white . . . .

Finally, three sections were measured along the northwestern belt of outcrop of the Champlainian limestones. In all of the sections measured along this belt of outcrop a great deal of difficulty was encountered in locating both the bottom of the New Market formation and the boundary between the Lincolnshire limestone and the basal member of the Edinburg formation. In all three sections the base of the New Market has been drawn at the top of the highest dolomite layer in the section; in cases where the upper part of the Beekmantown formation is limestone this gives the New Market formation a much greater thickness than elsewhere.

The first section measured along this belt of outcrop is located about two miles north of Forestville. Here the base of the New Market limestone can be fairly well established, but the boundary between the Lincolnshire limestone and the Edinburg formation could not be located.

Geologic section 22. In pasture 2.2 miles north of Forestville, Shenandoah County.

Edinburg formation, Upper member	
16. Limestone, black, fine-grained, thin- and wavy-bedded	
15. Limestone, gray, medium-grained, thin- and nodular-bedded.	121-1/2 ft.
14. Covered	13-1/2
Basal Edinburg formation or Lincolnshire limestone	
13. Limestone, dark-gray, fine- to medium-grained, clastic; contains nodules of black chert and local lenses of coquinoid limestone	70
12. Limestone, gray, medium-grained, clastic; no chert.	24
Lincolnshire limestone	
11. Limestone, black, fine-grained, fossiliferous; no chert.	10-1/2
10. Limestone, dark-gray, fine- to medium-grained; contains local lenses of black chert .	5-1/2
9. Limestone, black, fine-grained, thin-bedded . .	1
New Market limestone	
8. Limestone, dove-gray, aphanitic; weathers gray.	16
7. Limestone, dove-gray, aphanitic; weathers white, with "mosaic" surface.	33-1/2
6. Limestone, dark-gray, aphanitic, irregularly bedded.	3
5. Limestone, dove-gray, aphanitic; weathers gray.	15
4. Interbedded limestone and dolomite.	3-1/2
3. Limestone, dove-gray, aphanitic; weathers gray.	5-1/2
2. Dolomitic limestone, gray, fine-grained, banded	39
Beekmantown formation	
1. Interbedded dolomite and fine-grained limestone	

The second section measured along this belt is located about a mile and a half to the southwest. Here also the upper limit of the Lincolnshire limestone is difficult to locate; the base of the New Market limestone, on the other hand, is rather clearly marked by a thick dolomite layer.

Geologic section 23. In field north of Virginia Highway 42 and east of State Road 728, Shenandoah County.

Edinburg formation	
Upper member	
11. Limestone, black, very fine-grained, with shaly partings.	5 feet
10. Limestone, dark-gray, cobbly, fine-grained, thin-bedded	5
Basal member	
9. Limestone, dark-gray, cobbly, crystalline, medium-grained, with wavy argillaceous partings .	12
8. Limestone, light-gray, medium-grained, crystalline, thin- and wavy-bedded, rusty-weathering, with argillaceous partings.	15
Lincolnshire limestone	
7. Limestone, dark-gray, fine-grained, "porphyritic", cobbly, thin-bedded; weathers gray or pinkish . .	21
6. Limestone, dark-gray, fine-grained, thin-bedded, cobbly; contains nodules of black chert in lower part.	127
5. Limestone, dark-gray, fine- to medium-grained, crystalline, wavy-bedded; contains black chert stringers and reddish argillaceous partings . . .	51
New Market limestone	
4. Limestone, dove-gray, aphanitic, massive; contains many specimens of _Tetradium_.	49
3. Limestone, dove-gray, aphanitic, thin-bedded. . .	56
2. Dolomite and limestone, gray, fine-grained, mud-cracked	17
Beekmantown formation	
1. Dolomite, gray, fine-grained; weathers buff	

The third section is located about another mile and a half to the southeast. This same section was measured by Edmundson (1945, geologic section 36) with somewhat different results: according to Edmundson, the New Market limestone is only 125 feet thick here. In all probability some beds at the top of the Beekmantown formation have been included in the New Market limestone of this writer's section. The Lincolnshire limestone in this section is considerably thinner than in the section to the northeast.

<u>Geologic section 24</u>. In field 1.1 miles west-southwest of Forestville and north of State Road 614, Shenandoah County.

Edinburg formation
  Upper member
    8. Limestone, light-gray, fine-grained, nodular; contains shale bands
    7. Covered. . . . . 10 feet
  Basal member
    6. Limestone, dark-gray, nodular; contains tetracorals, bryozoans, stromatoporoids, gastropods, cephalopods, and *Nidulites*; contains nodules of black chert. 24
Lincolnshire limestone
    5. Limestone, black, medium-grained, thin-bedded; contains gastropods and trilobites; contains nodules of black chert 58
    4. Limestone, black, fine-grained, massive. 12
New Market limestone
    3. Limestone, dove-gray, aphanitic, massive 175
    2. Limestone, dove-gray, aphanitic, thin-bedded; contains argillaceous partings 32
Beekmantown formation
    1. Dolomite, dove-gray, aphanitic; contains nodules of white chert

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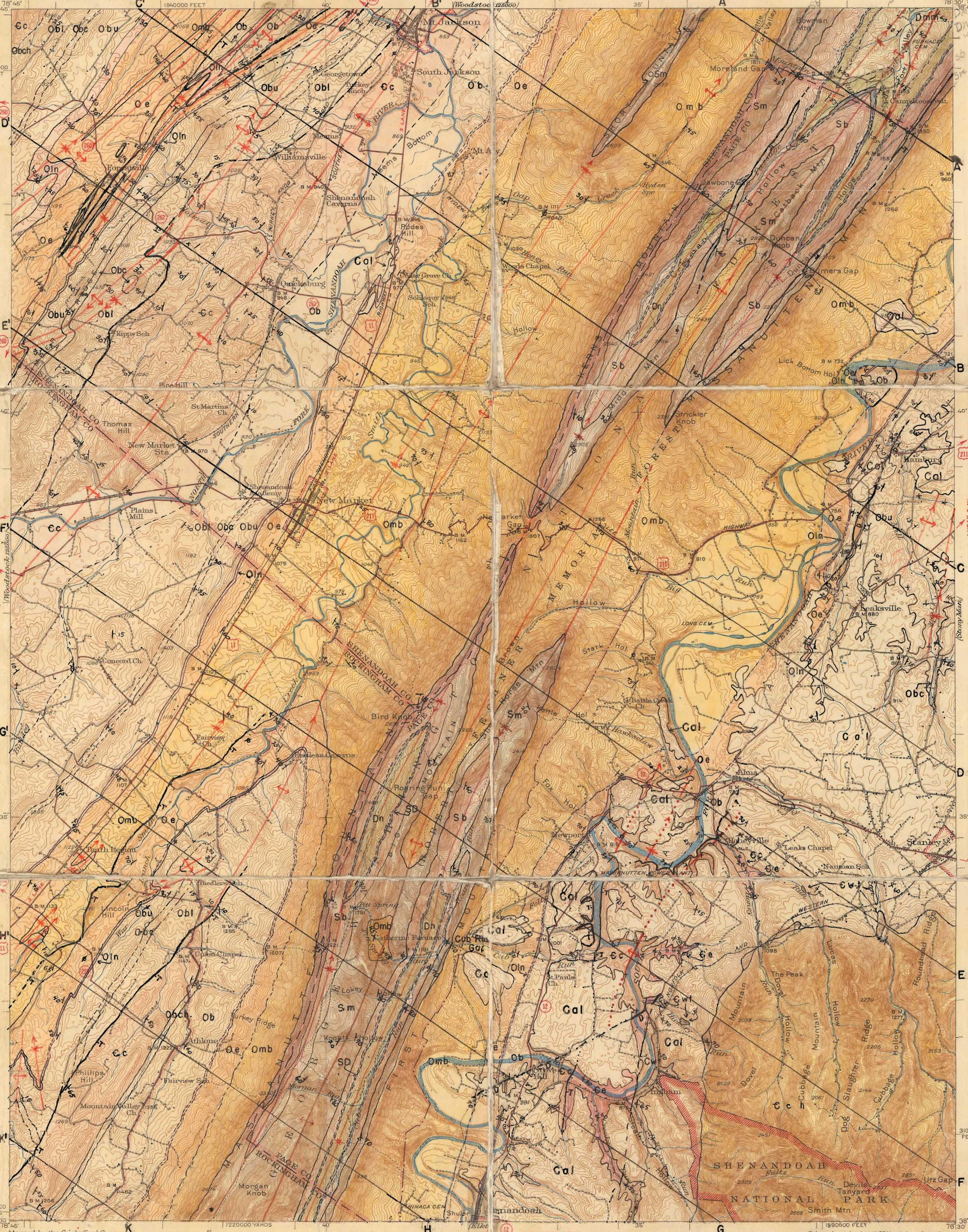

Mapped by the Geological Survey
1941–1942

Scale 1:62500

Contour interval 20 feet
Datum is mean sea level

Polyconic projection. 1927 North American datum
5000 yard grid based on U.S. zone system, B
10000 foot grid based on Virginia (North) rectangular coordinate system
To join Elkton and Stony Man maps use dotted projection corners

MT. JACKSON, VA.
Edition of 1947
N3830–W7830/15

Mt. Jackson quadrangle

Geology by Charles Thornton

LEGEND

Cal — High-level gravels

Unconformity

Dmm — Mahantango formation, "Marcellus" shale

Dn — Needmore shale

Disconformity

Catherine limestone
Tonoloway limestone

Sb — Bloomsburg formation

Sm — Massanutten sandstone

Disconformity

Omb — Cub sandstone, Martinsburg formation, Oranda formation (in west)

Oe — Edinburg formation (Upper member)

Oln — Edinburg formation (Basal member), Lincolnshire limestone, New Market limestone

Disconformity

Ob — Beekmantown (Obu, Upper member; Obc, Chert member; Obl, Lower member; Obch, Chepultepec member)

Cc — Conococheague limestone

Ce — Elbrook formation

Cwl — Waynesboro formation, Tomstown dolomite

Cch — Chilhowee group

CENOZOIC · DEVONIAN · SILURIAN · ORDOVICIAN · CAMBRIAN

Formation boundary

Low-angle reverse fault (T on hanging wall)

High angle fault (D on downthrown side)

Dotted contacts and faults inferred beneath high-level gravels